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Research Article

Interactive Simulation on Modern Physics: A Systematic Review

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ABSTRACT

Physics is a theoretical science, understanding the concepts requires actual visual representations and models. Physics instructors should teach physics using inquiry, discovery, demonstration, simulation, practical work, lab-based activities, and other practical experiences. The current status of knowledge and practice regarding interactive simulation in the teaching of modern physics is presented in this systematic literature review. By methodically evaluating and summarizing the most pertinent previous research publications published from December 2002 to January 2022, it offers guidance for instructional designers and scholars. After careful consideration and screening, a total of eleven studies were chosen for a thorough analysis and synthesis. The results showed that the objective of the research studies on using interactive simulation in modern physics is to enhance students' critical thinking skills and creative problem-solving skills. It has been demonstrated that interactive simulation technologies like Java applets and Physics Education Technology (PhET) are successful at teaching modern physics. The success or failure of employing interactive simulation is influenced by teachers, school staff, students, simulation design, and technology used. The findings imply that educational institutions should provide teachers and administrators with tutorials and training, and this review recommend that the interactive simulation should be available and that a gadget-friendly simulation must be developed.

Keywords*: interactive simulation, modern physics, physics, technology*

Introduction

Physics instruction poses a unique set of challenges in a variety of ways. It's a subject that's being talked about and may be accurately described as difficult. The emphasis in university Physics classes is on concepts, comprehension, and logical reasoning. There is also a need for students to develop strong analytical and

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mathematical skills. From that, physics is considered as one of the hardest subjects that students meet in school, and there is a need to address students' challenges with the subject in order to better understand the precise causes of their problems (Bray & Williams, 2022). According to Lederman & Abell (2020), physics is one of the subjects that students find least interesting out of all the sciences. This is because learning physics involves challenges that are unique to physics knowledge. Furthermore, since physics is a theoretical subject, understanding the concepts calls for actual visual representations and models. Physics educators should use inquiry, discovery, demonstration, simulation, practical work, lab-based activities, and other hands-on experiences to teach their students about physics.

In traditional physics teaching methods where teachers are active and students are passive and not responsible for their own learning, students are more likely to be failed individuals loaded with information based on memorization rather than creative individuals who can question and produce solutions by tackling problems. Students who receive an education in this manner are more likely to be unsuccessful people who memorize information than they are to be creative people who can ask questions and come up with solutions. Students' motivation and self-sufficiency are also harmed by this. To help students achieve better results in physics classes, it is crucial to take self-sufficiency into account when managing educational-training activities (Kocakaya & Gönen, 2010). Further, students in traditional physics courses do not comprehend the relevance of the subject to everyday life (Baran & Maskan, 2010). But, when students learn a subject in contexts that encourage active learning by connecting it to the real world, their learning is more successful and consistent (Yam, 2010). Moreover, teachers serve to facilitate the use of effective learning strategies in active learning scenarios in the classroom. Students who participate in active learning categorize information, research concepts, and make connections to prior knowledge in the cognitive, emotional, social, and physical domains (Tekerek & Ercan, 2012; Demirci, 2015). As a result, educators should consider how children may learn physics in a more interesting way by connecting it to technology. In recent years, technology has been more and more integrated into education with significant outcomes (Fallon et al., 2019). There are many ways that education can be made accessible, and the process of teaching and learning has improved as a result of technology. Also, in order to transform the atmosphere and give students more flexible learning tools, technological integration in the classroom has been given top attention.

Teaching-focused physicists have developed strategies and resources to improve students' attitudes toward physics and to inspire greater interest in learning the subject. This is due to the fact that students find physics difficult since they must contend with numerous representations at once, such as experiments, equations and computations, graphs, and conceptual explanations. And because students lack a strong foundation in situational comprehension and problem-solving, teachers are also having difficulty teaching physics (Dalagan & Mistades, 2010). Interactive computer simulations are one of the most popular teaching tools for physics. In recent years, this technology has been gradually incorporated into the teaching of science subjects, leading to significant improvements in the teaching-learning process. Technology like interactive computer simulations provides students with real-world experiences. Through interactive computer simulation, students have a wonderful opportunity to explore a setting that simulates actual scenarios. Interactive computer simulations allow users to interact with situations that aren't realistically possible. It provides a lively, engaging, and aesthetically exciting learning environment (Clark et al., 2009). By performing a specified task, students can practice problem-based learning and gain experience with the situation.

When the COVID-19 pandemic broke out, forcing many teachers to instantly change their methods of instruction, the usage of interactive simulations was strengthened. Instead of providing the curriculum in person, teachers required to devise ways to provide it electronically and simulations is utilized as a substitute for in-person laboratory when demand for pandemic-related home-lab kits outstripped supply (Tripepi, 2022). Computer simulations offer a wide variety of modelling choices for concepts and processes. Simulatio- ns help students make connections between their prior knowledge and the acquisition of fresh physical concepts that let them actively rethink their beliefs and improve understanding (Jimoyiannis & Komis, 2000). Researchers in Turkey, New York, and Hong Kong have found that computer simulations are effective in fostering more complex goals like inquiry and conceptual transformation as well as in developing subject knowledge and process skills. In a range of subject areas, including physics, chemistry, biology, and mathematics, Science of the Earth and Space, it has been shown that students' comprehension and achievement in general science process abilities have increased (Kulik, 2002).

However, despite the fact that numerous research studies on the use of technology in education have been conducted, there hasn't been much research on the use of interactive computer simulation in classroom instruction in the Philippines. Although interactive computer simulations are frequently used in science and engineering, schools hardly ever use them. This work aims to fill this knowledge gap. This study is a review of the literature with a focus on the integration and creation of an interactive simulation application for physics education. This notion was chosen since interactive simulation programs are a relatively new idea in the country.

Statement of the Problem

The primary goal of this systematic review is to present an in-depth analysis of the research that has been undertaken on interactive simulations in modern physics. This study would like to specifically answer the following questions:

1. What are the different technologies being used for interactive simulation in teaching and learning modern physics?
2. What are the main objectives of the research studies on using interactive simulation in modern physics?
3. What factors aid success or failure in the use of interactive simulation?

Methods

This chapter discusses the research design, criteria of selection, inclusion and exclusion criteria, data gathering procedure, data analysis and ethical considerations.

Research Design

A systematic literature review was conducted using the PRISMA guiding principle of Moher et al. (2021), to review scientific articles, and was divided into the following steps: a) selecting appropriate criteria, b) selecting articles, c) searching strategies, and d) data collection process. This approach calls for a range of steps to be completed in order to present a fair synthesis and interpretation based on a fair reading of the results from previous work. Relevant evidence that satisfies the pre-specified eligibility requirements must be obtained in the following steps in order for such endeavour to be successful because it might answer certain research questions.

Criteria of Selection

A manual search for peer-reviewed international journal papers was done to finish the initial screening. For this review, the search terms (keywords) from any terms relating to interactive simulations that were included were used. The authors of this review used a number of strategies to expand and combine literature searches, including the use of Boolean operators like "OR" to find any synonyms and "AND" to combine any search term for each of the three research questions. Any prospective reviewed reference list from each included study was searched in addition to the database search in order to find any additional pertinent papers that were missed by the database search. The next step would be to look for relevant published publications to include in the review by searching the title and abstract of each record. The other studies were removed after the initial screening of studies that are found to be relevant and valid publications. The selected publication was subjected to further screening of their text version, and the remaining published articles was included in the review after a thorough screening.

Inclusion and Exclusion Criteria

The authors agreed on particular inclusion and exclusion criteria that used in the study in evaluating whether a study should be included in light of the three research topics of this review. Table 1 lists the primary criteria.

Table 1. List of Inclusion and Exclusion Criteria guidelines in selecting relevant studies from online source

Inclusion	Exclusion
Relevant and valid publications	Book chapters or conference articles, workshops etc.
Studies published from December 2002 until January 2022	Full-text publications that are inaccessible
Articles with pedagogy or present interactive simulation on physics/modern physics	Articles without pedagogy and did not present interactive simulation on modern physics
Abstract and full-paper written in English	Missing data by any organized research technique
Contains interactive simulation technologies in teaching and learning	Publications that are not English
Has main objectives related on using interactive simulation	Reviews, abstracts, and publications that were not peer-reviewed
Researches contain reasons behind success and failure in the use of interactive simulation	

Data Gathering Procedure

Any evidence that satisfies the predetermined eligibility requirements and can provide answers to the precise research questions chosen have gathered to carry out the subsequent precise stages. The PRISMA statement's guiding principles served as the initial framework for data collection (Moher et al., 2009). According to Liberati et al. (2009), it is one of the best protocols that authors can use to: a) report honestly the strengths and weaknesses of any review investigation; b) adequately describe all eligibility requirements for study collection, information sources, data collection, and finally a synthesis of the results. In order to gather the most relevant studies, a search selection of scientific papers from three internet databases was provided. The StArt tool was used to download, arrange, and enter a total of thirty-seven articles. In addition, all studies were chosen in four steps based on the PRISMA statement before being examined. Following the removal of duplicates and identification of articles using the various search techniques previously discussed, Figure 1 shows the sources that were included and excluded at each stage.

The authors of this review classify papers based on their subject matter relevancy and contribution to the interactive simulation after completing the necessary searches and gathering all the relevant information from the included articles. All of the final publications chosen for review had a deliberate sampling (case studies or empirical research) based on the deliberate selection of a small number of data sources. The authors of this review then included and independently coded a sub-sample of eleven articles from a total of twenty-two articles (or 50%) in order to evaluate the inter-rater reliability regarding the quality coding of the selected articles.

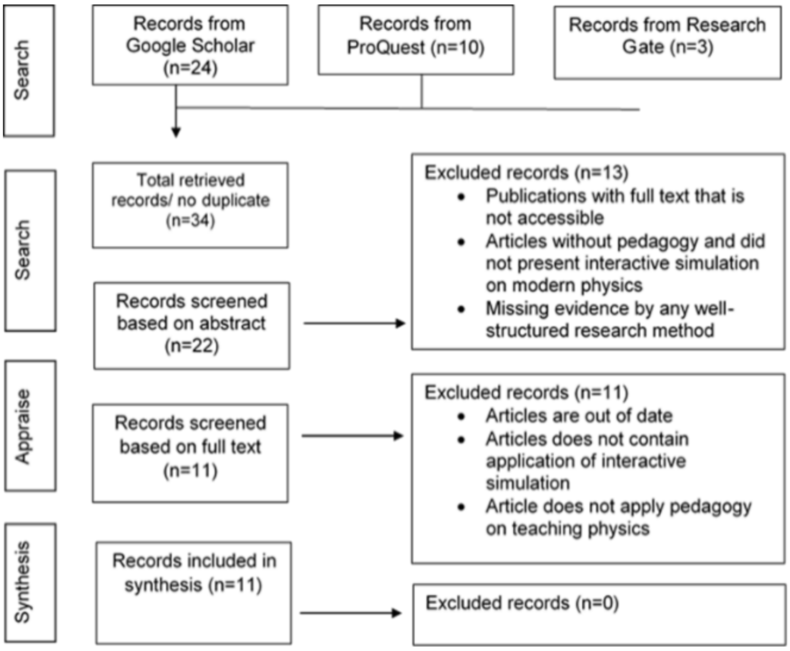

Figure 1: A flow diagram of the article selection process (adapted from Moher et al., 2009)

Data Analysis

The researcher completed the coding and data analysis as the final step. The relevant information from the studies that is relevant to the research question was coded. A spreadsheet then used to categorize the variables.

Ethical Statement

This study doesn't require an ethics review because it is a systematic review that relied on data from open access articles that are considered publicly accessible.

Reporting the Review

This chapter reports the findings. A wide range data on interactive simulation on modern physics. An integration of data and provide a state-of-the-art overview from the analysis of all the included studies produced to address the key research issues was used to elaborate the discussion on the benefits and challenges.

The main objectives of the research studies on using interactive simulation in Modern Physics

Many countries' educational systems were facing new issues in providing equal access to information for their inhabitants as well as active, participatory, and experiential learning in their education especially in modern physics (Oidov et al., 2012). Many studies have been conducted as a result of this to find solutions to problems and challenges. Oidov et al. (2012), developed virtual laboratories to address these needs and keep up with the rapidly expanding demand for knowledge. Similarly, Bringula, Sarmiento & Basa (2017) presented major challenges in teaching modern physics and offer suggestions for how to address these issues. Some searches also yield precise solutions to specific problems in modern physics. According to Gunawan et al. (2018), creativity is essential for understanding physics' abstract notions. The integration of information and communication technology in virtual laboratories is an example of innovation, which is why they set out to design a physics virtual laboratory that would enable effective learning for both male and female students. Also, hands-on activities have been established for general physics classes but not much for modern physics (Lopez et al., 2018). From this they have conducted a study about design computer simulations as a supplement to a modern physics class. The study attempted to teach the student how to connect input variables to output signals, allowing them to recognize physical concepts. Comparatively, computer interactive simulations are frequently used in science and engineering but are rarely used in schools (Rehman et al., 2021). For this reason, the authors of the study sought to evaluate how well the interactive computer simulation program PhET taught students about weight and mass.

To further develop students' critical thinking (CTS) and inventive problem-solving abilities, Sutarno et al. (2019), set out to construct a higher order thinking virtual laboratory (HOT-VLab) model based on the photoelectric effect notion (CPSS). Aminoto et al. (2021), attempted to develop a photoelectric effect experiment to assess the abilities of potential Jambi University physics teachers in designing the experiment. Learning that employed computer simulation could aid students in comprehending the development of modern physics (Tawil & Dahlan, 2017). Their study intends to examine the impact of PhET computer simulation on fostering students' creativity in quantum physics learning. Several lecturers have built and investigated computer simulation to aid students in studying quantum mechanics. On the other hand, TEALsim was developed to offer physics students and instructors a setting that would aid in understanding abstract concepts, make invisible phenomena visible, enhance conceptual understanding, allow live parameter manipulation to see the immediate impact, and offer a setting that was extensible by people who were not programming experts (Swandi et al., 2020).

Different technologies being used for interactive simulation

By fully utilizing students' core learning senses, such as viewing 3D objects and fundamental concepts with applets, web-based software as a teaching-learning medium for information processing has opened up new vistas in education (Gok, 2011). Java applets are Java programs that run-in conjunction with a web browser or another Java application. A Java application is a stand-alone program that runs with the help of a Java interpreter, such as the Java Virtual Machine (JVM). Two applets are dedicated to Minkowski diagrams and special relativity, and one is dedicated to quantum mechanics (Noce, 2022).

In the study of Tawil & Dahlan (2017), learning tools were combined with a simulation application and named Physics Education Technology (PhET). A lesson plan, student worksheets, 15 various types of simulation programs for teaching quantum physics, content for some quantum physics learning devices, and recommendations for designing simulation programs for instructors and students were all included in this software. Students can visualize and learn about some quantum particle phenomena with the help of all of the simulations. Enhancing student comprehension of the quantum matter property is particularly advantageous (Tawil & Dahlan, 2017). It can be difficult to convey to students the dynamic models commonly used in physics when limited to using pictures, words, and gestures in lecture. The teacher and students can concentrate their time and cognitive attention on building a knowledge of the physics by using simulations to aid this communication (Perkins & Adams, 2008).

Factors aid success or failure in the use of interactive simulation

Various research has identified the aspects that contribute to the success or failure of interactive simulations. Teachers must be cognitively capable of carrying knowledge to be utilized in their education and have the capacity and expertise to integrate new learning strategies in their classroom as one of the characteristics that promote success in the use of interactive simulation (Gunawan et al., 2018). Another crucial component is the teaching staff's expertise and abilities. It calls for specialized training (in-service) for physics teachers in order for them to be able to manage students' e-learning processes as well as to guide and monitor their learners' knowledge construction processes. It also calls for the provision of additional resources and support, as well as hardware requirements, such as school computers with Intel Pentium-IV or higher processors. Principals and training managers must also be genuinely interested in learning about and using ICT into the training process (Oidov et al., 2012). Aminoto et al. (2021), state that in order to help their students develop the abilities they need for the twenty-first century, teachers must be knowledgeable about a variety of instructional strategies and appropriate ways to use ICTs. Students must take an active role in their education, be accountable for their own learning, and function as independent learners (Rehman et al., 2021). According to Gok (2011), an experienced teacher is one of the aspects that aids success in the usage of interactive simulation, and a well-designed curriculum must still be a part of instructional design.

The fundamental principles of effective teaching should be applied to educational applets. These include the following: defining particular fundamental principles; encouraging students to use sense-making and reasoning in words and diagrams; building new concepts using students' prior knowledge; connecting to real-life experiences; increasing collaboration in activities; being careful not to limit students' exploration; and monitoring students' understanding (Finkelstein et al., 2006). Simulations used in high school education should provide students and teachers with a variety of activities. This makes them easy to integrate into classes, customize, differentiate, and prolong the time students have to experiment. A simulation that takes longer to create than to use in a class is usually not worth the time, and it always takes a few minutes to explain how the controls operate (Bringula et al., 2017). According to Swandi et al. (2020), simulations should be scriptable by physics instructors and students who are unfamiliar with complex programming languages. The simulations should resemble a real experiment as closely as possible, as well as the original experiment's setup, including input and output variables (Lopez et al., 2018).

The use of computer simulation-based learning software received a favorable reaction. One element that contributed to the success of the use of interactive simulation was the presentation's content of the computer simulation-based learning software, which was well-organized so that lecturers had no trouble implementing the learning. Additionally, the results showed that certain aspects of learning development were prioritized. For example, the first aspect was syntax or learning phases, the second was the social system, which prioritized aspects of collaboration between students and lecturers, and the third was the computer simulation-based learning, which was carefully executed. The lecturer's function as a facilitator or helper in the classroom learning process was the subject of the third principle, management/reaction principles. The fourth was the influence of supplemental and instructional resources, which concentrated on achieving such inventiveness in instruction (Tawil & Dahlan, 2017). According to Bringula et al. (2017), a simulation should be able to run on all of the student's current devices, such as smartphones, tablets, and notebooks, as well as on any operating system without the need for separate applets. NPAPI support was dropped by the majority of popular browsers in 2015, affecting Java (only applets) and Silverlight plugins. The majority of currently accessible physics simulations would have to be redone to be more widely applicable. We introduce our students to teaching tools available on these platforms as smartphones and tablets become more widely used. Because HTML simulations do not require applets, they are considered safe. Because students differ, simulations should have varying levels of difficulty to accommodate varying talents and motivation, allowing teachers to differentiate. Not every student will grasp a measurement method, and not every student will be pleased with just a dynamic animation. To avoid students becoming confused, the layers should be immediately distinguishable.

Results and Discussion

In the research presented, the fundamental objective of employing simulation in the teaching and learning of physics is to provide students a better understanding of the said subject. Also, one of the goal of simulations is to assist students in discovering and producing fresh facts that will benefit the society. Moreover, employing simulation in physics teaching and learning process is to link the ideas and principles covered in the curriculum to everyday life so that students can understand hard and complicated concepts. Additionally, simulations were included in the lesson to foster students' critical thinking abilities since researchers discovered that they might aid in their comprehension of current physics.

According to Marco (2006), Web-based education is not just about the technology but also the quality of the material. Web-based software is one of the technologies utilized in integrating simulation in the teaching and learning process of modern physics. The success of e-learning courses can only be guaranteed by using teaching materials that are high-quality, multimedia-rich, and clearly built using e-learning instructional paradigms. Java applications that coexist with a web browser or another Java software, JESS uses graphical structures to explain complicated system models in an accessible visual format (Kazymyr & Demshevska, n.d.). Additionally, based on Esquembre (2004), Easy Java Simulations can be used as a tool to demonstrate to students how we, as teachers, build simulations with Easy Java, and then asking them to comprehend, modify, or improve our simulations as well as create their own can help create a setting where students engage in effective pedagogical practices. Through interactive engagement strategies, which involve both hands-on and head-on, open-ended tasks carried out in groups with the assistance of an instructor and enhanced by peer and/or teacher discussion, conceptual knowledge is fostered. The Physics Education Technology (PhET) program was developed using Moore, Chamberlain, Parson, and Perkins' research. PhET simulations are designed to meet the requirements of various teaching methodologies. They can help with a range of learning goals. Additionally, they may be included into the content, process, and emotional goals of teacher-led demonstrations, lively discussions, in-class activities, homework, and laboratories. The design features that promote student engagement and inquiry also improve the dynamic role of the instructor, creating a singular experience. an opportunity to research and present material in answer to actual student inquiries.

Additionally, the effectiveness of using simulation in teaching and learning modern physics depends on the subject matter knowledge and skills of the instructor as well as their proficiency with the simulation. In order to motivate students to learn, according to the researchers, it is crucial for teachers to be computer savvy, inventive, and have a variety of teaching techniques. Zacharias (2005), provided proof that science instructors may move beyond superficial analysis by developing well-articulated formal explanations of the phenomena under study when given the right conditions, such as when employing simulations. The researcher also acknowledges that the dynamic interplay of the simulation experience within the whole curriculum may be responsible for the improvement in the quality of the instructors' explanations. A good physics lesson should support the sort of learning that leads to conceptual comprehension. Such learning takes place when physics instruction focuses on fostering interactive learning in the classroom to support individual self-direction in developing physical scientific understandings (Dykstra et al., 1992). In addition, 4 out of 11 studies discuss how the presentation of computer simulation-based learning software contributes to the effectiveness of physics teaching and learning. But, according to a Rutten et al. (2012), improved learning is not always a result of better visualizations, which are supported by continuous ICT improvements. Despite the fact that visualizing has some impacts, the majority of investigations have shown none. Regarding the comparison of various representation types, the research demonstrates that idealized graphics best enable transfer to an abstractly comparable simulation while concrete representations offer the best support within the simulation itself. Consequently, it simply demonstrates the effectiveness of simulation in learning and teaching. The ability of the instructor to instruct and assist pupils in physics is crucial.

Conclusion

This systematic review is important because several interactive simulations have been developed in various ways of teaching modern physics. To shed light on future implementations, it is critical to understand present practices. Eleven articles were included in this review, which was organized around three primary research questions. First, the findings revealed that the goal of the research studies on using interactive simulation in modern physics is to improve students' critical thinking skills and creative problem-solving skills while learning modern physics because teachers believe that simulation can help students understand the course of modern physics, which is difficult to teach. Second, Java applets and Physics Education Technology (PhET) are interactive simulation technologies that have been shown to be effective in teaching modern physics. Finally, the success or failure of employing interactive simulation is influenced by teachers, school staff, students, simulation design, and technology used. Teachers, as well as administrators and training managers, must be informed and acquainted with a variety of instructional strategies and appropriate ways of applying ICTs to support their twenty-first-century students' talents, according to the findings. Furthermore, the simulation employed must accurately match a real experiment, as well as the original experiment's design, including input and output variables, and must vary in difficulty to accommodate students. Students must work together to rehearse and participate in various scenarios.

To summarize, this review makes three contributions. First, it explains the research goals for using interactive simulation in the Modern Physics course. Second, it lists the effective technology utilized in interactive simulation, providing researchers with multiple insights into the effects of various technologies. Finally, it gives evidence about the aspects that contribute to the success or failure of interactive simulation in Modern Physics teaching and learning.

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