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The Effects of Computer Simulations on Students' Science Process Skills: Literature Review

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Abstract

Some concepts in science education are incomprehensible and complex. Therefore, they need explanatory educational processes. These educational processes should also develop students' science process skills (SPSs). This article reviewed the research about computer simulations whether or not they have an effect on students' SPSs in science education. It focuses on three questions: how the use of computer simulations develops students' SPSs, how computer simulations are used in order to better improve learning processes and outcomes and whether computer simulations can replace laboratory experiments with computer simulations. The literature revealed that although computer simulations are more effective in science teaching to overcome traditional teaching, it has been determined that presenting science concepts through simulations without using other teaching methods is insufficient to gain SPSs. Besides, the use of virtual laboratories in online learning still leaves some problems.

Keywords: Computer Simulations, Science Process Skills, Science Learning

Introduction

Today, science and technology are developing rapidly. Against this, traditional education approaches in which the teacher gives a lot of lectures while the students listen, record and memorize (Tosun & Yildiz, 2015; Haryadi & Pujiastuti, 2020) are insufficient in raising individuals and developing their skills. In addition, science education should prepare students for the ever-increasing competition between countries and enable them to keep up with the conditions of the 21st century with higher achievement standards.

The rapid development of information technology and the use of computers and internet in education have led to a paradigm shift in various fields, including the development of learning methods (Siahaan et al., 2017; Saputri, 2021; Yildiz, 2021). With the development of technology and knowledge, there is a shift in the learning environment from print to digital. Therefore, it is necessary to take advantage of the opportunities provided by the use of information and communication technology (ICT) through the learning process (Hırça & Şimşek, 2013).

In the 21st century society, the competence of individuals can be defined by integrating information and communication technology (ICT) into the learning process. Therefore, 21st century learning has its own specific challenges, namely, building informed communities with ICT expertise and SPSs (Haryadi & Pujiastuti, 2020).

Integration of ICT into the Computer-Assisted Instruction

Students turn into passive information receptors of knowledge and information. In order to end this lack of teaching related to non-constructivist approaches, some empirical studies have revealed innovative and student-centered approaches that promote the acquisition of skills among students (Nganyadi, 2021). Nowadays, many studies in the published literature indicate that there is a strong relationship between the use of computers and students' acquisition in teaching and learning processes (Altun & Alev, 2007).

Computer technologies are an integral part of modern science and science education. The use of computers in science can be divided into five categories: symbolic manipulation, data collection, simulation, numerical analysis, analysis and visualization (Gold & Tobochnick, 1996). The ICT-based learning activities include making presentations using laptops/computers, making observational videos, search for learning resources through the internet, send emails and business productivity software such as text editor and spreadsheet, enterprise software, data storage and security, network security and others (Ashrafi & Murtaza, 2008; Van Laar et al., 2017).

Çetin (2018) claimed that computer technologies can transform learning by providing teachers with more opportunities, providing students with more cooperation with their peers and experts. In the context of education, the real role of ICT is seen as a tool that will ensure the formation of effective and efficient learning processes.

Computer-Assisted Instruction (CAI) is an interactive teaching technique in which a computer is used to present teaching materials and monitor the learning taking place (Onasanya, Daramola, & Asuquo, 2006). CAI is a tool which makes the learning process more interesting and remarkable by using a combination of text, graphics, audio and video for achieving the learning goals planned by the teacher (Siahaan et al., 2017; Haryadi & Pujiastuti, 2020). Therefore, CAI, which addresses the students' five senses, allows students to access a wide range of information sources and encounter different perspectives (Onasanya, Daramola, & Asuquo, 2006; Bakac, Kartal, & Akbay, 2011).

Comparison of Simulation Experiments and Laboratory Experiments

Computer simulations are a product of the current development of digital information technology. It is a logical consequence of adapting to the development of information and communication technologies, including the use of various virtual laboratories (Saputri, 2021). Teaching through a simulation can cause students to gradually

deduce the characteristics of the conceptual model of the simulation, which in turn can lead to changes in the original concepts of the students (de Jong & van Joolingen, 1998).

Computer simulations are sometimes called computer experiments because they have a lot in common with laboratory experiments (Gold & Tobochnick, 1996). The similarity of simulations with laboratory studies can be seen in some respects. Examples in lab work are the same as models in computer simulation. Physical devices are like computer programs. Calibration in laboratory work is similar to computer programs in computer simulation. Data analysis is performed in both laboratory studies and computer simulation. Therefore, it is interesting to conduct research on laboratory experiments and computer simulation in the field of science teaching-learning (Sumardi et al., 2014).

According to de Jong and van Joolingen (1998) students can systematically explore hypothetical situations, a simplified version of a process or system to interact with. They also can change the time scale of events and tasks, apply what they have learned, and have the advantage that they can solve problems in a realistic environment without stress (de Jong & van Joolingen, 1998; Hırça & Bayrak, 2013; Cayvaz & Akçay, 2018). On the other hand, Sumardi et al. (2014) stated that the experimental method which includes real things, tools, and measuring instruments is more effective on students' cognitive achievement and acquiring science process skills than simulations. However, not all science subjects can be demonstrated by doing experiments in the classroom (Hırça & Bayrak, 2013).

There are some concepts in science learning that are difficult to directly observe. For example, Siswanto et al. (2018) stated that the phenomenon of parabolic motion which is a combination of uniformly accelerated and accelerated motion can be demonstrated by simulation in the most detailed form. Finkelstein et al. (2006) indicated that the forms of energy and energy changes that exist in everyday life can be visualized through PhET simulation. Therefore, it is very important to use teaching activities that will be able to comprehensively demonstrate the basics of scientific concepts for students to fully understand (Akçay et al., 2005; Siswanto et al., 2018).

Examples of Computer Simulation Software in Science Education

PhET, which is a simulation developed by the University of Colorado, is one of the most common easy to use software in science education. PhET simulations designed to demonstrate the basics teaching physics, biology and chemistry for the benefit of classroom learning or individual learning (Perkins et al., 2006; Daskan & Yildiz, 2020).

Figure 1: A screen of parabolic motion at PhET simulation

PhET simulation that can be accessed easily and free of charge by students not to burden students financially helps students to acquire the relationship between real-life and underlying knowledge (Haryadi & Pujiastuti, 2020) and provides feedback to students in the creative workplace (Perkins et al., 2006).

Algodoo educational software is very suitable for teaching and learning physics in a computer-based learning environment. The ability of this software is that it is able to visualize physical phenomena in a similar way to real situations. Algodoo shows scientific interactions in a more interesting way with virtual remarkable animations.

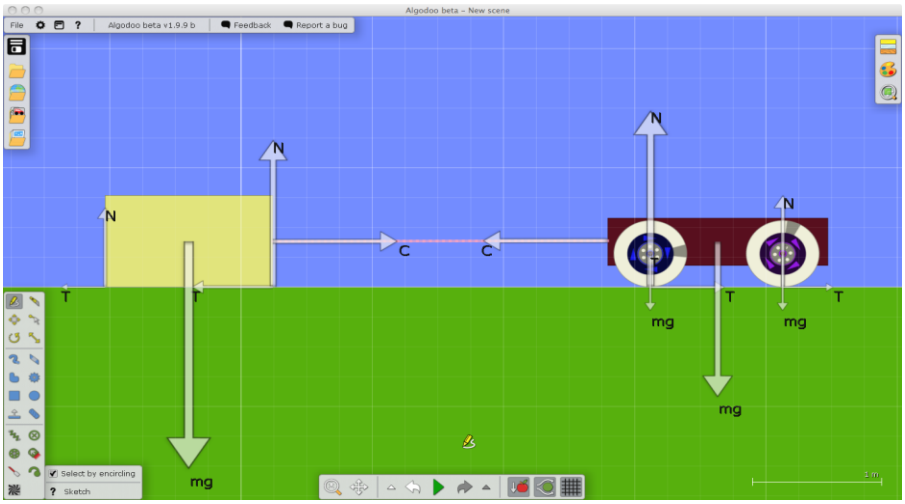

Figure 2: A screen of Newton Laws at Algodoo simulation

The Algodoo educational software presents a fun and motivating learning environment for students creating an interaction between drawing and physics courses. With Algodoo, students can test physical theories and laws or their own hypotheses to learn by doing in a computer environment. Students can also design their own physics-based games by taking into account gravity, friction force, and even the friction coefficient of air (Hırça & Bayrak, 2013; Cayvaz & Akçay, 2018).

Educational Aspect of Computer Simulations

In elaborating constructivists' ideas, Elliott et al. (2000) stated that constructivism is a learning approach that argues that individuals actively build their own knowledge and that reality is determined by the student's experiences. Svein Sjoberg defines the basic ideas of the constructivist learning approach, as the knowledge is not passively received from outside, but actively constructed by the learner (Sjoberg 2007).

Simulations can provide a more complex and realistic learning environment than other educational strategies. They can also make complex science concepts more simple and understandable. Therefore, Perkins et al. (2006) and Sjoberg (2007) asserted that science simulations also support constructivist approaches. Finkelstein et al. (2006) indicated that when reviewed based on the Dale's Cone of Experience, science simulations such as PhET simulation is included in the most concrete level, where 90% of students will be actively involved in learning activities to observe, conduct experiments, and conclude the data obtained.

The use of virtual laboratories in online learning still leaves some problems. Saputri (2021) stated several problems arise in the implementation of virtual laboratories which are lack of students' ability to perform practical procedures, students' lack of understanding of the error method and low skills of students' science processes are problems that arise during the implementation of online applications.

On the other hand, Siswanto et al. (2018) emphasized that it is important that the simulations used in the studies are developed by researchers under the supervision of education experts in order to adapt to the learning activities performed by the students.

Haryadi and Pujiastuti (2020) conducted research to determine the presence or absence of a significant effect of the use of PhET simulation media on the learning achievements of the basic energy material in the life system. The results of the study show that learning using PhET software simulations is 37% better than traditional learning. It can be concluded that PhET software simulation can improve students' science process skills. However, Saputri (2021) stated that mastery of student science process skills is low during the implementation of online learning with virtual laboratories.

The Relationship Computer Simulations with Students' SPS

The learning approach not only conveys knowledge but also emphasizes the process of scientific inquiry. One of the learning approaches that facilitates students to act like scientists is SPS activities. In this learning approach, the teacher acts as a facilitator, guiding and directing students' learning activities so that students can independently construct necessary facts, understand concepts and apply new values into their lives (Siahaan et al. 2017). By this approach, students learn to conduct scientific studies to solve problems similar to those conducted by scientists (Siswanto et al, 2018).

Science education should direct students to master the science process directly through experience (MEB, 2005). In other words, learning science should provide students with the opportunity to develop their science process skills (SPS). Therefore, the key to learning science is to develop students' SPS (Supriyatman & Sukarno, 2014).

SPSs (SPS) means a uniform series of actions or tasks performed in order to do, make or achieve something in science (Nganyadi, 2021). Science education SPS can be divided into two groups: "Basic" and "Integrated". The basic SPS refers to the following six actions without a specific sequence: Basic SPS include observing qualities, sorting/classifying, measuring quantities, predicting, inferring, experimenting, and communicating. Integrated SPS are complex processes that combine two or more basic SPS, such as formulating hypotheses, interpreting data, controlling variables, and conducting experiments (Azizoğlu & Dönmez, 2010).

Although real laboratories can be used to develop students' science process skills in science learning, in order to comprehensively teach the science concept, an approach is required that makes it easier for students to fully understand the phenomenon (Siswanto et al., 2018). In such a case, simulated experiments have great potential to address the complex activity of the problem solving process (Huppert, Lomask, & Lazarowitz, 2002). Scientific approach-integrated virtual simulation can be used as an alternative method to significantly enhance students' SPS (Siahaan, et al., 2017; Siswanto et al., 2018).

However, although learning activities are conducted on materials that are difficult to observe in the real situation, science process skills should be established within each student (Siswanto et al., 2018). Simulated experiments are especially convenient to link the use of simulations to inquiry learning (Eysink et al., 2009). Therefore, computer simulation softwares can affect students' academic success potential (Huppert, Lomask, &Lazarowitz, 2002).

Computer simulations include a system or process model that allows the student to explore phenomena by manipulating input variables and observing changes (Eysink et al., 2009). Therefore, computer simulations can also enable students with low reasoning ability to cope successfully with learning concepts and principles in SPS that require high cognitive skills (Huppert, Lomask, & Lazarowitz, 2002).

The Effects of Simulations on Students' SPS

Studies on the comparison of simulations with laboratories have been conducted for more than thirty years. Simulation programs are developing as computer technology develops. The availability of computers, related equipment such as smart boards and mobile devices has increased, computer simulations have become available for a wide range of science topics. This, in turn, has led to the fact that simulations have become an integral part of many science curricula.

When simulations are not becoming more common in science education, Wade (1996) conducted a study with ninth grade biology students. The researcher determined the effects of traditional teaching methods, laboratory experiences and computer-assisted instruction integrated with laboratory experiences on the development of 116 ninth grade biology students' SPS. In this study, controlling variables, defining operationally, hypothesizing, modeling, and interpreting data skills of students and their attitudes toward learning science were assessed. Data indicated that although computer-assisted instruction integrated with laboratory experiences has positive effects on their attitudes, there wasn't enough time to determine differences between students' developing SPS.

Supriyatman and Sukarno (2014) investigated how to improve student teachers' science process skills and mastery of concepts through using interactive computer simulations. They concluded that when they obtained data through tests, by applying the inquiry learning model using an interactive computer simulation, mastery of the concept and SPS of pre-service teachers could be improved. Haryadi and Pujiastuti (2020) find out the effects of the application of PhET simulation in physics learning in the matter of temperature and heat. They concluded that applying physics learning on temperature and heat material using ambient PhET simulation was 37% more effective than the control group using direct learning. They stated that PhET simulation software-based learning is interactive learning in physics learning and that students can improve their SPS. Siswanto et al. (2018) were conducted to obtain a description of learning activities that develop student's SPS in physics learning, referring to the syntax of scientific learning activities. During the in-class activities, virtual simulations activities were implemented with 31 students face-to-face and learning activities were carried out. The results of the research showed that there was a significant increase in the students' SPS and that there was a significant difference between the pre-test score and the final post score.

Siregar, Rajagukguk and Sinulingga (2020) investigated the improvement of students' SPS through the scientific inquiry models using algodoo simulation. They found out that there was an interaction between the scientific inquiry model with algodoo simulation and student adversity quotient in improving students' science process skills. Huppert, Lomask and Lazarowitz (2002) investigated the effect of computer simulation on students' academic achievement and mastery of SPS in relation to their cognitive stages.

The researchers indicate that concrete and transition operational students in the experimental group achieved significantly higher academic achievement than their counterparts in the control group. The girls in the experimental group had equal success with the boys.

In the other study, Nganyadi (2021) investigated the effect of CAI on secondary students' acquisition of SPS and retention in biology courses. The findings revealed that students taught biology achieve higher than those taught using the lecture method. The findings also revealed using CAI effect a significant difference in the mean acquisition score of students in favor of the experimental group. Nganyadi (2021) investigated the effect of CAI on secondary students' acquisition science process skills and retention in biology courses. The findings revealed that students taught biology achieve higher than those taught using the lecture method. The findings also revealed using CAI effect a significant difference in the mean acquisition score of students in favor of the experimental group.

Inadequacies of Computer Simulations in Science Teaching

However, several studies have focused on the fact that using only simulations in education will not be effective. Yang and Heh (2007) investigated and compared the effects of computer simulation teaching and traditional laboratory teaching on tenth graders' achievement of physics, SPS performance and computer attitudes. One hundred and fifty students from four grades are sampled in a private high school. They found out that the experimental group achieved significantly higher average scores on academic achievement in physics and SPS. There was no significant difference between the groups in terms of computer attitudes. They concluded that computer simulation has the potential to help tenth graders to improve their physics academic achievement and SPS.

In the other study, Huppert, Lomask and Lazarowitz, (2002) stated that a highly structured approach is required to understand the use of simulations as a teaching tool. Therefore, students' academic achievement can demonstrate the potential impact that a computer simulation program can have, and enable students with low reasoning ability to successfully cope with learning concepts and principles in science that require high cognitive skills.

Siahaan et al. (2017) researched development of students' science process skills (SPS) on linear motion concept by utilizing simple computer simulation. The process of developing science process skills of 23 seventh grade students was examined based on the normalized outcome analysis from pre-test and post-test scores for all sub-concepts. The result of the study showed that students' SPS are dramatically improved by 43% (moderate) on summarizing skill, 70% (high) on prediction skill, 47% (moderate) on observation skill; 44% (moderate) on communication skill and 49% (moderate) on classification skill. Results of the study clarified that the use of computer simulations in physics teaching can

moderately improve general science skills. Supriyatman and Sukarno (2014) stated that low level SPS of students are the main basic factors of many problems that science teachers encounter while teaching science process skills. Nevertheless, Saputri (2021) indicated that simulations can be used as a solution to deal with students' low science process skills during online learning. They can also collaborate in offline learning with real practical application in the lab.

Using Computer Simulations Integrating Other Science Teaching Methods

There are studies in the literature that the use of simulation integrating with other methods will be more effective in science teaching. For example, some researchers stated that combining simulation and collaborative learning will be more effective on students' SPS (Eun & Young, 2017; Chen, Hua, & Ge, 2014; Phillips & Graeff, 2014; Karaçöp & Doymuş, 2013).

For instance, Eun and Youn (2017) state that when simulations were combined with cooperative learning students' academic performances, communication skills, and their performance scores were improved. They also suggested applying this combined method in training sessions to improve educational outcomes. Similarly, Chen, Hua, and Ge (2014) claim that simulations and cooperative learning provide effectiveness and advantages in the classroom environment.

In another study, Phillips and Graeff (2014) state that these activities provide an improvement in students' attitudes, confidence and understanding of concepts. Finally, Karaçöp and Doymuş (2013) found that learning and simulations together were more effective than traditional teaching methods in a housing cooperative on a chemical bond issue. As a result of these studies, it has been seen that teaching a subject with simulations and cooperative learning especially reveals its advantages. Çetin (2018) also stated that if simulations are effectively integrated with cooperative learning, the success of high school students will increase, and students' ideas about interactive whiteboards and science lessons will change over time.

Discussion and Conclusion

The rapid development of information technology affected the use of computers in education. Therefore, there is a shift in learning media from print to digital (Siahaan et al., 2017; Saputri, 2021). SPS in learning are very important that every student has, because these skills are used in everyday life. SPS are learning processes designed so that students can find facts, understand scientific concepts and theories with scientific knowledge with intellectual skills through activities like a scientist. Many studies indicate that there is a strong relationship between ICT use and students' acquisition in teaching and learning processes (Altun & Alev, 2007; Çetin, 2018). ICT can transform learning by providing teachers with more opportunities and providing students with greater collaboration with

peers and experts, as well as increasing access to information, ideas and difficult topics that are expressed and communicated (Çetin, 2018).

On the other hand, the literature revealed that although computer simulations are more effective in science teaching to overcome traditional teaching, it has been determined that they should not be used in teaching without taking into account the opinions of teachers. Besides, presenting information only with simulations without using other teaching methods is insufficient to gain SPS. For example, Sumardi et al. (2014) indicated the experimental method which works with real things, tools, and measuring instruments is more effective on students' cognitive achievement and acquiring science process skills than simulations. However, de Jong and van Joolingen (1998) completely disagree with the conclusion that science teaching can be successful only by experiment due to the abstract structure of science concepts. According to de Jong and van Joolingen (1998), although real laboratories can be effective on science learning, in order to comprehensively teach the science concept, an approach is required that makes it easier for students to fully understand the phenomenon. Students systematically explore hypothetical situations, and can change the time scale of events and tasks and they can solve problems in a realistic environment without stress through a computer simulation environment.

Huppert, Lomask and Lazarowitz, (2002) called attention to the fact that implementing courses only through simulations will not be effective on students especially with low reasoning ability to successfully cope with learning concepts and principles in science that require high cognitive skills. On the other hand, Saputri (2021) has revealed various problems arising in the application of virtual laboratories in the form of students' lack of skills to perform practical operations, students' inability to understand the error method, and students' lack of SPS.

One other important thing is that the teacher is in the center of the teaching and learning process. Thus they must follow the latest developments in science so that in the whole learning process the teacher and students will learn together but the teacher has the task of directing and managing the class (Haryadi & Pujiastuti, 2020).

As a result, some concepts in science education can be abstract, incomprehensible and complex for students. Therefore, students need training with teaching methods that explain abstract, incomprehensible and complex science concepts. Moreover, the aim of science education is not only to present concepts, but also to provide students with SPS. Therefore, the educational methods should also develop the SPS that students need throughout their lives. Considering this aspect, simulations are a method that is constantly increasing in use to make science concepts more concrete in the literature. According to the results of the study, using simulation methods in combination with other teaching methods should be more effective and will reduce its deficiency.

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