Reviewing inquiry-based learning approaches in virtual laboratory environment for science education

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Εκπαιδευτικές προσεγγίσεις διερευνητικής μάθησης σε περιβάλλον εικονικού εργαστηρίου για την εκπαίδευση επιστημών

Reviewing inquiry-based learning approaches in virtual laboratory environment for science education

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Abstract

In science education, students' active involvement in experimental procedures contributes to higher performance achievements compared to traditional lecturing, as laboratories play a key role and help learners develop the necessary skills of inquiry. Inquiry-based learning, a learning method based on students' personal involvement in the cognitive process through searching, querying and posing questions, is an educational approach where in the case of research, the learner formulates hypotheses which tests them via experimentation and observation of the experimental results. The educational value of the inquiry learning method has been verified in several studies, where the application of the inquiry learning approach resulted in more effective learning, compared to traditional teacher-centered methods. The evolution of the Information and Communication Technology (ICT) contributed towards the popularity of the inquiry-based learning, since it supports the development of educational approaches and environments which facilitate the inquiry learning process. Virtual reality laboratories give the user the opportunity to conduct the same scientific inquiry provided by hands-on experiments but with the advantages of the virtual environment. The present study focuses on the identification of the inquiry-based learning applications and methods used based on virtual laboratories in the field of science. The peer-reviewed literature was the main source of information and data. The findings of the reviewed studies indicated that virtual labs, when used in combination with hands-on labs in inquiry learning, support learners and help them gain deeper conceptual understanding of science.

Keywords: *Virtual laboratories, inquiry-based learning, science education*

Περίληψη

Στην εκπαίδευση επιστημών, η ενεργή συμμετοχή των εκπαιδευόμενων στις πειραματικές διαδικασίες συμβάλλει στην επίτευξη υψηλότερων επιδόσεων σε σύγκριση με την παραδοσιακή διδασκαλία, καθώς τα εργαστήρια διαδραματίζουν βασικό ρόλο και βοηθούν τους μαθητές να αναπτύξουν τις δεξιότητες τους στο πεδίο της έρευνας. Η διερευνητική μάθηση, η μάθηση που βασίζεται στην προσωπική εμπλοκή του μαθητή στη γνωστική διαδικασία μέσω της αναζήτησης, της διατύπωσης αποριών και ερωτήσεων είναι μια εκπαιδευτική προσέγγιση όπου στην περίπτωση της

έρευνας, ο εκπαιδευόμενος διαμορφώνει υποθέσεις και στη συνέχεια εξετάζει εάν αυτές ισχύουν μέσω πειραματισμού και παρατήρησης των αποτελεσμάτων. Η αξία της διερευνητικής μάθησης σαν παιδαγωγική μέθοδος, έχει επιβεβαιωθεί μέσα από αρκετές έρευνες, όπου η εφαρμογή της είχε ως αποτέλεσμα την αποτελεσματικότερη μάθηση σε σύγκριση με τις παραδοσιακές δασκαλοκεντρικές μεθόδους διδασκαλίας. Η εξέλιξη των Τεχνολογιών Πληροφορικής και Επικοινωνιών συνέβαλε στην αύξηση της συχνότητας εφαρμογής της διερευνητικής μάθησης στην εκπαίδευση επιστημών, καθώς η τεχνολογία υποστηρίζει την ανάπτυξη εκπαιδευτικών προσεγγίσεων και περιβαλλόντων που διευκολύνουν τη μάθηση. Τα εικονικά εργαστήρια συμβάλλουν στη δημιουργία τέτοιων εκπαιδευτικών προσεγγίσεων και παρέχουν στον χρήστη τη δυνατότητα να διεξάγει την ίδια επιστημονική έρευνα που παρέχεται από τα πρακτικά πειράματα, αλλά με τα πλεονεκτήματα του εικονικού περιβάλλοντος. Η παρούσα μελέτη επικεντρώνεται στον εντοπισμό και την παρουσίαση των εφαρμογών διερευνητικής μάθησης σε περιβάλλοντα εικονικών εργαστηρίων, στον τομέα της επιστήμης. Η επιστημονική βιβλιογραφία ήταν η κύρια πηγή πληροφοριών και δεδομένων. Τα ευρήματα των μελετών που ερευνήθηκαν έδειξαν ότι τα εικονικά εργαστήρια όταν χρησιμοποιούνται σε συνδυασμό με πρακτικά εργαστήρια, στα πλαίσια της διερευνητικής μάθησης, υποστηρίζουν τους εκπαιδευόμενους και τους βοηθούν να κατανοήσουν σε βάθος τις έννοιες της επιστήμης.

Λέξεις-κλειδιά: *Εικονικά εργαστήρια, διερευνητική μάθηση, εκπαίδευση επιστημών*

1. Introduction

Although learners' active participation in educational process constitutes a key challenge both for educators and educational institutions, the approaches proposed are still debated. These approaches help learners gain knowledge and acquire useful skills in order to be prepared for the world (van Riesen, Gijlers, Anjewierden, & de Jong, 2018). Considering science education, students' active involvement contributes to higher performance achievement on assessments compared to traditional lecturing (Freeman et al., 2014). Not only do they learn the science in a more solid way, but the process of developing the skills of inquiry teaches them "to learn how to learn". A pedagogical approach enabling effective active learning is inquiry based learning or inquiry learning. However, the way inquiry based methods are contributing to promotion of student learning is still inviting controversy (Lazonder & Harmsen, 2016). Inquiry based learning can be defined as an educational process where the learner formulates hypotheses and then tests them via experimentation and results' observation, in order to discover new or existing relations (Pedaste et al., 2015). Another definition (Lazonder & Harmsen, 2016) states that it is the method in which "students conduct experiments, make observations or collect information in order to infer the principles underlying a topic or domain". Students do not obtain the abilities of inquiry simply by learning words such as hypothesis and inference or by following the steps of an experimental scientific procedure. They must experience inquiry directly; they must manipulate conditions to gain the scientific knowledge (Dow et al., 2000). Inquiry based methods, when applied to science education enable learners to comprehend information about a topic through self-directed investigations (Lazonder & Harmsen, 2016). In this context, the emphasis is placed on learner's active participation and his responsibility for discovering new knowledge (De Jong & Van Joolingen, 1998) through exploration and application of scientific reasoning (Kollöffel & de Jong, 2013). The successful application of inquiry learning method depends on students' meaningful

and effective regulation of the learning process, as it is a complex and demanding task (Manlove, Lazonder, & Jong, 2009). The effectiveness of inquiry learning has been presented in several studies, where inquiry learning approach resulted in better learning compared to traditional instruction methods (Alfieri, Brooks, Aldrich, & Tenenbaum, 2011; Furtak, Seidel, Iverson, & Briggs, 2012; Minner, Levy, & Century, 2009).

Having as a target the facilitation of understanding complex scientific processes, inquiry learning approach is divided into inquiry phases which guide students and help them identify the important features of scientific thinking. Several studies present phases of the inquiry cycle, but eleven are the most frequently used: Orientation, Questioning, Hypothesis Generation, Planning, Observation, Investigation, Analysis, Conclusion, Discussion, Communication and Reflection (Pedaste et al., 2015). The same study, after analyzing the descriptions and the definitions of inquiry phases, presented a new inquiry-based learning framework with five phases: Orientation, Conceptualization, Investigation, Conclusion and Discussion.

- Orientation is the process of problem definition and learners' interest stimulation.
- Conceptualization is the process of research questions and hypotheses formulation.
- Investigation is the process of taking actions in order to respond to the research questions and hypotheses.
- Conclusion is the process of drawing conclusions from the data collected at the investigation phase.
- Discussion is the process of presenting outcomes to other learners and educators and interacting over them.

Inquiry-based learning has become popular in the educational and research community. Historically, it has been around in school science courses for less than a century (Bybee & DeBoer, 2003). Before 1900, most educators believed that students learn science by memorizing scientific methods and by getting direct instructions. John Dewey in 1910 questioned this belief and stated that science knowledge will deepen if educators give less emphasis to the accumulation of information and more to thinking. By the 1950s and 1960s, inquiry was presented as an approach to teaching science that involves not only information and thinking but also active engagement (Schwab, 1966).

The ICT evolution contributed towards the popularity of the inquiry-based learning, since it supports the development of educational approaches and environments which facilitate the inquiry process. Computer learning environments do implement inquiry-based learning since they provide affordances (e.g. interaction, guidance, reality adaptation) which are not offered by traditional educational methods (Furtak et al., 2012). When learning environments are appropriately designed following inquiry learning guidelines, they could support the learning process effectively (Alfieri et al., 2011; Rutten, Van Joolingen, & Van Der Veen, 2012). According to Zacharia and Olympiou (2011) these computer learning environments offer increased opportunities for interaction and students' active participation. Such an environment is a virtual laboratory, where learners conduct experiments, collect experimental data and develop new understandings through observing and manipulating conditions in a virtual environment (Jong, Linn, & Zacharia, 2013). Virtual laboratories give the user the opportunity to conduct the same scientific inquiry provided by hands-on experiments but with the advantages of the virtual environment (Sypsas, Kiourt, Paxinou, Zafeiropoulos, & Kalles, 2019; Toth, Ludvico, & Morrow, 2014) As a result, virtual laboratories provide science teachers with educational tools which support the inquiry based learning approach (i.e. reality adaptation, as virtual experiments designers can

highlight noticeable information, remove insignificant details and modify model characteristics leading to the deeper understanding of certain phenomena). Additionally, learners can observe multiple representations of objects which are not present in the real world (e.g. electrons) leading to comprehension of phenomena under study (Olympiou, Zacharia, & de Jong, 2013) and to improved learning outcomes (Paxinou, Zafeiropoulos, Sypsas, Kiourt, & Kalles, 2018). In such an environment, the experimental results are observed in order to comprehend the relationship between variables in the conceptual model underlying the virtual lab (Jong et al., 2013). As users perform their experiments in the virtual laboratory environment, they get familiar and become active participants in the educational process (Paxinou, Karatrantou, Kalles, Panagiotakopoulos, & Sgourou, 2019; Sypsas & Kalles, 2018). Various studies have shown that virtual experiments can enable students to use inquiry approaches to manipulate materials and variables that might be difficult to use in hands-on experiments (Jong et al., 2013).

The motivation of this study is the identification of the inquiry-based learning applications and methods used based on virtual laboratories in the field of science. Although, virtual laboratories are used for some years in science education, their usage in combination with inquiry learning is not fully exploited. So, the advantages they may offer as educational environments for inquiry learning are presented so that educators may be informed and decide to invest on using them. The main contribution of this work is, thus, to present a review of studies, concerning the use of virtual laboratories under the inquiry learning framework in the domain of science education, in order to reveal the various educational applications that are used. This presentation, gives the educators the opportunity to select the most appropriate educational approach for their educational settings.

The rest of this paper is structured in three sections. The next (second) section presents the methodology used for the exploration of the literature. The third section provides the results of the review concerning the virtual laboratories used under the inquiry learning framework. The paper concludes by summarizing and providing thoughts for further development.

2. Methodology

The review for peer-reviewed literature was conducted using key archival resources, namely Digital Libraries ScienceDirect, ERIC (Educational Resources Information Center), ISI Web of Science and DOAJ (Directory of Open Access Journals). The search terms were general, so as to include as many relevant studies as possible. Search terms used were, *virtual laboratories, science inquiry learning AND ICT, inquiry based learning AND virtual laboratories*; a total of 54 articles were selected based on the specific search criteria. Firstly, the papers' abstracts were identified as relevant to the search criteria and worthy of further study and afterwards, the full articles were accessed. Finally, the full texts of 24 studies were read and assessed for final worthiness in order to identify only the publications which dealt with inquiry-based learning approaches in a virtual laboratory environment in science domain. The analysis of these publications was based on the criteria presented in Table 1.

Table 1: Articles inclusion criteria

	Articles inclusion criteria
IC1	Peer-reviewed articles published in journals, International Conferences/Workshop Proceedings
IC2	Full results presentation
IC3	Thorough methodology presentation
IC4	Frequency of citations
IC5	English language studies

3. Inquiry learning approaches under virtual laboratories environment

According to Banchi & Bell (2008) there are four levels of *inquiry*, based on the extent of the teacher's guidance and the amount of information given to the students. These four levels are the *limited (or confirmation)*, the *structured*, the *guided* and the *open* inquiry. The limited inquiry is the most guided form, where students develop all these skills that are totally necessary to eventually perform open inquiry, the least guided form of inquiry learning.

An analysis of the reviewed publications resulted in the identification of different inquiry based approaches in a virtual laboratory environment for science education, which are presented in the following sections. These approaches vary depending on the form of guidance implemented in inquiry learning and also on different variables such as the age and prior knowledge of the learners. Additionally, some papers presented the design of the experiments based on inquiry learning approach under a blended educational environment (hands-on in combination with virtual laboratories) in order for the learners to gain the offered skills from the proposed approach.

3.1 Guided inquiry learning approaches

Guided inquiry learning can improve learners' skills such as analysing problems, formulating hypotheses, defining research questions, designing and conducting experiments, collecting and analysing data and finally drawing conclusions for the experimental procedure (Mäeots, Pedaste, & Sarapuu, 2008). Moreover, various researches suggested that guidance has a positive effect on inquiry learning activities and learning outcomes (Lazonder & Harmsen, 2016). As a result, the majority of the researches under study (62.5%) explore the guided inquiry approach in virtual laboratory environment concerning the science domain.

In the physics domain, virtual laboratories were used in numerous studies. In a study by Başer & Durmuş (2010), the effectiveness of inquiry learning through Virtual Laboratory Environment (VLE) when compared to Real Laboratory Environment (RLE) was explored. 87 pre-service elementary school teachers enrolled in a science course and participated in the study. The results showed that supported inquiry learning when used in VLE and RLE had the same effect on students' understandings of concepts in electricity.

In another study the additional approach in the form of inquiry learning in a virtual lab was investigated (Kollöffel & de Jong, 2013). The traditional instruction was supplemented with a guided inquiry learning approach in a virtual lab. 56 undergraduate students in engineering courses participated. They were provided with a virtual lab-based inquiry learning environment with guidance. As the results suggested,

participants in the blended virtual lab environment outperformed participants in the traditional lab environment concerning both conceptual understanding and procedural skills. However, the authors of the study mentioned the supportive role of the virtual lab as it cannot replace hands-on experimentation.

Zacharia (2007) investigated the combined use of hands-on and virtual laboratories in electric circuits conceptual understanding. The instructional method of inquiry based approach was applied to both environments and 88 undergraduate students took part in the research. Research findings suggested that the combined use of hands-on and virtual laboratories under the inquiry based learning approach had a stronger effect on learners' conceptual understanding than traditional experimentation alone.

The Go-Lab federation of online labs adopted the inquiry learning as the central pedagogical approach (de Jong, Sotiriou, & Gillet, 2014). The guided approach was selected as it has proven to be more effective than other lab approaches (Jong et al., 2013). Go-lab offers educators the capability to create their own inquiry learning spaces by suggesting scenarios and lesson plans. Thus, learners were offered virtual laboratory experiments in inquiry learning spaces and were also provided with guidance which helps them to achieve the learning outcomes set by the educator.

In another study simulation was used for physics education under three pedagogical considerations involving a consistent simulation world, a data table for ease of data collection and a game (Wee, 2012). Students' feedback denoted that simulation can support inquiry learning and thinking when guided inquiry tasks are challenging and correctly designed. They also noticed the need for strong inquiry learning activities.

The effects of virtual versus physical manipulation were investigated in a research by Chen, Chang, Lai, & Tsai (2014) in the physics domain (Boyle's law). 68 11th-grade students participated and were instructed to plan, experiment, evaluate, improve the experiment, conclude and finally design a new experiment in a guided inquiry learning approach. Students showed positive attitudes toward innovative ways for experimentation and appeared to be more engaged than they were in traditional laboratory activities.

The design of new physics experiments by secondary education students was examined in another research project (Hatzikraniotis, Kallery, Molohidis, & Psillos, 2010). In a blended approach involving hands-on experiments, simulated experiments and microscopic model simulations, students, after performing guided investigative tasks, demonstrated ability in experiment design skills, such as forming hypotheses, evaluating the experimental procedure and drawing conclusions.

A similar study exploring students' ability to design experiments based on guided inquiring learning used a virtual lab "ThermoLab" was conducted by Lefkos, Psillos, & Hatzikraniotis (2011). The aforementioned virtual lab was used to design, develop and apply guided experiments. Based on this approach students were guided to design and conduct experiments using virtual objects. Finally, they had the opportunity to develop their experiments and improve their experimental skills.

A multifaceted virtual laboratory in the fields of Optics and Electricity was used for teaching intervention in a high school in Greece (Taramopoulos, Psillos, & Hatzikraniotis, 2012). 32 students participated in the research which was based on guided inquiry. The results revealed that regarding the conceptual enhancement, an improvement is observed when virtual lab embedded in a guided inquiry teaching sequence is used.

In the chemistry domain, a study which involved secondary education chemistry students revealed that students preferred to use a virtual laboratory in order to conduct experiments (Pyatt & Sims, 2012). Concerning the guided inquiry-based lab exercises

used in the aforementioned study, students preferred the virtual and online choices to carry out the experiments compared to the traditional lab experiments. Moreover, suggestions on how inquiry based lab instructions could be designed were presented, for example students to perform labs at home in order to be prepared for hands-on sessions. Additionally, when the experimental apparatus is too complex, the virtual lab experience is necessary.

The international move towards inquiry and more authentic student experience of the sciences has led researchers to investigate new educational approaches towards this direction. Donnelly, O'Reilly, & McGarr (2013) employed case studies of science teachers using a virtual chemistry laboratory (VCL) with their students in an explicitly guided inquiry manner. The results suggested key aspects of practical work, which deter educators from adequately supporting inquiry learning, and pointed out how a VCL can overcome many of these obstacles. Although the use of a VCL frees students and teachers from the constraint of safety and allows them to investigate more openly, results also indicated considerations in stand-alone usage of a VCL.

Blended inquiry with hands-on and virtual laboratories in biotechnology domain have been examined in a study by Toth et al. (2014). The electrophoresis experiment was used as it is an excellent model for learning-related concepts and processes. In that study a virtual and a hands-on laboratory were used in order to explore the benefit of using virtual labs to ground students' knowledge construction, before hands-on investigation. Both learning environments used the guided inquiry approach and supported students in designing experiments, evaluating data from experimental trials and concluding on the experimental procedure. The results provided evidence for the design of blended inquiry-learning environments that integrate virtual and hands-on laboratories.

The application of virtual biology lab as a preparation tool was applied in a distance education setting (Paxinou et al., 2018). The guided inquiry approach was used in order to prepare 43 learners for their microscopy experiment in their physical wet lab. Results indicated that the students used the virtual lab achieved better grades than the students used the traditional on-hands session.

In another study in the biology domain (Meir, Perry, Stal, Maruca, & Klopfer, 2005) 46 undergraduate students conducted two inquiry based experiments, namely diffusion and osmosis in a virtual laboratory environment having a workbook that guided them through the experiments. Results indicated that students were helped to overcome several common misconceptions about diffusion and osmosis.

Finally, another study combined the guided and the open inquiry approach (Paxinou et al., 2019). At first, 31 out of 67 undergraduate students used the Instruction mode (guided learning) of the virtual lab (the Onlabs software, http://onlabs.eap.gr), as shown in Figure 1. Then, they used the Experimentation Mode where the user performed a complete experiment without instructions. She/he explores, experiments, designs and selects the steps of the microscopy procedure (open inquiry learning). Findings highlighted the simulation-based learning environment of the 3D virtual laboratory as a promising alternative method for their preparation, especially for distance learning students.

Figure 1. Onlabs guided mode

3.2 Open inquiry learning approaches

Inquiry can be conducted at different levels depending on the learners' prior knowledge and developmental stages (Smetana & Bell, 2012). Thus, educators formulate the complexity of students' inquiry by explicitly predetermining one or more component steps, while permitting students to make related decisions (Toth, Brem, & Erdos, 2009). This is, then, the level of open inquiry where all essential steps of inquiry (i.e. search, evaluation, concluding, and reasoning) are decided independently by learners.

As simulation tools are found to be appropriate to support inquiry learning (De Jong & Van Joolingen, 1998), an environmental virtual field laboratory was developed by Ramasundaram, Grunwald, Mangeot, Comerford, & Bliss (2005) in order to study environmental properties and processes that stimulate the higher-order cognitive skills of students. The open inquiry approach selected led students to mimic the steps and methodologies practiced by scientists, including hypotheses formulation, observation, testing hypotheses, evaluating and drawing conclusions. During another research a STEM-based virtual lab was developed as an alternative education tool for improving scientific literacy of junior high school students on the domain of water pollution (Ismail, Permanasari, & Setiawan, 2016). Students used the virtual lab to support scientific inquiry and the results revealed that there were improvements in students' scientific attitude after their involvement with the STEM based virtual lab.

A physics virtual laboratory, Demolab, was used to explore learners' perceptions of Internet-based learning environments in combination with open inquiry learning (Chuang, Hwang, & Tsai, 2008). The students stated that they preferred many features of constructivist Internet-based learning environments. The results further suggested that male users appeared to better adapt to the constructivist Internet-based learning approach than female users did. This is explainable because male users might often have better computational backgrounds, enabling them to resolve technical problems.

Gunhaart & Srisawasdi (2012) chose computer simulation from Physics Education Technology (PhET) as a cognitive tool to construct conceptual understanding on

properties of sound wave at the microscopic (unobservable) level. Therein, thirty 11-grade students participated in the research where structured inquiry learning within a hybrid science laboratory environment was applied in order to measure the effect on students' conceptual understanding. Findings demonstrated that the hybrid science laboratory environment could have positive effect on students' understanding of concepts of sound wave properties.

Two mobile simulation learning environments, AR simulation and traditional simulations, were developed under a study by Wang, Duh, Li, Lin, & Tsai (2014). Thus, forty university students had the opportunity to use their own devices for interaction and the arrangement of inquiry steps. Both simulations supported collaborative inquiry learning and students were engaged in higher-level inquiry actions, such as evaluating experimental data and drawing conclusions.

Donnelly, O'Reilly, & McGarr (2011) proposed a Virtual Chemistry Laboratory (VCL) as a practical approach to implement inquiry learning in chemistry education. The views of science teachers on the potential integration of a VCL into the Irish Chemistry Syllabus were explored. Results indicated the VCL application in addressing and raising awareness of many up-to-date issues in science and teacher education. In another study (Bortnik, Stozhko, Pervukhina, Tchernysheva, & Belysheva, 2017) virtual lab was used as a tool of students' pre-lab autonomous learning. 50 university students participated in the study using a virtual lab-based inquiry learning environment for chemistry before traditional laboratory work. Findings showed that virtualized tools were suggested as a supplementary and supportive element in education when used in an inquiry learning environment. Additionally, findings indicated that a blended approach combining virtual and practical laboratory may be a valuable teaching and student engagement tool.

3.3 Guided versus open inquiry learning approaches
Since inquiry learning process can be guided or open the comparison between them could lead the educators to choose the appropriate approach. This comparison was the purpose of two studies (Jaakkola, Nurmi, & Veermans, 2011; Piraksa & Srisawasdi, 2014). The aim of the first study was to explore learning outcomes of 50 elementary school students when using simulations alone and simulations combined with real circuits in the domain of electricity. Additionally, the study investigated how these outcomes were affected by procedural guidance (open inquiry learning approach) and guidance for experimental process (guided inquiry learning approach). The results indicated that procedural guidance was insufficient to promote conceptual understanding, but when students were given more guidance as in the case of guided inquiry learning approach, they managed to increase their knowledge. Finally, the study concluded that the blended use of real and virtual labs in combination with guidance during the discovery process could help students to gain better understanding of the subject under study.

In the second study the effect of inquiry-based learning into a blended environment of hands-on laboratory and simulated laboratory was explored. 66 secondary school students participated in the study in the domain of physics. The effect of the intervention regarding the type of inquiry (open vs guided) was measured. Findings demonstrated that students' motivation was increased for both types of inquiry and in combination with blended laboratory experimentation could be considered as an appropriate educational approach for teaching and learning of science by inquiry.

3.4 Brief presentation of approaches and discussion

In the following table the studies are classified according to the inquiry learning approach that is used.

Table 2: Inquiry based learning in virtual laboratory environment

Primary author (publication year)	Domain	Inquiry learning approach	N	Conclusions
Başer et al. (2010)	Physics	Guided inquiry learning	87	Supported inquiry learning when used in VLE and RLE had the same effect on students' understandings of concepts in electricity
Kollöffel et al. (2013)	Physics	Guided inquiry learning	56	Participants in the blended virtual lab environment outperformed participants in the traditional lab environment concerning both conceptual understanding and procedural skills
Zacharia (2007)	Physics	Guided inquiry learning	88	The combined use of hands-on and virtual laboratories under the inquiry based learning approach had a stronger effect on learners' conceptual understanding than traditional experimentation alone
de Jong et al. (2014)	Science	Guided inquiry learning	-	Learners were offered virtual laboratory experiments in inquiry learning spaces and were also provided with guidance which helps them to achieve the learning outcomes set by the educator
Wee (2012)	Physics	Guided inquiry learning	-	Simulation can support inquiry learning and thinking when guided inquiry tasks are challenging and correctly designed. Need for strong inquiry learning activities
Chen et al. (2014)	Physics	Guided inquiry learning	68	Students showed positive attitudes toward the innovative ways for experimentation and appeared to be more engaged than they were in

				traditional laboratory activities
Hatzikraniotis et al. (2010)	Physics	Guided inquiry learning	-	Students, after guided investigative tasks execution, showed ability in experiment design skills
Lefkos et al. (2011)	Physics	Guided inquiry learning	14	Students had the opportunity to develop their experiments and improve their experimental skills
Taramopoulos et al. (2012)	Physics	Guided inquiry learning	32	Regarding the conceptual enhancement, an improvement is observed when virtual lab embedded in a guided inquiry teaching sequence is used
Pyatt et al. (2012)	Chemistry	Guided inquiry learning	184	Students preferred the virtual and online choices to carry out the experiments compared to the traditional lab experiments
Donnelly et al. (2013)	Chemistry	Guided inquiry learning	4	Considerations in stand-alone usage of the VCL were indicated, while the blended approach would be more effective both for educators and learners
Toth et al. (2014)	Biotechnology	Guided inquiry learning	32	The results provided evidence for the design of blended inquiry-learning environments that integrate virtual and hands-on laboratories
Paxinou et al. (2018)	Biology	Guided inquiry learning	43	Students in distance learning education improved their understanding of concept concerning microscopy, when they attended a skype session to be prepared in microscopy experiment via a virtual lab
Paxinou et al. (2019)	Biology	Guided inquiry learning/ Open inquiry learning	67	The majority of students found the educational use of simulation to be a useful supplement to traditional teaching resources
Meir et al. (2005)	Biology	Guided inquiry learning	46	Students were helped to overcome several common misconceptions about diffusion and osmosis

Ramasundaram et al. (2005)	Environmental	Open inquiry learning	-	Students mimic the steps and methodologies practiced by scientists
Ismail et al. (2016)	Water pollution	Open inquiry learning	59	Improvements in students' scientific attitude after treatment with STEM based virtual lab
Chuang et al. (2008)	Physics	Open inquiry learning	109	Students preferred many features of constructivist Internet-based learning environments
Gunhaart et al. (2012)	Physics	Open inquiry learning	30	The hybrid science laboratory environment could have positive effect on students' understanding of physics
Wang et al. (2014)	Physics	Open inquiry learning	40	Students were engaged on higher-level inquiry actions
Donnelly et al. (2011)	Chemistry	Open inquiry learning	13	VCL application in addressing and raising awareness of many up-to-date issues in science and teacher education
Bortnik et al. (2017)	Chemistry	Open inquiry learning	50	Virtualized tools were suggested as a supplementary and supportive tool in education when used in an inquiry learning environment

Virtual labs were exploited in inquiry learning environments where experiments play a key role. More than half of the studies used the guided inquiry learning approach. Only one study examined the transition from the guided inquiry to the open inquiry approach, using a 3D virtual reality biology lab (Onlabs, http://onlabs.eap.gr) as an educational application that offers a high level of realism regarding microscopy and it strengthens the students' learning outcomes when combined with traditional learning activities. Onlabs provides the user with three modes: the *Instruction Mode*, the *Evaluation Mode* and the *Experimentation Mode*. The Instruction Mode helps the student to perform under instructions, a complete microscopy procedure of a test specimen. The procedure is divided into steps and for each step a written instruction appears at the top of the screen, as shown in Fig. 1 (Paxinou et al., 2019). In case the user cannot complete a step, a written hint appears to his help. The Instruction Mode provides the student all the appropriate guidance and knowledge required to find the solution and perform each step of the microscopy procedure successfully (guided inquiry learning). After the user is well trained in microscopy by practicing with the Instructional Mode, he selects the Experimentation Mode where the user performs a complete experiment without instructions. She/he explores, experiments, designs and selects the steps of the microscopy procedure (open inquiry learning).

4. Conclusions

After years of research virtual laboratories have been part of various educational approaches, combined with inquiry based learning, in a diversity of domains (physics, chemistry, biology etc.). The guidance under such an educational environment is needed, especially when learners are of early age (i.e. pre-secondary education). Furthermore, guidance could also be needed in self-regulated learning in a distance education setting (Zacharia, 2007). Crucial part of laboratory success is the instruction design by the educators when inquiry learning is deployed. Particularly, according to Alfieri et al. (2011), laboratories guidance should be carefully designed, so as to offer learners the best possible benefits. Thus, the laboratory tasks used in virtual laboratories under inquiry learning approach have to be developed according to the inquiry learning guidelines in order to have the desired results in learners' science education.

The current study presents different researches in the science domain, where virtual laboratories were used in different inquiry learning approaches, namely guided or/and open inquiry. The findings of the aforementioned studies indicated that virtual labs when used in combination with hands-on labs in inquiry learning, support learners and help them gain better conceptual understanding of the science domain. However, most of the reviewed studies suggested that virtual laboratories should not substitute physical ones.

The increasing number of virtual laboratories and their application in science education makes the literature review useful. This presentation, gives the educators the opportunity to select the most appropriate educational approach for their educational setting. Thus, educators who want to apply inquiry based learning approach in their science class may benefit from this review, as they will find educational applications and examples that, possibly, fulfill their needs after required adjustments.

Subsequently, we plan to develop appropriate experimental tasks for Onlabs, based on inquiry learning, in order to measure the effect of this approach in a distance education setting (Hellenic Open University).

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