

World Journal on Educational Technology: Current Issues

Volume 10, Issue 1, (2018) 041-051

www.wj-et.eu

Choices of pre-service science teachers laboratory environments: Hands-on or hands-off?

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Suggested Citation:

Kapici, O.H. & Akcay, H. (2018). Choices of pre-service science teachers laboratory environments: hands-on or hands-off? *World Journal on Educational Technology: Current Issues*. 10(1), 041–051.

Received date; 15 November 2017 revised date; 23 December 2017 accepted date 15 January 2018

Selection and peer review under responsibility of Assoc. Prof. Dr. Fezile Ozdamli, Near East University, Cyprus.

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Abstract

Learning in laboratories for students is not only crucial for conceptual understanding, but also contributes to gaining scientific reasoning skills. Following fast developments in technology, online laboratory environments have been improved considerably and nowadays form an attractive alternative for hands-on laboratories. The study was done in order to reveal pre-service science teachers' preferences for hands-on or online laboratory environments. Participants of the study were 41 pre-service science teachers who were enrolled in a 13-week course on laboratory applications in science education. Findings showed that more than half of the pre-service science teachers would prefer to use hands-on laboratory environments for both conceptual teaching in their classrooms and to develop their students' science process skills. The reasons behind their choices are discussed.

Keywords: Online lab, hands-on lab, virtual lab, science and technology education, pre-service science teachers.

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1. Introduction

Laboratory exercises are often regarded as one of the crucial parts of science education. There are several studies (Hofstein & Lunetta, 1982, 2004; Roth, 1994; Tobin, 1990) in which laboratories' status in science education were discussed. All these studies and some others (Bybee, 2000) emphasised that school science laboratories have an enormous potential for teaching and gaining skills in science. Within this respect, it is an indispensable fact that the laboratory activities should not be limited to only teaching specific content knowledge, but also should be used for teaching inquiry skills.

1.1. Inquiry-based science learning in laboratories

Inquiry generally refers to learning through investigating, exploring and discussing. In other words, it can be regarded as doing science like scientists by proposing ideas, explaining and justifying claims based on the evidence arising from scientific investigations (Hofstein & Lunetta, 2004). In inquiry-based learning environments, students can create hypotheses and test them, gather data and reach a conclusion. Furthermore, there are many studies in which inquiry-based teaching shows benefits over traditional approaches and demonstrations (Minner, Levy & Century, 2010). However, it is not an easy task to achieve productive inquiry-based learning for both teachers and students in classrooms. Students have difficulties since they have to think deeply to be more mindfully active, collaborate with peers and self-regulate their behaviour (Marx et al., 2004). Teachers who use an inquiry-based approach also should use appropriate pedagogical techniques, develop their content knowledge, be aware of how to manage the classroom and should use different assessment approaches (Blumenfeld, Krajcik, Marx & Soloway, 1994; Edelson, Gordin & Pea, 1999; Marx, Blumenfeld, Krajcik & Soloway, 1997). In other words, teachers are crucial stakeholders in the inquiry learning process of students (Eick & Reed, 2002).

Laboratories in science education usually provide opportunities for students to interact with real equipment, data gathering techniques and models (NRC, 2006). Hands-on laboratory environments are common in science education. However, teachers face difficulties while teaching in the laboratory. Nivalainen, Asikainen, Sormunen and Hirvonen (2010) categorise these challenges under four core categories. These are inadequate domain knowledge, inconvenient usage of instructional approaches, difficulties in organisation about teaching practice and restriction of the laboratory facilities. The current study focuses on the latter core category. In another study, Yoon and Kim (2010) called such difficulties as insufficient external support and safety issues. Lack of materials in laboratories, limited class time for experiments, safety and financial issues are also some major drawbacks for a hands-on laboratory approach (Redel-Macias, Pinzi, Martinez-Jimenez, Dorado & Dorado, 2016; Yang & Heh, 2007). As an alternative, there are major developments in information technology especially in education, which provide pedagogically supported online learning environments including online laboratories, for inquiry learning. Based on these developments, many researchers (Bhargava, Antonakakis, Cunningham & Zehnder, 2006) claim that there is a need for the implementation of online labs as supplement or replacement of traditional laboratories.

1.2. Online laboratories

Online labs are science labs provided by computer technology (de Jong, Linn, & Zacharia, 2013). These kind of labs are often seen as an adequate alternative for hands-on laboratories as it becomes clear from the following quote: 'Well-developed and pedagogically appropriate online laboratory experiences can serve to supplement or replace existing hands-on lab experiences, reducing the need for equipment and lab space and offering suitable alternative to students' (Darrah, Humbert, Finstein, Simon & Hopkins, 2014, p. 804).

Computer-supported learning environments that include online labs are also one of the best means for inquiry-based learning, because of its advantages for students like providing direct feedback, multiple representations and so on (de Jong, 2006; Furtak, Seidel, Iverson & Briggs, 2012). Indeed, most studies that make a comparison show that the learning outcomes are similar for students both in hands-on and online labs. For example, both approaches enable students to develop their collaborative working abilities and inquiry skills, to gain conceptual understanding and provide students with an opportunity to explore nature of science (de Jong et al., 2013). However, there are some major different opportunities provided by physical hands-on labs compared to online labs. For instance, whereas the physical hands-on labs help students to develop their practical laboratory skills, or enable them to experience challenges through designing experiments as scientists face (de Jong et al., 2013); online labs can just serve the necessary knowledge by reducing confusing details (Trundle & Bell, 2010), provide different tools to make learning easier (Ford & McCormack, 2000) and allow students to make experiments about sub-microscopic (normally invisible) topics such as chemical reactions or electricity (Jaakkola, Nurmi & Veermans, 2011; Olympiou, Zacharia & de Jong, 2013; Zhang & Linn, 2011).

Computer-supported learning environments (e.g., online labs.) may pose obstacles for most students (Zacharia et al., 2015) due to its richness and transparency of the content in computer-supported learning environment (Zacharia & Olympiou, 2011). Richness refers to an amount of information and a range of relations that a learner can extract from online learning environments (Swaak, van Joolingen & de Jong, 1998; Zacharia & Olympiou, 2011). Transparency refers to how a user can easily perceive the content provided by computer-supported learning environment (Swaak et al., 1998). It is also probably possible that students may be unsuccessful not only in computer-supported inquiry-based learning, but also in general inquiry learning environments if they do not have sufficient self-regulating skills (Azevedo, 2005; Quintana et al., 2004; Zacharia et al., 2015). Self-regulated skills of students for learning include determining learning aims and controlling cognitive, affective and social dimensions of learning through reaching the aims (Pintrich, 2000; Zimmerman, 2000). Providing guidance is crucial in order to develop students' self-regulated skills (Lazonder & Harmsen, 2016; Zacharia et al., 2015). It is an indispensable fact that both physical hands-on and online labs reach a successful conclusion when they are supported with worksheets and teacher and/or online guidance through investigations (de Jong et al., 2013). In other words, teachers and/or worksheets are main supporters for students in hands-on laboratory environments. On the other side, scaffolding tools and/or teachers are primary assistants for the students in online lab environments. There are differences for learners but there are also different roles for teachers in virtual lab environments compared to hands-on lab environments. For example, experimentation in online lab environments goes much faster, so teachers are more quickly and more often asked for the feedback. It is also very hard for a teacher to manage a full class working with online labs on his/her own. Now, we would like to know what science teachers think about online laboratory environments. That's why, the main purpose of current study was determined as to reveal pre-service science teachers' views about online labs, and to compare how teachers see the benefits and the drawbacks of online labs and hands-on lab environments on middle school students' gaining science process skills. Owing to the fact that pre-service science teachers are possible users of online science labs, their views about it are crucial in order to develop online labs better to use it in a learning environment. Within these respects, the research question was determined to reach the goal as follows: What do pre-service science teachers think about online laboratory environments compared to hands-on laboratory environments?

2. Method

Survey method was used in the study. Survey method is questioning individuals on a topic or topics and then describing their responses (Jackson, 2011, p. 17). Questionnaire, which involves two open-ended questions, was used in order to reveal pre-service science teachers' views about using online

laboratory environments for teaching concepts in their classrooms for the future and the convenience of online laboratories to develop middle school students' science process skills.

2.1. Participants and the course

The study was done with 41 pre-service teachers, who were enrolled in the course of laboratory applications in science education-I, in the department of science education at a state university. The study was done with the volunteer participants, who confirmed that their views can be used for research studies. Participants' specific information and characteristics (such as name, age, racial, etc.) did not unveil in the study. Seven participants (17%) of the study were male and the other 34 of them (83%) were female. Participants took physics, chemistry and biology laboratory courses – all of which were done by a hands-on approach – until this course. All participants took the course for the first time. The teacher training programme involves basic science courses (e.g., general physics, general chemistry, general biology, mathematics, etc.), educational science courses (educational psychology, curriculum and instruction, classroom management, etc.) and science education courses (teaching science, nature and philosophy of science, laboratory applications in science, etc.).

The main objective of the course laboratory applications in science education-I is to equip pre-service science teachers with knowledge and experience about teaching science through hands-on laboratories. This course was scheduled for 4 hours a week.

2.2. Research procedure

The study was done in the fall term of 2016 and lasted throughout the semester and covered approximately 13 weeks. All elements of the course and all experiments were done in a computer laboratory via computers. Experiments about three topics from physics (gears, potential and kinetic energy, buoyancy), one topic from chemistry (acid and base), one topic from biology (natural selection) and one topic from astronomy (meteors) were done via an online laboratory environment in the study. The Go-Lab platform, offering a large set of online laboratories, was used in this study (see www.golabz.eu).

Go-Lab is a project supported by the European Union. The Go-Lab portal (sharing platform) provides online science laboratories for usage by the students in science related courses. One of the main goals of this project is to support students to gain science process skills through acting as scientists. To achieve these goals, the Go-Lab platform uses what is called Inquiry learning Spaces (ILSs) that combine multimedia material (text, videos, etc.), online labs and dedicated scaffolds (apps). Six topics about the ILSs, which were mentioned above, were used in current study.

In the first week of the semester, pre-service science teachers were introduced to the Go-Lab online learning environments. The Go-Lab project and its content were explained to the participants. Some examples from the Go-Lab portal (www.golabz.eu) were presented and pre-service science teachers were made some trials with online labs. In the next week, an ILS about astronomy from the Go-Lab portal was translated into Turkish and the ILS based on this lab was created by the research team. Pre-service science teachers followed the course, as if they were students, and did all experiments with the labs included and all apps available in the ILS (such as hypothesis scratchpad, conclusion tool, reflection tool, concept mapper and so on) (for more information please see www.golabz.eu) via computers. In the next week, teachers followed additional ILSs; each ILS implementation lasted for two weekly course hours (3 hours per week). Participants determined their own hypotheses or research problems, made their own online experiments, gathered and analysed data, and reached their own conclusions. The instructor guided the pre-service science teachers when they experienced difficulties during the lesson. At the end of each ILS, the students' reflections were gathered. The same procedure was followed for all six ILSs throughout the semester.

2.3. Data collection and analyses

At the end of the semester, two main questions were asked to the participants in the written form in order to answer the research questions. These are

- If you were a science teacher in a school, which has sufficient materials in labs and sufficient technological equipment, which type of labs (online science labs or hands-on science labs) would you prefer to use in your science classes in order to teach conceptual knowledge? Could you explain your reasons, please?
- What do you think about the appropriateness of lab types for middle school students in order to gain science process skills? Could you explain your reasons, please?

Pre-service science teachers wrote their answers for these questions during their given 60 minutes time, and then, their papers were collected. All documents were analysed using the document analysis technique which is a systematic way for assessing printed and electronic documents (Bowen, 2009). Content analysis which is a sub-type under document analysis technique was used in this study. Content analysis allows the researcher to organise information, gathered from the sources, within categories in order to answer the research questions (Bowen, 2009). The authors of this paper read all the response sheets of the pre-service science teachers separately. For the first question, responses were first classified into three categories: Pre-service science teachers who preferred online labs or hands-on lab environments, or both. Then, the reasons presented by pre-service science teachers for their choices were categorised. The same process was followed for the second question. The researchers discussed the categories and themes for the reasons and reached a consensus at the end. Furthermore, relative frequency and percentage distribution techniques were used to show the findings in numerical form, which represented different views of pre-service science teachers about the online labs in a different way.

3. Results

Pre-service science teachers' views about laboratory environments are the main focus of this study. In order to reveal their ideas about hands-on and online laboratories, pre-service science teachers' responses about two main questions, which were mentioned above, are presented at below.

Table 1. Pre-service science teachers' preferences about types of laboratory environment

# of pre-service science teachers, who would like to prefer to use	<i>f</i>	%
○ Hands-on laboratory environment	23	56.1
○ Online laboratory environment	3	7.3
○ Combination of two types of laboratory environments	15	36.6

Table 1 shows the general views of pre-service science teachers about hands-on and online laboratories. More than half of the pre-service science teachers advocated that if they were science teachers at middle schools, who would have sufficient materials at science labs and adequate technological equipment for online labs, they would prefer to use hands-on labs for all the experiments in the curriculum instead of using online labs. Only three pre-service science teachers hold the opposite view, which is choosing to use online labs for whole experiments in science course instead of hands-on labs. Furthermore, 15 pre-service science teachers stated that they would like to use both hands-on and online labs in their science courses based on the topics or units.

After the participants' first reactions, detailed information was requested to further detail their thoughts. The primary reason for pre-service science teachers to prefer hands-on labs is physicality. They believe that touching the materials, seeing the real equipment and doing the experiments by students themselves in the real context, which are provided by hands-on labs, are much more beneficial for middle school students. For example, one of the pre-service science teachers stated that

‘I would prefer to use hands-on lab approach since students should get familiar with laboratory environment and culture, they should touch the materials and conduct experiments. Although online labs provide convenience for time and economy, doing experiments with real equipment in hands-on lab environments enables students to understand concepts better, because students are more active mindfully and are able to see the materials in 3-D form in such lab environments’. They also advocated that hands-on lab environments promote middle school students’ psychomotor skills better than online lab environments. For instance, a pre-service science teacher stated that ‘Developing students’ psychomotor skills at middle school ages is important and hands-on lab environments present more facilities than online labs. This is for me one of the reasons to prefer the hands-on approach’. Some pre-service science teachers also stated that hands-on lab environments enable students to be more active in the learning process, which causes more meaningful and deeper understanding. They also base this opinion on physicality. They stated that students may easily forget what they have seen or said, but it will be difficult to forget what they actually did. In hands-on lab environments, students make their own measurements, design their own experiments and discuss with friends are some other examples given by the participants so as to support their views. However, pre-service science teachers, who would prefer to use online labs, have three main ideas to support their views. The first one is that online labs enable students to visualise abstract concepts into a concrete form. Because of the fact that middle school students have difficulty to understand abstract concepts, online labs will fill the gap and provide meaningful learning environment. The second idea is that online labs need less time and materials than hands-on lab environments. These pre-service science teachers emphasise that teachers usually mention that the curriculum requires more time but there is less time to teach. That is why using online labs may be one of the solutions to use the time efficiently. The last idea is that online labs provide safer learning environments for middle school students. There are some topics such as acid and base, electricity or heat and temperature which may be dangerous for middle school students to make real experiments. For this reason, online labs may be used to teach these topics. As an example, one of the pre-service science teachers stated that ‘I prefer to use online lab since there is no need for equipment or any risk due to lack of materials in the experiment. In addition, I think that it is easier to observe the process and the results in an online lab. It also presents safer environment for middle school students’.

Some pre-service teachers claimed that they are eager to use both types of lab. They said that some topics are more appropriate to use in hands-on lab and some others are more compatible for online labs. These pre-service science teachers used the claims projected by the both group of pre-service teachers, who are hands-on lab supporters and online lab supporters. They stated that psychomotor skills are crucial and physicality is an important issue to gain such skills. For this reason, hands-on labs are more suitable. On the other hand, some experiments may be dangerous or may require more time than determined time in the curriculum and for these kinds of experiments online labs may be more proper.

For the second question, there were just two groups of pre-service science teachers, one of which is supporting the view that hands-on lab environments are better for science process skills, and the other one advocating the idea that online labs facilitate to gain such skills; in this case, the combination was not mentioned. Table 2 shows the distribution of pre-service science teachers’ views about it.

Table 2. Pre-service science teachers’ views about the effects of laboratory environments on gaining science process skills

# of pre-service science teachers, who support the view that	f	%
<i>Hands-on laboratory environment is better for middle school students in order to develop their science process skills</i>	31	75.6
<i>Online laboratory environment is better for middle school students in order to develop their science process skills</i>	10	24.4

According to the results, pre-service science teachers mainly think that hands-on lab environments are more appropriate for middle school students in order to develop their science process skills. They think that although both types of lab environments are suitable for developing science process skills, their main claim to prefer hands-on lab environment is physicality and being more active through experimenting in such lab classes. However, pre-service science teachers, who prefer to use online labs in their science courses, said that online lab platform offers several scaffolding tools for students which are beneficial for science process skills. These tools may help students to gain such skills easily. For instance, one of the pre-service stated that 'There are several scaffolding tools in online lab such as the hypothesis scratchpad, conclusion tool or concept mapper. These are beneficial tools for middle school students in order to gain science process skills. It is also easy to collect and analyse data in online lab environment. That's why, it seems to me that online labs are more appropriate to develop students' science process skills'. Another pre-service science teacher said that 'Students can also make much more experiments and frequently use these skills through online lab environment in limited course time'. These are the some main reasons for pre-service science teachers to prefer online lab environment to develop middle school students' science process skills.

4. Discussion

Laboratory exercises are of crucial importance in science education not only for teaching conceptual knowledge but also to develop students' inquiry skills. Nowadays, online labs become increasingly available as an alternative for physical laboratories. Within this respect, pre-service science teachers' views about online lab environments are of importance to ensure their success. Based on the findings of the current study, more than half of the pre-service science teachers support the view that hands-on lab environment is more appropriate than online labs for teaching conceptual knowledge since students are more active during the experiment which means that they act as 'real' scientists in such lab environment. In another study done by Klieger, Ben-Hur and Bar-Yossef (2010), they concluded that junior high school teachers had difficulties about computer integration in laboratory work and technical problems. In our study, pre-service science teachers based their views on a constructivist learning approach which claims that students learn better by hands-on activities. Another main idea for those pre-service science teachers is physicality. Gire et al. (2010) also concluded in their study that hands-on science experimentation—physicality—enables students to gain experience as scientists in real-world context. Physicality is identified as actual and active touch of concrete material and apparatus (Zacharia & Olympiou, 2011, p. 318). In related literature, it is possible to find three types of views about physicality in science labs. One of them is advocating that experiments for students should involve hands-on manipulation and concrete materials (Clark, 1994) as pre-service science teachers in current study. Reference point of this group of viewer is that hands-on experimentation is appropriate with cognitive development as from concrete concepts to abstract concepts (Flick, 1993). In other words, theoretical frameworks about physicality in science labs (Jones, Andre, Superfine & Taylor, 2003; Jones, Minogue, Tretter, Negishi & Taylor, 2006) are related with cognitive load theory and working memory. For example, in their study, Jones et al. (2006) claims that tactile experiences may decrease the cognitive load during learning and this may give rise to encourage more complex understandings. Nevertheless there is no tested theoretical framework that can explain exactly if and how touch affects one's learning (Zacharia & Olympiou, 2011, p. 319). One of the reasons for pre-service science teachers to prefer hands-on lab environments might be that this was the first time for them to face with online labs. They took all their lab courses within the hands-on lab environments until this course. Course time may be inadequate for pre-service science teachers in order to understand online lab environments meaningfully.

On the other hand, the group of online lab supporters believes that online labs are efficient at least as much as hands-on lab environments. There are also many studies (Herga, 2016; Reuter, 2009; van der Meij & de Jong, 2006) which concluded that online labs have meaningfully positive effects on students' achievements. Zacharia and Olympiou (2011) state that because that the online learning environments provide multiple representations, their impacts on students' understandings are

significant. Out of presenting multiple representations, online labs are more controllable and variable (Triona & Klahr, 2003), enable students to experiment more in limited time and helps them to develop their related skills (van Joolingen & Zacharia, 2009), allow students to access the lab without time-bound whether at or out of school (Redel-Macias et al., 2016), and also safety, cost-efficiency, offer minimisation of errors especially due to environment and materials, rapid and dynamic data visualisation (Hsu & Thomas, 2002). Similar views points like time efficiency and providing safety environment were mentioned by some pre-service science teachers who would like to use online lab environments. It was also interesting that although the online lab environment provides several scaffolding tools for students, there were only a few pre-service science teachers who used them. This might be pre-service science teachers' experience since scaffolding tools generally are beneficial for beginning learners.

The last view about labs in science education is taking advantage of both types of lab environments via combining them instead of using one of them alone. Moreover combinations of hands-on and online lab environments give better results than using the labs alone (Olympiou & Zacharia, 2012). There are many studies (Jaakkola & Nurmi, 2008; Kolloffel & de Jong, 2013; Olympiou & Zacharia, 2012; Toth, Morrow & Ludvico, 2009) in which combinations of two lab types compared with different versions of themselves and/or with alone versions. Pre-service science teachers hold similar ideas with the literature which are combinations of hands-on and online laboratories remedy the deficiencies of each other.

Pre-service science teachers usually find hands-on lab environments better for students in order to develop their science process skills. Yet, the online laboratories in this study were developed with respect to inquiry-based science teaching, which means that all laboratory required to use science process skills such as developing hypothesis, gathering and analysing data, making conclusion or reflection. The reason for this result might be that pre-service science teachers think that middle school students are at younger ages and needs to do practice by hands-on activities through experimentations.

5. Conclusion

Pre-service science teachers' views about hands-on and online laboratory were investigated in the current study. Although it is obvious fact that the question of whether to use an online laboratory or a hands-on laboratory is highly context-specific, pre-service science teachers are usually eager to use hands-on lab environment in their future professional careers. Just a few of them emphasised that the context that s/he is going to teach has a role to choose laboratory environments. Majority of pre-service science teachers mainly think that students will learn better when they are physically and mindfully more active through lab time. They believe that touching materials –physicality – is one of the crucial requirements for learning. They also advocate that in order to develop younger students' science process skills, hands-on lab environment would be preferred. Online labs are more beneficial for older students to develop their skills especially after gaining some primary skills.

This study has some limitations. The study was done with just 41 pre-service science teachers at a public university. Therefore, a general conclusion from this study for all teachers is hard to draw, but the findings reveal some critical points for researchers and teacher educators. For example, pre-service teachers should be convinced that online lab environments are beneficial for both teaching conceptual knowledge and developing science process skills as much as hands-on lab environment. This can be achieved through courses about instructional technology and teaching in laboratory courses. Theoretical frameworks and example case studies can be used to discuss in such courses. The deficiencies of both hands-on and online lab environments should be emphasised and it should be taught that the teachers should use the strong sides of both lab types.

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