Computer Simulation as Pedagogical Tool for conceptual understanding of Science

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ABSTRACT

The most important thing in science education is the practical side and hands-on training, especially in secondary schools, where the students gradually begin to embody their learning and use their observation skills, analysis, and conclusion. There are different ways, methods, and strategies of science teaching due to the accumulation of information and the increase and complexity of knowledge; it has appeared urgent to find a style or method to simplify and facilitate the transfer of information in the minds of students. Educational computer simulation programs are considered to be one of the best and most powerful educational computer programs when used in science education if properly programmed. Computer simulation has a great potential for the enhancement of the teaching and learning of science concepts. Computer simulations facilitate the learning of abstract concepts and provide interactive, authentic and meaningful learning opportunities for learners. In addition to that, through simulations learners get instant feedback and also would have the chance to make observations (Bell & Smetana, 2008). The purpose of this paper was to investigate the contribution of a computer simulation in the field of science and how computer simulation brings improvement in conceptual understanding of science concepts.

Keywords: Computer Simulation, Pedagogical Tool, Conceptual Understanding, Science

INTRODUCTION

Computers have revolutionized the field of education in many ways, providing teachers and students with a wide range of tools and resources to enhance teaching and learning. The use of computers has become an integral part of our educational system that has changed the face of the teaching-learning process. This integration has been made possible due to the simultaneous development of different learning materials in various forms such as au multimedia tools like videos, animations, and, interactive presentations and, audio-visual aids. These audio-visual aids used can easily be combined in the educational setting resulting in the development of computer-based instruction techniques (Jimoyiannis & Komis, 2001).

The use of Computers has enabled online collaboration between students and teachers, facilitating communication, feedback, and teamwork. And this teaching-learning process has altered as a result of the usage of computers, which have eventually become a crucial component of our educational system. Collaborative tools can help students work together on projects and assignments, irrespective of the places they work from. Computer simulations can be used to provide students with virtual experiments and lab experiences, helping them to explore scientific concepts and phenomena in a safe and controlled environment. And Students' access to internet

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resources makes it simpler and more convenient for them to conduct research. By educating students to examine and evaluate the reliability of online sources, computers can also assist students in developing critical thinking abilities.

Thanks to extensive efforts these brand-new instructional tools are now an essential and indispensable component of education. Suitable learning environments, high levels of engagement, self-paced learning, continuous feedback, learner-centered approaches, and design based on individual learner needs are some characteristics related to technology-based education. Our current educational system is regularly updating the resources through the modernization of different system components to stay up with the rising technological developments in the global, national, and regional environments.

The urge to improve science education has stepped up the production of Computer -related materials like computer-aided learning which gears towards the modernization of education (Caday, 2004). One of the steps in this direction has been the emergence of smart schools which are equipped with new learning or delivery system like science laboratories, computer laboratories, and language laboratories. This aims to improve the quality of education to produce globally competitive interventions such as using multimedia technology, redefining the role of the teacher i.e., from being a provider of knowledge to the facilitator of learning, and, creating greater opportunities for individualized learning.

Computer Simulation as Pedagogical Tool

A computer simulation is defined as "software that incorporates a model of a system (natural or artificial; for example, equipment) or a process" by de Jong and van Joolingen (1998). These tools have the potential to improve learning outcomes in scientific classes in ways that were not before achievable (Akpan, 2001). The benefits of a learning environment with a computer simulation over textbooks and lectures include the ability for students to stress-free practice tasks and problem-solve in a realistic environment while exploring hypothetical situations and interacting with a simplified version of a process or system (van Berkum& de Jong, 1991).

When a learner learns how events are caused, they can strengthen their conceptual grasp of a phenomenon by discovering that predictions are validated by later events in a simulation (Windschitl& Andre, 1998). The ease with which experimental variables can be manipulated allows for the stating and testing of hypotheses. Other possible motivations for teachers to use computer simulations include the provision of ways to support understanding with various representations, such as diagrams and graphs, and the saving of time, allowing them to devote more time to the students instead of the setup and supervision of experimental equipment (Blake & Scanlon, 2007).

Computer simulations can assist genuine inquiry techniques, such as forming questions, developing hypotheses, gathering data, and revising theories, by emphasizing the learner as an active agent in the process of knowledge acquisition. As they progress through a simulation, students may gradually infer characteristics of the conceptual model, which could affect their initial assumptions (de Jong & van Joolingen, 1998). Computer simulations can be effective teaching tools by actively engaging students in exploring and learning, as learning through doing is more memorable than learning through hearing, reading, or seeing (Akpan, 2001).

This discovery learning technique has been popular due to the trend towards more learner-centered rather than teacher-centered education (Veermans, van Joolingen, & de Jong, 2006), but

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there are limits to how much control can be transferred from the instructor to the learner. The creation and modification of hypotheses, the design of experiments, the interpretation of data, and the regulation of learning are all difficult for students to do when the processes of discovery learning are not adequately supported in a computer simulation (de Jong & van Joolingen, 1998). While giving students learning support limits their ability to explore the simulation world at their leisure to some extent, the scaffolding it provides enhances their performance in simulation-based learning (van Berkum& de Jong, 1991).

Given that computer simulations are now widely available for an extensive range of science subjects, they have become an essential part of several science curricula (Rutten et al., 2012). Researchers have sufficiently attempted to see the effectiveness of simulations for the teaching of conceptual understanding of science topics (Lee et al., 2021). Based on an experimental study involving primary school students in New Zealand, Fallon (2019) concluded simulations can be valuable for teaching simple physical science concepts, and offering students the openings to be involved in higher-order thinking processes. Lee et al. (2021) noted that this pedagogical approach is a great way to develop learners' attitudes toward science topics, including optical lenses, moon phases, kinetic modular theory, trajectory motion, and electromagnetism.

Simulations are used in a variety of settings, including in education, aviation, nursing, social work, and transport (Rooney &Nyström, 2018). The use of simulations for science learning is currently a widespread practice (Langbeheim& Levy, 2019; Rooney &Nyström, 2018, Rutten et al., 2012). Their adoption in teaching science topics has the potential to result in higher learning improvements in ways not previously possible (Akpan, 2001). Further, they have secured a room in the classroom as strong accompaniments to the repertoire of teachers, either as a supplementary element to existing teaching approaches or as a substituting part of the curriculum (Rutten et al., 2012).

Computer simulation emphasizes the learner as an active agent to construct their knowledge. They have extraordinary potential to facilitate authentic inquiry practices that include articulating questions, hypothesis formulation, exploring the effect of data in a situation, and theory revision (Rutten et al., 2012). Wang et al. (2010) also highlight the value of simulations as they let learners effortlessly manipulate objects (virtual manipulatives), generate novel representations, and carry out experiments to test hypotheses and tentative ideas.

Meaning of Conceptual Understandings

The word "concept" signifies many different things to a science educator. Concepts are how the human mind is built (Lawson et al., 2000; Konicek-Moran and Keeley, 2015). In their most basic forms, concepts resemble mental images of things like energy, force, evaporation, respiration, heat, erosion, and acceleration (Carey, 2000). These are abstractions created by individuals who sought to comprehend what was taking place in their reality. The terms "conservation of energy," "food chain," and "closed system" are examples of concepts that can be expressed in more than one word or a single brief phrase (Konicek-Moran and Keeley, 2015). Concepts may also consist of more than one word or a short phrase (Konicek-Moran and Keeley, 2015), such as conservation of energy, food chain, or closed system. Concepts imply meaning behind natural phenomena such as phases of the moon, transfer of energy, condensation, or cell division. When we use a concept, there is usually some understanding of what is associated with it.

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Concepts, according to Cognitive Scientists, are intricate representational structures in and of themselves (Carey, 2000). Moreover, conceptions can be created directly by extrapolating from a variety of examples and experiences. It might be challenging to illustrate or make instances of concepts real in some situations. It is challenging to demonstrate notions like "atom" or "molecule" as examples, for instance. A concept like "molecule" is illustrated by building representations or models so that it can be understood more clearly. Concepts aid students in making sense of more complicated ideas within a specific representational structure. Hence, concepts could serve as the foundation for more intricate or even abstract representations.

Instruction to promote conceptual change requires time and effort on the part of learning (Adadan et al., 2010) and is also carefully designed (Vosniadou et al., 2001). However, the practice of science instruction has emphasized memorizing a lot of science concepts (Chin, 2004). Students who are excellent at memorizing facts and definitions often engage in what may be called literal understanding (Konicek-Moran and Keeley, 2015). Students with this understanding, could explain any page in a textbook or reproduce any graph or picture at a moment's notice exactly as it appeared in the book. These students might not have been able to understand basic concepts that provide explanatory evidence for ideas about phenomena. For instance, the concept of evaporation. Students rely on their memorization of terms of evaporation, but the students lack a conceptual understanding of what happens after the water evaporates. The students use the words evaporation, yet do not understand where the water went or where it came from to explain a natural phenomenon. The important learning process is students think through all arguments on their "own" and "construct" further knowledge upon already understood concepts.

Meaningful science learning called for conceptual understanding rather than memorization (Adadan, Trundle &Irfing, 2010). Meaningful learning is not the transmission of knowledge from the teacher to the students; it requires knowledge to be constructed by the learner (Jonassen, Peck, & Wilson, 1999). Students who construct well-connected and hierarchically arranged conceptual frameworks have conceptual understandings of certain concepts (Mintzes& Wanderse, 1998). When students have an understanding of a concept, they can (a) think about it, (b) use it in areas other than in which they earned it, (c) state it in their own words, (d) find a metaphor or an analogy for it, or (e) build a mental or physical model of it (Konicek-Moran & Keeley, 2015).

Computer Simulation in Conceptual Understanding of Science

Computer simulation has an overwhelming potential for the enhancement of the teaching and learning of science concepts. As Smetana & Bell (2012) noted in their study, there has been a long history of research on the use of computer simulations. Since they give students the ability to make observations and receive immediate feedback, computer simulations help students understand abstract topics in a more participatory, authentic, and meaningful way (Bell & Smetana, 2008). Science simulations can provide genuine environments that are structured by following relevant domain principles. It is possible to portray spatial, temporal, and causal phenomena that are too huge (hurricanes), too small (chemical reactions), too quick

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(earthquakes), or too slow (plant growth) to be directly observed or manipulated (Quellmalz et al., 2012).

Digital instructional technologies have increasingly entered scientific classrooms as a result of technological advancements. Computer simulation is a technological advancement. Computer simulations are dynamic models created by computers that display simplified or theoretical representations of elements, phenomena, or processes in the actual world (Bell et al., 2008). Therefore, a simulation is a depiction or model of an action, an item, or some other phenomenon (Thompson, Simonson, & Hargrave, 1996). When real-world observation is difficult or when there are better teaching opportunities, simulations are utilized to simulate those things (Scalise et al., 2011). A computer simulation is a program that enables students to engage with a computer model of the natural or physical world or a theoretical system (Weller, 1996).

Simulation provides learner-centered environments that allow students to explore systems, manipulate variables, and test hypotheses (Windschitl, 1998). Also, these tools can be used by professors to demonstrate concepts or directly by students to investigate a range of phenomena that aren't often accessible. Also, with the use of Simulations, students can gain and apply knowledge to better grasp the connections between the subjects under investigation. Animations, visuals, and interactive laboratory experiences can all be used in simulations.

Simulations can aid in the growth of understanding of complicated events by fusing animations and visualizing scientific concepts (Akpan, 2001). When equipment is unavailable or impractical to set up in the classroom, simulations might be utilized in place of those situations (Wieman et al., 2010). Simulated experiments can also be used to carry out tasks that would be impossible without them.

In simulations, variables can be easily altered in response to questions from students, but this is not always achievable with real equipment. Before using real equipment in the lab, students can practice laboratory methods (Akpan, 2001). Also, they can practice simulations at home to repeat or expand on experiments done in class for further understanding. Studies that compared the use of simulations with traditional learning appear to show that using simulations can successfully enhance traditional learning.

Within traditional instruction, learners can be useful add-ons, for instance serving as pre-laboratory exercises or visualization tools. Chang, et al. (2008) proved that learning by using simulation in optical lenses topic leads to a significantly greater improvement in learning outcomes in comparison with traditional laboratory practices.

The first reason why using simulation concerns the need to understand complex phenomena in science. For instance, DNA, molecular structure, atom, or molecule. Hmelo, Holton, and Kolodner (2000) suggested that structures are often the easiest aspect of a complex system to learn; in molecular genetics especially, understanding the structure of molecules such as DNA and RNA is crucial to comprehend their functions. Simulations, in this case, can help to organize small pieces of information into large pieces of information, reducing the amount of memorization required by increasing the logical connections between ideas (Tversky et al., 2002). Simulation allows learners to view and interact with models of phenomena and processes (Plass et al., 2012).

The second reason why using simulation concerns the need to understand the learned scientific concepts of scientific phenomena in an everyday life situation. Some scientific phenomena in science occur very fast and take place in multiple locations; for instance, cell division. Simulation can facilitate the development of students' evaluation skills to understand the

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phenomena at the molecular level (Sanger, Brecheisen, & Hynek, 2001). Starting, stopping, and replaying a simulation can allow focusing on specific parts and actions. A simulation that allows zooming and control of speed are even more likely to be facilitating (Tsui & Treagust, 2004; Tversky et al., 2002). Simulations may be used to show students scientific phenomena that cannot be observed easily in real-time. For example, they can allow students to see things in slow-motion, such as lightning, or speed up, such as the earth's revolution. They are used to model phenomena that are invisible to the naked eye, such as cell division. The Simulation utilizes situations that require several repetitions of an experiment, for example rolling a ball down a slope while varying mass, the angle of inclination, or the coefficient of friction.
The third reason why using simulation concerns the need to understand and emphasize the breadth and depth of scientific knowledge. Simulations can bridge this breadth and depth of students' knowledge because simulations have the potential to make learning abstract concepts more concrete (Ramasundarm et al., 2005). Simulations can make abstract science phenomena more accessible and visible to students. For example, understanding scientific phenomena such as the circulatory system is difficult for some reasons. It is a complex interactive system that ranges in scale from the heart or blood vessels visible through the skin to blood cells circulating in capillaries much smaller than the human visual range. Simulation has the potential to make abstract scientific concepts, such as the circulatory system, more accessible and visible to students. Muller, Sharma, &Reimann (2008) explained that simulations allow learners to represent visually and dynamically important concepts that would otherwise be invisible. They can provide detailed representations of unobservable scientific phenomena (Stieff, 2011; Ryoo& Linn, 2012). They can also animate dynamic changes in scientific processes that are difficult to infer from static illustrations found in textbooks (Marbach-Ad, Rotbain, & Stavy, 2008; Ryoo& Linn, 2012). In particular, simulations or animations can help students visualize a phenomenon that might otherwise be difficult to depict (Chang, Quintana, &Krajcik, 2010). Thus, the benefit of simulations is making science abstract concepts more accessible, and visible, and can help students to understand science concepts. When students are unable to observe or experience abstract science phenomena directly, simulation can play a crucial role in helping them understand those phenomena.

Other benefits from the simulation do not only work on conceptual understanding but also increase student engagement to learn science. Shellman and Turan (2006) have reported an improvement in students 'participation, motivation, and preparation for simulation exercises. Moreover, simulations have the potential to advance multiple science learning goals, including motivation to learn science, understanding of the nature of science, science process skills, scientific discussion and argumentation, and identification with science and science learning (Honey & Hilton, 2011).

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Table 1. Summary of studies highlighting advantages of simulation

Sr.no.	Advantages of using Simulation in Science Learning	Studies
1.	Computer simulations are one of the most effective ways to understand and visualize concepts that are otherwise invisible to students	(Finkelstein et al.,2005)
2.	The use of computer-aided instructional material develops a favorable attitude and enhances students' interest in the learning physics	(Fraser, Pillay, Tjatindi& Case, 2007).
3.	Computer simulations enhance students' problem solving skills by providing them an opportunity to practice and refine their higher order thinking Strategies	(Quinn, 1993).
4	The use of simulation helps students to understand difficult science concepts	Plass et al., 2012; Webb, 2012; Sarabando, et al., 2014
5	Simulation works to improve understanding concept of science, not only students' understanding, but also pre-service teachers' understanding	Liu &Hmelo-Silver, 2009; Ryoo& Linn, 2012; Bell, Maeng, &Binns, 2013; Nielsen & Hoban, 2015
6	Simulation enhanced students' active involvement in the learning process; facilitated their practice and mastery of concepts and principles	River &Vockell (1987)

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7	Simulation allows users to experience and interact with an environment similar to the real world	Matveevskii&Gravenstein, 2008; Ruggeroni, 2001

Table 2: Summary of studies related to disadvantages of simulation

Sr.No.	**Disadvantages of using Simulation in Science Learning**	**Studies**
1.	Lack of realism (in a real environment, people can feel and taste, while in simulation this cannot happen)	Sadideen et al., 2012
2.	Students have time flexibility to think and react in problem-based scenarios: there is no stress for quick thinking as in real situations	Byrne et al., 2010
3.	Compared to laboratory experiments, simulations have the disadvantages that they are only able to show outcomes that are pre-programmed, and can only be manipulated to a limited extent. Moreover, they do not do much to develop the skill of handling lab equipment	Karlsson, Ivarsson, &Lindström, 2013

Conclusion:

Keep in mind that simulations are a tool for supporting science education. As with other educational tools, the effectiveness of simulation is limited by how they are used. Instructional strategies proven to support meaningful learning should be adhered to when using simulations. Students should be actively engaged in the acquisition of knowledge and encouraged to take responsibility for their learning. Science content should be placed in the context real world.

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