VIRTUAL INQUIRY: USING VIRTUAL EXPERIMENTS IN INQUIRY- BASED SCIENCE TEACHING

Konstantinos Karampelas
University of the Aegean,
Greece

Abstract

This paper aims to examine the possibility to use virtual simulations in inquiry-based primary science teaching. Virtual simulations are concluded in research to generally assist science teaching as they assist experimentation and skills. Inquiry-based teaching is considered by research as an effective approach to science teaching, since it promotes and develops skills not only about science content but also science process and nature. This research aims to investigate if simulations can be beneficial specifically in inquiry–based teaching in primary schools. Through a qualitative approach it was concluded that simulations assist skills required in inquiry teaching, but not all.

Virtual Simulations in the Science Class

Virtual experiments and computer simulations have been described to be useful in science teaching. Science teaching, according to current approaches is expected to be based in experimental laboratory, hands-on activities, which help learners understand phenomena and the applications of the new knowledge they construct. These experiments, however, are not always easy to implement in the science classroom, as they are expected to be carried out under safe conditions, planned carefully so that no interference of real world unexpected factors can emerge and affect the results. For example, even though using batteries, cables and lighting are useful to experiments, in order to learn about electricity and circuits, it is important to make sure, that no learner will be harmed from dangerous materials and that these materials will actually work. So safety and assurance of the result is required in experimental processes, if they are to assist in science teaching. Virtual experiments provide this advantage. Indeed, virtual experiments and simulations help learners work in a rather idealized computer, virtual, environment, and they can understand better the simple cause-and-effect relationship, among variables, in testing and experiments. For instance, in the simulation it is easy to see that when applying force in an ideal situation, with no friction, the object may move endlessly, which is difficult to be seen in actual world. Besides that, in the simulation it is easy to experiment with science phenomena, even nuclear reaction, with no risk (Jakkola & Nurmi, 2007).

Another major advantage that computer simulations and virtual experiments offer is the possibility to investigate phenomena and concepts that are not easy for learners to understand through their every day experience, such as phenomena and concepts relevant to topics of space and astronomy, human anatomy, air, wildlife and marine ecosystems. This way, educators and learners can broaden their opportunities for engaging in experimentation and learning in science fields of study that would be difficult to approach in a regular classroom otherwise. Relevant to this advantage, is the possibility they offer to observe and understand phenomena and concepts of the microworld. Molecules, atoms and their anatomy are not easy to understand for learners, neither is their behavior and its relationship to concepts and effect in natural phenomena. Simulations can help learners see how the flow of electrons, the electric current, runs or should run across electric circuits to let electric devices function properly. They can also help learners see how heating objects such as ice, provides energy and velocity to molecules, which then gradually leads to change in states of matter. This investigation of concepts and phenomena from a microscopic point of view is very significant in science learning and is strongly assisted by virtual experiments. In short, virtual simulations expand the opportunities of learners to get involved in discourse, observe, hypothesize, plan experiments, carry out experiments, test data, construct new knowledge and apply it, by providing possibilities to apply such skills in plenty of science topics (Jakkola & Nurmi, 2007; Zacharia, 2003).

Despite the advantages that simulations' use provides to learning, challenges exist as well. First, when working, experimenting and learning in a virtual environment, which can be oversimplified, learners do not have the opportunity to meet the authentic environment, in which scientists work, and the knowledge they may construct may differ from the one they can apply in the real world. When observing, for example, the greenhouse effect in a simulation, learners may get an idea about the outcomes, but may miss crucial information about variables, such as time needed, room temperature, light volume, which in only the real world may actually be understood and evaluated (Pinto et al., 2014; Zacharia, 2003). Apart from that, Chang, Chen, Lin, and Sung (2008), claim that the benefits of simulations are rather restricted to experimenting, but not to scientific exploration. Additionally, as Jakkola and Nurmi (2007) suggest, a teaching intervention using simulations, requires careful planning and teaching designing.

Inquiry in Science Teaching

Scientific work is highly dependent on inquiry. This is the main reason why research in science education stresses the importance of science teaching to include and, in fact, be based on inquiry. Thanks to inquiry, science teaching can be linked with authentic, real-life science phenomena, processes and challenges, which are similar to those that scientists come across in their work. By using skills, such as observation, critical thinking, group work, information searching, analysis of data, learners can construct knowledge and develop deeper understanding around science, more compatible to the scientific work and nature. This can be done with the help of approaches such as inquiry – based science teaching, instead of traditional approaches emphasizing only superficial learning concepts of various topics (NRS, 2000).

Teaching Inquiry-Based Science

According to Eastwell (2009), there are four different levels of inquiry research to be conquered by learners. The first level is confirmation research. At that level, learners are asked a question, which they would answer by using data given to them, through a pre-decided methodology, in order to reach pre-determined findings. In other words, at that level, learners would confirm a theory or a set of findings, with the help of activities such as experiments. The second level is structured research. At that level, learners are also asked a question. They would use data given to them in order to reach pre-determined findings. However, they are given the flexibility to select the methodology, they would use. The third level is guided research. At that level, the learners are asked to plan by themselves the methodology and activity they would implement, in order to access the necessary data and answer the question given to them, so that they would reach results, which are not pre-determined. Finally, the ultimate and desired level is open research. At that level, learners should also point out the question they should answer to explain a phenomenon of everyday life. As soon as the question is pointed out, learners would have to plan research activity to hypothesize, gather data, implement methodology and present the answer. As learners, move from one level to a higher one, they develop deeper skills relevant to scientific inquiry and adopt more stable attitudes towards science, the nature of science and scientific process (Eastwell, 2009; Přinosilová, Mechlová, & Kubicová, 2013).

Current pedagogy stresses also the effectiveness of computer assisted science inquiry. Information and communication technologies (ICT) are justified to contribute significantly to the promotion of learning. By providing access to information and opportunities for observing, hypothesizing, gathering data, analyzing, engaging in discourse and constructing knowledge, ICT serves as a useful tool in science teaching (Sun, Looi, & Xie, 2014). Virtual simulations are an example of ICT applications, which can help learning through experimentation and inquiry process as they can accommodate all the skills and tasks that inquiry learning requires in an attractive way. Conducting inquiry-based simulation laboratory experiments, or combining hands-on laboratory experiments with the use of relevant simulations, can enhance learners' understanding of science concepts, processes and nature (Zacharia, 2003).

Involving Simulations in Inquiry-Based Science Teaching

So teaching science through a computer-assisted inquiry-based approach has plenty of benefits. It promotes and requires development of important knowledge around science concepts and phenomena, skills such as critical thinking, involvement in discourse and development of friendly attitudes towards science both as sum of information and as process. Implementation of inquiry-based science teaching requires involvement in laboratory activities, which assist the active participation of learners in the learning process and in the inquiry tasks.

Simulations can help inquiry-based science teaching. First, they provide grounds for experimentation. By using them, learners can hypothesize, gather data, test, analyze and construct knowledge. It is quite convenient that this experimentation can be easily repeated, so that more accurate data for analysis can be gathered. Second, they expand the selection of contexts for inquiry learning. Promoting inquiry learning and discourse in topics such as astronomy, anatomy and the microworld would be out of question otherwise. Third, simulations are justified through research to promote positive attitudes towards science and science processes (Zacharia, 2003). This is important, especially in the higher levels of guided and open research, where there is focus on planning and questioning (Eastwell, 2009; Přinosilová et al., 2013).

The challenges of simulation use should not be neglected though. It is still not clear if simulations can assist learners' ability to engage in discourse and investigate questions and fields of study, which are important skills in inquiry (Chang et al., 2008). There is also the risk of developing an oversimplified idea of experimentation and the applications of experiments. Moreover, there is the challenge created by the need for careful planning (Jakkola & Nurmi, 2007; Pinto et al., 2004).

Planning the Research

This research examines benefits of using simulations to effectively implement and promote inquiry-based science teaching. Having in mind the potential of simulations in that direction, a series of science teaching interventions was carried out.

The Research Context

During these sessions, the inquiry-based approach was followed and simulations were used. The context of this study was a primary school in Greece and more specifically the Science Club, where learners who share interest in science take part. The main reason for the selection of this context was the fact that teachers who are working in the clubs have the opportunity to select which approach to follow, with no restriction from any pre-designed curriculum or syllabus (Law 3966/2011).

Confirmation research. The learners of the clubs got involved in activities around science topics, such as ecology, human anatomy, states of matter, electromagnetism. There were activities addressed at the confirmation research level. During these, learners would use the simulations, in order to confirm a hypothesis. This would be done by testing values of variables, for example, how the color of subjects affects temperature. These tasks were predesigned in detail. Learners would be given instructions about what to do. All information, such as values was selected for the learners well in advance. The findings are known too. By following all the instructions and information given, learners would confirm a pre-stated hypothesis and become familiar with simulations as means for experimentation (Přinosilová et al., 2013).

Structured research. There were activities addressing structured research. During these activities, learners would use simulations to confirm hypotheses, but they would also explain their actions. They would be presented with a question and be explained how to answer it. They would be asked to evaluate the instructions given to them and explain their importance. They would have to describe why the values they would measure were appropriate to answer the question. After carrying out the instructed experiment, they would explain what and how they did. In some cases, they would be asked to identify alternatives, for example, different values that they could give in the simulations or different contexts. In short, learners would work as in the confirmation research level, but more critically (Přinosilová et al., 2013).

Guided research. There were activities addressing guided research. During these, learners would be presented with the question and hypothesize, but they would be given flexibility to plan the experiment they would execute. After selecting the simulations, learners would engage in discourse to find out what values to use. Then they would carry out the experiment and evaluate their plans. In case the initial question was not answered, learners would repeat the experiment with new values. Learners would have to justify each action decided and its' link to the starting question or hypotheses (Eastwell, 2009; Přinosilová et al., 2013).

Open research. There were activities that addressed open research. During these, learners would be given stimulations to plan investigations, by observing or discussing a phenomenon. Learners would identify what exactly they would investigate and what question to ask. Afterwards they would plan the experimentation, with the selection of the suitable simulation from those known, used or seen before. In some cases, it was also done, by explaining and deciding what this simulation could be like and by searching simulation sites online to find an appropriate one. Precision of variables would follow, along with carrying out the experiment and evaluating the process (Eastwell, 2009; Přinosilová et al., 2013).

Through these sets of activities, the basic features of inquiry-based learning would be promoted. Initially, there would be emphasis on carrying out experiments, analyzing data and making conclusions in confirmation research tasks. Then there would be emphasis on searching for information, sharing and communicating findings in structured research tasks. There would be emphasis on designing and carrying out investigations in guided research tasks. Finally, in open research tasks there would be emphasis in deciding and asking questions, along with creating artifacts (NRC, 2000). By paying attention to these features with the help of simulations, learners would develop knowledge constructing, skills and positive attitudes towards science process, which is expected and promoted by science learning through inquiry (Zacharia, 2003). At the same time, there will be benchmarking with challenges that may arise due to oversimplification or demanding planning required (Jakkola & Nurmi, 2007) or lack of promotion of discourse and investigation skills (Chang et al., 2008).

Forming the Research Questions

Implementation of inquiry-based science learning is known to have many advantages in science teaching, as it promotes more profound learning about science content knowledge, skills, processes and attitudes through active engagement of learners in science real-life topics. It evolves across four levels: confirmation research, structured research, guided research, open research (Eastwell, 2009; Přinosilová et al., 2013). Simulations are justified to assist science learning, as they are an attractive application that can help carrying out experimentation in many ways, as well as data analysis, science discourse, problem-solving and knowledge construction, which are important elements of inquiry-based science learning (Zacharia, 2003).

The research was planned to evaluate the assistance of simulations in inquiry-based science learning. Bearing in mind the levels of inquiry based teaching, to accomplish this evaluation the following research questions should be answered:

1. Did the use of simulations assist in confirmation of theories?
2. Did the use of simulations assist in evaluation of experimentation?
3. Did the use of simulations help in planning research projects?
4. Did the use of simulations help in identifying questions and topics of research?

Methodology

This research is of qualitative nature. The topic of this research is to evaluate if the use of simulations assists inquiry-based science teaching. The selection of the appropriate methodology for this evaluation has to take into consideration two different dimensions. The first is the evaluation of the inquiry-based learning. The other is evaluation of simulations used in each experiment (Cohen, Manion, & Morrison, 2011).

Evaluation of inquiry-based learning can be based on both formative and summative assessment. The former is done throughout the course. While learners are working on inquiry-based tasks, they demonstrate their knowledge, skills and attitudes about science processes and inquiry. Learners can present their ideas about using simulations. It is possible this way to prove if they can use them effectively and understand their importance in experimenting, engaging in discourse and learning science. By observing or interviewing them, it is possible to get data about their progress, give feedback and conclude about learners' achievement. The latter is done probably by the end of the course or periods of the course. It includes methods such as revision tests and note-portfolio. Revisionary tests provide important data, however they can be distorting unless planned at appropriate time and way. Moreover, since inquiry refers to processes, it is not easy to identify the kind of tests that can examine accurately inquiry features in learners. On the other hand, a portfolio of notes about learners' work, completed gradually throughout the course shows important information about learners' performance and use of simulations in inquiry tasks. A combination of interviews with learners, observations of the tasks and analysis of learners' portfolio of notes, includes both formative and summative assessment approaches and can give accurate data about the way learner, approach, treat and use simulations to carry out inquiry investigations (Harlen, 2013; Worth, Duque, & Saltiel, 2009).

Evaluation of ICT applications, such as simulations, in education should be based on the appropriate selection and use of relevant indicators. For this research these indicators should emphasize the output of teaching, which refers to learners' knowledge, skills, attitudes and confidence in using and understanding the necessity of simulations. In this case as well, the most appropriate information can come from continuous interviews with learners, observations of the way they use simulations and from self-reports, which can be included in a portfolio of notes (Wagner et al., 2005).

In short, the most appropriate methodology for this research includes interviews, observations and notes. So, an interview and observation guide was formed. The interviews and observations were transcribed and analyzed. Afterwards they were coded, in other words they were given labels, relevant to points of the research questions. The codes were grouped to nodes (Cohen et al., 2011).

To answer the first question, there was emphasis on hypothesizing, analyzing data and drawing conclusions with the help of simulations, such as "What are you going to do now?" "What do you think will happen?" "Which data will you use?" "What does the result mean?" "Did you expect that?" The codes that were used for this research questions, under the node CONFIRMATION, were *hypothesis, analysis, concluding*, and *data explanation*.

To answer the second question, there was emphasis on using simulations for explaining and evaluating the instructions, describing the process, proposing alternatives, such as "What does this step mean?" "Why do you think this is necessary?" "Does this help us find what we are looking for?" "Do you think this can be done in another way?" The codes used for this research question, under the node EXPLANATION, were *description, evaluation, alternative*, and *necessity.*

To answer the third research question, there was emphasis in using or selecting simulations, planning the research project, analyzing the initial question, identifying variables, such as "What does our question have to do with?" "What topics [concepts] we are working with here?" "What simulation should we use?" "What number [value] should we use here?", "Do we answer our question like that?" The codes used for this question, under the node PLANNING, were *simulation selection, variables, value identification, question understanding, planning,* and *evaluating.*

To answer the fourth research question, there was emphasis on using or selecting simulations for identifying question, evaluating question, clarifying the relevant topics, evaluating their plan in coordination with the initial question as set by the learners, applying their findings, such as "What do you observe here?" "What does the simulation show?" "Can we explain that?" "What can we do to explain that?" "Will the simulation help?" "So what do you think you have learnt from that?" "Do you think the initial observation was now explained?" The codes used for this question, under the node TOPIC IDENTIFYING, were *questioning, explaining questions*, *clarifying topics*, and, *simulation using*.

The codes reflected the basic skills and characteristics of inquiry-based learning and simulation use and the nodes reflected groups of them (Eastwell, 2009; Přinosilová et al., 2013; Zacharia, 2003). By identifying the nodes in the interviews, observations and notes, it was possible to conclude whether these characteristics are developed appropriately or if the challenges mentioned in literature, actually arose (Chang et al., 2008; Jakkola & Nurmi, 2007; Pinto et al., 2014)

Findings

The findings, as shown from interviews, observation and learners notes, were generally positive. It was shown that using simulations helped, at least to an extent, the promotion of inquiry-based learning in science.

1st Research Question

With regards to the first research question, learners showed that they were able to use simulations to confirm theories. All learners were observed to conduct the experiment and follow the instructions given to them with ease. They were able to use the data and explain their findings, after carrying out the relevant analysis and construct new knowledge as expected. These findings are compatible with those of relevant research projects stating that generally simulations and virtual experiments can promote skills relevant to justifying theories (Zacharia, 2003). In fact, they kept asking with apparent enthusiasm "Are we going to use the simulation?" demonstrating that indeed simulations are attractive means for learners (Jakkola & Nurmi, 2007). There is only one side of the findings, which is not so positive. There were learners that omitted hypothesis as part of the experiment. During interviews, when asked about hypothesizing, many learners gave responses such as "We need to do the experiment before knowing what happened," showing that they do not attribute to hypothesis the appropriate importance, which is crucial for inquiry learning and scientific work (Eastwell, 2009). This negligence might be attributed to inappropriate design (Pinto et al., 2014). It can be concluded, therefore, that the level of confirmation research has been well conquered with the help of simulations, as most relevant skills such as experimenting, analyzing data were developed (Harlen, 2013; NRC, 2000; Worth et al., 2009).

2nd Research Question

With regards to the second research question, it can be stated that participants (learners) did become familiar with evaluating experimental tasks and instructions given to them, as required in structured research. Firstly, all learners were able to describe the instructions given to them and explain their importance in relation to the initial question set to them. Secondly, there was also apparent familiarization of learners in disseminating, communicating and explaining the results of their experiments. Thirdly, learners realized the assistance of simulations in such tasks, as it was seen by responses such as "We can see what molecules do, when we heat the water in the computer… but we cannot see it with the eye."

The data indicates support in using simulations to help learners develop skills of critical thinking towards experimentation (Zacharia, 2003; Worth et al., 2009). The only concerning point is that learners had difficulty in giving alternatives whenever they were asked. In fact, the only kind of alternative they could provide was at the level of giving different values to variables. It was difficult for learners to suggest other activities from other contexts. This might be attributed to the oversimplification that simulations are known to provide, which was seen as easy and convenient for learners and understand and explain and does not let them link phenomena with real-life situations

(Pinto et al., 2014). Overall, however, it is indicated that learners benefit from the use of simulations in carrying out experiments and explaining, justifying their actions towards answering the initial question (Harlen, 2013; NRC, 2000; Worth et al., 2009).

3rd Research Question

With regards the third research question, the findings were partly encouraging. Some skills of planning research were found to be sufficiently developed; however, others not. On one hand, most learners showed that they were able to analyze the question as set to them to understand the variables used in the experiment. This also helped them identify appropriate simulations that they could use in order to answer the question. This is compatible to the research finding that simulations can be helpful in terms of providing grounds for discourse (Jakkora & Nurmi, 2007), which is essential part of inquiry-based science learning (Eastwell, 2009; Harlen, 2013). On the other hand, learners demonstrated difficulty in describing what they would do with the simulation and the variables, which created challenges in identifying values for the experiment. When learners were asked in interviews how they were going to use the simulation, the answers given were sometimes too broad, or answers such as "We are going to play with that," demonstrating that learners would treat the simulation more as means for amusement than as a learning tool. Such responses demonstrated that learners did not have the appropriate understanding that the simulation may be in fact referring to authentic real-life situations where scientific phenomena are applied (Chang et al., 2008; Pinto et al., 2014). In short, data suggests that with the use of simulations learners managed to develop some skills linked to guided research, such as analyzing questions and identifying experimental tasks. However, the planning process remained challenging for most of them (Harlen, 2013; NRC, 2000; Worth et al., 2009).

4th Research Question

With regards to the fourth research question, findings indicate that learners were challenged to identify questions and fields of investigation. On one hand, when they were observing the phenomena on the simulation, they had ease in linking it with the concepts of science, which are relevant. When investigating the greenhouse effect, they immediately linked it to concepts such as *light*, *energy*, *temperature*, *transparent material*. They were also able to note precise relationships between these concepts and use simulations to demonstrate them, for example, "Too much light means higher temperature." Such skills are necessary for the implementation of inquiry-based learning (Harlen, 2013), and the use of simulations favors it, as also seen from research (Zacharia, 2003). On the other hand, learners had some difficulty in identifying the question (hypothesis) that they should form and the experiment they would carry out to answer it. The precise understanding of concepts seemed to be done rather fragmentary. When it was needed to combine concepts in order to form the problem to investigate, there was little response. When in interviews they encouraged to combine them, most learners would simply repeat the same concepts and fragmented links. In some cases they would give repetitive answers such as "We can see it in the simulation." These do not show deep understanding of the concepts. This is not so positive for the promotion of inquiry learning (Eastwell, 2009; Harlen, 2013). This challenge might be attributed to the stated disability of simulations to promote investigation skills of learners (Chang et al., 2008).

Conclusions

This research aimed to identify the possibility to use virtual simulations in inquiry-based science teaching. Virtual simulations are known by research to assist knowledge construction, experimentation, skill and attitude development (Zacharia, 2003). Inquiry-based learning is justified to assist profound understanding of science, not only as sum of information, but also as process (Eastwell, 2009; Harlen, 2013). A combination of these two approaches could be beneficial, since research has identified that some (but not all) simulations assist particular skills required in inquiry (Chang et al., 2008; Jakkola & Nurmi, 2007). A study was carried out to verify that. The research was qualitative with data collected using interviews, observations and learners' notes (Cohen et al., 2011).

Learners were involved in focused activities using simulations on tasks and skills relevant to inquiry: to confirm a theory, to experiment critically, to plan a research, to form questions (Eastwell, 2009). The findings showed that learners used effectively the simulations to confirm a theory and experiment critically. However, there were challenges in research planning and question forming. The main conclusion was that simulations can assist inquiry-based learning in primary school science. Probably though there is need for more careful design and concern about the development of several skills mainly those linked to science discourse (Chang et al., 2008).

It is acknowledged that this research, which examined a particular group of learners involved in inquiry-based learning with the help of simulations, in a particular period of time limits generalizing the findings (Cohen et al., 2011).

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Author Details

Konstantinos Karampelas
kkarampelas@aegean.gr