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Research Article

Using Computer-Based Simulations to Scaffold Critical Thinking in Secondary School Physics in Tanzania

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Abstract

The study investigated computer-based simulations as a scaffolding for students' critical thinking in physics among secondary schools in the Rombo district, Tanzania. Despite the significance of physics education, students struggle with abstract concepts, leading to low enrollment rates and diminished critical thinking skills. The research aims to provide insights for improving instructional methods and fostering both student engagement and critical thinking in physics. The study was guided by the research question "To what extent do computer-based process simulations aid critical thinking?" and was framed by Scaffolding theory, which underlines the importance of structured support in enhancing students' cognitive skills. The study employed a convergent design under a mixed-methods research approach. The target population was 3426 participants. A sample of 359 respondents was selected through stratified random and purposive sampling. Quantitative data were collected using questionnaires and achievement tests, while qualitative data were collected through an interview guide. Data collection instruments were pilot-tested in two public secondary schools. Reliability for the Likert-type items was estimated using Cronbach's Alpha coefficient, whereby alpha 911, obtained for students' questionnaires. The study found that computer-based process simulations aid critical thinking among students in physics subjects. An experiment tested the hypothesis: simulations improved mean (M = 63.06), p<.05, and effect size (d = 2.7). It was recommended that the government should prioritize in-service training for physics teachers and provide necessary technology in schools.

Keywords

Computer-based Process Simulations, Critical Thinking, 21st Century, Scaffolding

1. Introduction

Physics is highly important in today's world due to its wide-ranging applications and contribution to various fields such as technological advancements, energy and environmental sustainability, medical applications, communication and information technology, space exploration, and astronomy [8]. In the United States of America, various teaching methods are employed in the teaching of Physics, including lecture-based instruction, hands-on laboratory work, problem-solving exercises, interactive discussions, demonstrations, and computer-based simulations. Computer-based simulations (CBS) provide learners with immersive and interactive environments allowing them to explore real-world scenarios, problem-solving, critical thinking, and decision-making [22]. Teachers often use demonstrations and computer-based simulations to illustrate complex and abstract concepts. Using simulations in

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teaching geometrical optics is more effective in physics success than teaching in a traditional laboratory environment [18]. Process Simulations utilize computer programs or apps to simulate physical systems or phenomena, allowing students to explore and manipulate variables in a controlled virtual environment.

The use of computer-based simulations in teaching has evolved and expanded globally over time. Today, numerous countries around the world utilize computer-based simulations as an effective educational tool to enhance learning experiences across various science subjects [14]. Collaborative aspects of these simulations promote teamwork and communication skills, aligning with the modern need for effective collaboration [3]. Additionally, interacting with technology in this context enhances students' technological literacy, and the problem-solving opportunities presented by simulations equip students with the skills necessary to address real-world challenges. This integration not only enriches students' understanding of physics but also empowers them with a diverse skill set crucial for success in the contemporary landscape.

Computer-based simulations are classified into four classes, which are physical simulations, process simulations, procedural simulations, and situational simulations [20]. In physical simulations, students manipulate the parameters to absence the effect and hence foster collaborative learning. Process simulations aid critical thinking while procedural and situational simulations foster creativity and overcome misconceptions among learners [23]. Due to the widespread recognition of computer-based simulations, it is essential to address the effectiveness of computer-based process simulations in enhancing critical thinking among secondary school students.

In South Africa, Computer-based simulations are used in teaching to enhance understanding and engagement with the subject. CBS helps students create multisensory connections, enabling them to become actively engaged in learning through various settings [15]. Process simulations help students to grasp abstract concepts and establish connections between theory and real-world phenomena. In East Africa, Rwandese students are taught science subjects by the use of computer-based simulations as they create multisensory connections, enabling them to become actively engaged in learning through various settings. Effective teaching of physics requires the use of well-designed computer-based simulations, as it simplifies the teaching and learning of physics, especially in abstract concepts [16]. Consequently, the lines between abstract concepts become closely connected in virtual reality [9]. While computer-based simulations in Rwandan science education have shown the potential for active learning, it was crucial to investigate how these simulations enhance students' critical thinking.

In Tanzania, physics is taught as a core subject in secondary schools from form one to form two, but it becomes an optional subject as students get into form three. The syllabus of Physics in Tanzania is regulated by the Ministry of Education, Science, and Technology. The syllabus aims to develop students' understanding of fundamental Physics concepts, principles, and applications. According to the Tanzania 2014 Educational Training Policy (ETP) 2023 version, section 2.4.3 (d), secondary education aims to develop competence in students through self-learning and development in science and technology. Despite the great emphasis on learning physics, statistics show that the extreme level of difficulty students associate with physics has led to students' diminishing interest in physics.

This apparent decline in students' interest in physics is reflected in the enrollment rate of physics students in form three, as it is still low because, in 2020 (28%), 2021 (24%), and 2022 (22%), students sat for Physics CSEE. Most schools in Tanzania teach Physics subjects by using lectures, demonstrations, group discussions, laboratory experiments, and problem-solving activities [17]. Despite the policy emphasis on developing competence in secondary school students, there are concerns about how students learn physics, leading to lower enrollment in this subject compared to others. This situation has prompted the researcher to investigate the effectiveness of computer-based process simulations in enhancing critical thinking in physics within public secondary schools in the Rombo district. By exploring this relationship, the study aims to provide insights into improving physics education and addressing the challenges of student engagement and understanding of the subject.

2. Statement of the Problem

Enhancing critical thinking in physics has become difficult for both students and teachers due to the presentation of abstract concepts. Students are facing difficulties in grasping abstract and complex concepts, which leads them to lose interest in physics. In Rombo, particularly, only 24% of students who sat for CSEE 2021-2023 did Physics. Teachers face challenges in teaching complex and abstract concepts to students when using traditional methods of teaching [16]. Employers are also struggling to recruit experienced employees who can apply their expertise in fields of work such as teaching, engineering, transportation, technology, scientific research, and innovation [10]. This problem needs to be addressed to ensure learners develop critical thinking, collaboration, and creativity skills, which are required for success in today's dynamic and competitive world. Various studies, like [7, 13, 15], conducted on computer-based simulations and found that computer-based simulations enhance learning but inadequately focus on critical thinking. Therefore, this study investigated the effectiveness of computer-based process simulations in enhancing critical thinking in physics subjects in public secondary schools in Rombo district, Tanzania.

3. Research Question

The study was guided by the following research question;

To what extent do computer-based process simulations enhance critical thinking among secondary school students in the Rombo district?

4. Research Hypothesis

H_1: There is a significant difference in mean scores between the experimental group and control group on the extent of computer-based process simulation on enhanced critical thinking of students in physics concepts.

5. Significance of the Study

This study will help teachers, students, and other education stakeholders understand the effectiveness of computer-based process simulations in enhancing critical thinking in Physics subjects in secondary schools. Teachers will develop insights into the importance of integrating computer-based simulations in teaching Physics concepts. Learners will be assisted in critical thinking, collaborative learning, and creativity. Also, the study will provide potential influence on educational policy and theory reform by providing empirical evidence, guiding pedagogical practices, shaping technology integration educational policy, informing curriculum development, supporting teacher training, and contributing to theoretical advancements in the field of education.

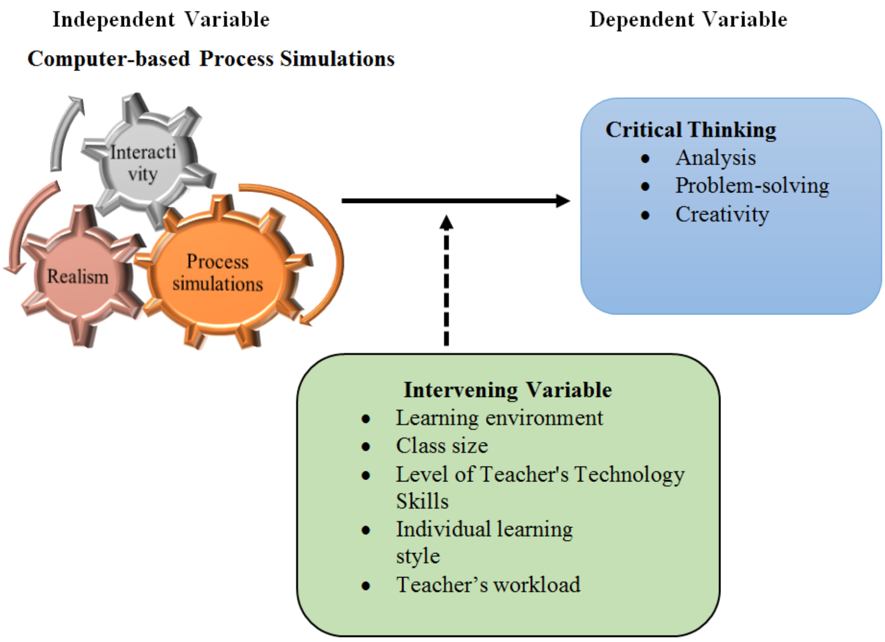
6. Theoretical Framework

The study was guided by Scaffolding theory, also known as the Zone of Proximal Development (ZPD), which is a concept within educational psychology that was developed by Lev Vygotsky (1920s and 1930s), a Russian psychologist and educational theorist. It focuses on the idea that learning and cognitive development occur within a zone that lies between a learner's current level of understanding and their potential level of understanding with the assistance of a more knowledgeable other [2]. According to scaffolding theory, learners can tackle tasks that are just beyond their current capabilities, but with guidance and support, they can gradually bridge the gap between what they already know and what they are capable of learning.

Scaffolding theory acknowledges that learners have unique needs, abilities, and prior knowledge. It emphasizes Gradual Knowledge Construction [1]. Scaffolding theory recognizes that learning is a process of constructing knowledge and understanding. It emphasizes the gradual nature of learning, where learners build upon their existing knowledge and skills [25]. By providing scaffolding, educators support learners in moving from their current level of understanding to a higher level, promoting deeper comprehension and problem-solving abilities. However, different observers may have different interpretations of a learner's ZPD, leading to variations in the level of scaffolding provided and potentially affecting the effectiveness of instruction [27]. Scaffolding theory emphasizes the gradual reduction of support as learners gain competence. Applying scaffolding theory to a study of computer-based simulations scaffolding to students' critical thinking in physics provides valuable insights into instructional design and support strategies. Begin by assessing students' prior knowledge and understanding of physics concepts relevant to the computer-based simulations. This assessment will help determine each student's ZPD, indicating the tasks and activities that are challenging yet attainable with appropriate support. This step is crucial for designing effective scaffolding interventions.

Conceptual Framework

The conceptual framework Figure 1, shows dependent, independent, and intervening variables. The independent variable is computer-based process simulations, which include realism and interactivity. Realism includes the extent to which simulations accurately reflect real-world processes and scenarios, and interactivity involves the level of student engagement. The dependent variable is critical thinking. Critical thinking involves analysis as the ability to break down complex information into smaller parts, creativity, and problem-solving. There are other factors apart from computer-based simulations that affect the use of computer-based simulations in learning physics. These include access to resources, classroom environment, teacher's computer literacy, students' prior knowledge, individual learning style, and workload. The use of computer-based simulations, as well as the control of intervening variables, will lead to the achievement of 21st century learning skills in Physics.



Source: Researcher's Construct (2024)

Figure 1. *Effectiveness of Computer-Based Process Simulations in Enhancing Critical Thinking.*

7. Review of Empirical Studies

The extent to which Computer-based Process Simulations Aid Students' Critical Thinking in Physics in Secondary Schools

Examining the extent to which computer-based process simulations support learners in critical thinking in secondary schools provides a scaffolded learning environment that allows students to grasp and navigate intricate subject matter effectively.

This study investigates the extent to which computer-based simulations enhance critical thinking among secondary school students in Tanzania, addressing gaps identified in previous research. For instance, the effects of metacognitive scaffolding on students' performance and confidence judgments in simulation-based inquiry in Taiwan [24] highlighted the importance of integrating cognitive strategies into simulation-based inquiry. While metacognitive prompts significantly improved both conceptual understanding and confidence judgments, findings may not be generalizable to the Tanzanian context due to differing technological infrastructures and educational priorities. Similarly, a study on computer-based scaffolding in sustainable project-based learning incorporated computer-based scaffolding into a project-based programming course and showed that with the support of computer-based scaffolding, all participants maintained a high level of motivation during the course, resulting in improved performance by 35.49% in product quality and 38.98% in subject knowledge [21]. However, the study collected data from students only, which limited the triangulation of information from different key informants. In filling this gap, the current study involves teachers and students to enhance the triangulation of information. A meta-analysis of simulation-based learning included 145 empirical studies and investigated the effectiveness of different scaffolding types and technology in simulation-based learning environments to facilitate complex skills, reporting a large positive overall effect: g = 0.85 [4]. This supports the assertion that computer-based simulations are among the most effective means to facilitate the learning of complex skills across domains. However, relying on second-hand information may not provide a comprehensive understanding of the extent to which computer-based simulations scaffold learners on complex concepts. Therefore, this study collects first-hand information from the field to provide a comprehensive understanding of the phenomenon. Additionally, the development of a collaborative problem-solving environment that integrates a scaffolding mind tool and simulation-based learning showed that learners using the scaffolding mind tool performed significantly better than those using traditional study sheets, indicating more diverse cognitive processes [13]. However, this study used achievement tests only as data collection instruments, which limited the triangulation of information from different sources. To address this limitation, the current study employs both quantitative and qualitative research instruments in data collection. Lastly, a study on the use of computer-based simulations in teaching and learning Ohm's Law in Dodoma Secondary Schools, Tanzania, gathered data using 120 questionnaires and 18 interviews with students and teachers, respectively, highlighting positive perceptions regarding the use of computer-based simulations [7]. However, the focus on a specific topic like Ohm's Law limits the broader understanding of the effectiveness of computer-based simulations in teaching physics as a whole. Therefore, this study uses a mixed-method approach to examine the extent to which computer-based simulations enhance critical thinking in physics among students in secondary schools by involving teachers and students as key informants.

Demonstration of Research Gaps

The reviewed studies have mainly concentrated on the effect of computer-based simulations on students' performance. There is scant literature written on the extent to which computer-based process simulations enhance critical thinking as an essential 21st-century learning skill. Teachers' voices on how they perceive the use of computer-based simulations on students' critical thinking in physics are visibly missing. Understanding teachers' views is crucial, as they play a key role in implementing these technologies in the teaching and learning process. In Tanzania, none of the reviewed studies has investigated the extent to which computer-based simulations enhance critical thinking in Physics in secondary schools. Therefore, this study filled the gap by investigating the extent to which computer-based process simulation enhances critical thinking in physics for public secondary schools in the Rombo district, Tanzania.

8. Research Methodology

The study employed a convergent research design under a mixed methods research approach by collecting both quantitative and qualitative data [6]. An experiment was conducted to test the hypothesis. The target population was 43 public secondary schools, 48 physics teachers, 43 heads of schools, and 3,335 form three and four physics students. The sample was obtained through stratified random sampling and total population purposive sampling. A sample of 12 schools, 12 physics teachers, 12 heads of schools, and 355 students was selected from the target population. Quantitative data was collected using questionnaires and achievement tests, while qualitative data was collected through interview guides. Content validity was ensured by physics experts, and face validity by research experts from the faculty of education at Mwenge Catholic University (MWECAU). Data collection instruments were pilot-tested in two public secondary schools not included in the main study. The reliability of Likert-type items in the questionnaires was estimated using Cronbach's Alpha coefficient, whereby alpha=.91 was obtained, and the questionnaire was acceptable for the study. The trustworthiness of qualitative data collection instruments was ensured through peer debriefing and triangulation. Quantitative data were analyzed by using descriptive and inferential statistics with the aid of SPSS version 26. Qualitative data were analyzed by adhering to the seven steps of thematic analysis [6]. Ethical considerations were adhered to through the use of informed consent, ensuring confidentiality, avoiding plagiarism, ensuring anonymity, and avoiding fabrication of data.

9. Findings and Discussions

The study aimed to examine the extent to which Computer-Based Process Simulations Enhance critical thinking in physics for Public secondary school students in Rombo District, Tanzania. The five-level Likert scale was used to analyze which 1 = Very Low Extent (VLE), 2 = Low Extent (LE), 3 = Neutral (N), 4= High Extent (HE), and 5 = Very High Extent (VHE). The rate of percentages described as $\leq$ 20 = extreme minority, 21 – 49 = Minority, 50 – 59 = Moderate, 60 – 69 = Majority, 71 – 89 = Very High Majority, 90 – 99 = Extreme majority, 100 = overwhelming majority [19]. Responses from students are summarized in Table 1.

Table 1. *Students' Responses on the Extent Computer-Based Process Simulations Enhance Critical Thinking in Rombo District secondary schools (n = 316).*

Statements	VLE		LE		N		HE		VHE		
	f	%	F	%	f	%	F	%	f	%	M
Computer-based process simulations aid critical thinking on resistance in materials	0	0.0	2	0.6	0	0.0	68	21.5	246	77.8	4.77
Static electricity is deeply learned when computer-based process simulations are used	4	1.3	3	0.9	0	0.0	23	7.3	286	90.5	4.85
Computer-based process simulations aid critical thinking on the concept of density in different substances	4	1.3	4	1.3	0	0.0	32	10.1	276	87.3	4.81
Magnetic fields around magnetic materials are well learned with the aid of computer-based process simulations	0	0.0	4	1.3	0	0.0	36	11.4	276	87.3	4.85
Computer-based process simulations help in a	1	0.3	4	1.3	0	0.0	49	15.5	262	82.9	4.79

Statements	VLE		LE		N		HE		VHE		
	f	%	F	%	f	%	F	%	f	%	M
meaningful understanding of the principle of conservation of linear momentum											
Lenz's law is well understood with the aid of computer-based process simulations	1	0.3	4	1.3	0	0.0	27	8.5	284	89.9	4.86
Energy band theory is well learned with the help of computer-based process simulations	0	0.0	0	0.0	0	0.0	3	0.9	313	99.1	4.99
Computer-based process simulations aid critical thinking on the concept of electromagnetic waves	11	3.5	2	0.6	0	0.0	67	21.2	236	74.7	4.63
Mechanism of vision and hearing is well mastered with the aid of computer-based process simulations	4	1.3	0	0.0	0	0.0	28	8.9	284	89.9	4.86
Nuclear fission and fusion are meaningfully understood when computer-based process simulations are used.	0	0.0	4	1.3	0	0.0	7	2.2	305	96.5	4.94
Grand Mean											4.84

Source: Field Data (2024)
[Keys: 1= Very Low Extent (VLE), 2 = Low Extent (LE), 3 = Neutral (N), 4 = High Extent (HE), 5 = Very High Extent (VHE), F = Frequencies, % = Percentages, M = Mean]

Data in Table 1 show that, the extreme majority (99.3%) of students indicated that to a very high extent and high extent Computer-based process simulations aid critical thinking on resistance in materials while an extreme minority (0.6%) of students indicated that computer-based process simulations to a low extent aid critical thinking on resistance in materials. The mean score for students was 4.77. This implies that computer-based process simulations aid critical thinking on resistance in materials. These data reveal a striking consensus among students regarding the effectiveness of computer-based process simulations in enhancing critical thinking in the resistance of materials. These strongly suggest that integrating computer-based simulations in Physics teaching is a powerful strategy for enhancing critical thinking skills related to resistance in materials. It underscores the necessity for educators to adopt an innovative teaching method that not only improves students' understanding of complex concepts but also promotes essential critical thinking skills. By embracing technology in the classroom, teachers create a more dynamic and interactive learning environment that prepares students for real-world applications in Physics. Similarly, the researcher, during a face-to-face interview with Physics teacher "2", had this to say:

> The simulations encourage Students to engage in hypothesis-driven inquiry. Before running a simulation, I ask them to predict what will happen based on their understanding of the principles involved. After they manipulate the variables and observe the results, they analyze discrepancies between their predictions and the outcomes, which foster critical thinking and deeper conceptual understanding. Although, the school has few computers *(PT_2 Personal Communication, 1st October 2024)*.

Also Physics teacher of school "6" gave the view that;

> I believe simulations can significantly enhance critical thinking by allowing students to experiment and visualize complex concepts. For instance, if students could manipulate variables in a simulation of a physics phenomenon, they could explore cause and effect in a way that is often difficult with traditional methods *(PT_6 Personal communication, 4th October 2024)*.

The insights from Physics teachers 2 and 6 support the assertion that computer-based simulations enhance critical thinking among students. Teacher 2 emphasizes the importance of hypothesis-driven inquiry, highlighting that before running a simulation, students are encouraged to predict outcomes based on their understanding of physics principles. This process enhances a deep understanding of physics principles. Similarly, teacher 6 points out that simulations allow students to experiment and visualize complex concepts, facilitating an exploration of cause–and–effect relationships that traditional methods often struggle to convey. Both teachers underscore the interactive nature of simulations as a key factor in promoting critical thinking, as students actively manipulate variables and analyze outcomes. The findings are in line with those of the study by [13], who affirmed that computer-based simulations combined with a guided inquiry approach lead to higher average learning outcomes in critical thinking skills among students. Thus, computer-based process simulations aid critical thinking among students in Physics.

On the other hand, data in Table 1 show that, the extreme majority (95.9%) indicated that, to a very high extent and high extent computer-based process simulations aid critical thinking on the concept of electromagnetic waves, while an extreme minority (4.1%) indicated that, to a very low extent and low extent computer-based process simulations aid critical thinking on the concept of electromagnetic waves. The students' mean score was 4.63. This implies that computer-based process simulations aid critical thinking on the concept of electromagnetic waves. The findings support the argument that integrating computer-based simulations into the study of electromagnetic waves is an effective strategy for promoting critical thinking and deeper comprehension of complex scientific concepts. The findings are in line with [21, 4, 7], who affirmed that the computer-based simulation-assisted problem-based learning model improves students' critical thinking skills in Physics learning.

Furthermore, data in Table 1 show that, the extreme majority (97.8%) indicated that, to a very high extent and high extent static electricity is deeply learned when computer-based process simulations are used, while the extreme minority (2.2%) indicated that, to a very low extent and low extent static electricity is deep learned when computer-based simulations are used. This suggests that computer-based process simulations enhance deep learning of static electricity, which leads to critical thinking among students. The combination of deep understanding and critical thinking skills significantly enriches the overall learning experience, preparing students to apply their knowledge in real-world contexts. This was supported by a Physics teacher from school "5" during a face–to–face interview, who had this to say:

I use simulations to illustrate various physics concepts, such as motion, forces, and energy. For example, in a simulation of motion in a straight line, students can adjust parameters like angle and initial velocity to see how these changes affect the distance covered by an object. This interactive approach allows them to visualize and experiment with concepts that are often abstract *(PT_5 Personal communication, 4^{th} November 2024).*

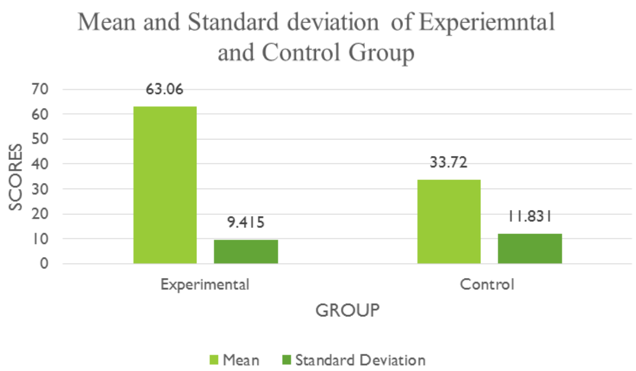
The insights provided by Physics Teacher "5" highlight the critical role of simulations in teaching fundamental physics concepts such as motion, forces, and energy. By allowing students to adjust parameters like angle and initial velocity in a simulation of motion in a straight line, the teacher facilitates an interactive learning environment where abstract concepts become tangible. This hands-on approach not only engages students but also promotes active experimentation, enabling them to visualize the relationships between different variables and their effects on motion. The findings align with Piaget's cognitive constructivism theory, emphasizing hands-on exploration and active learning. Teachers' insights highlight how simulations facilitate hypothesis-driven inquiry and visualization of abstract concepts, fostering critical thinking.

Hypothesis Testing

In determining whether the use of computer-based process simulations significantly enhances critical thinking skills among students, the independent sample t-test was used. This was done by comparing the experimental and control groups to assess if the determined differences were statistically significant. Students from School C were selected as the control group, while students from School E served as the experimental group. Both groups consisted of Form Three Physics students. The experimental group was taught using on-shelf simulations for two weeks, whereas the control group received instruction through lectures, group discussions, and demonstrations of teaching methods for the same period. Following the two-week instructional period, a standardized achievement test containing 10 multiple-choice and 10 fill-in-the-gaps items was administered to both groups to determine the extent to which computer-based simulations enhanced critical thinking skills. The following hypothesis was tested in this study:

H_0: There is no significant difference in mean scores between the experimental group and control group on the extent of computer-based process simulation on enhanced critical thinking of students in physics concepts.

The mean performance and standard deviations of the experimental and control groups were summarized in Figure 2.



Source: Field data (2024)

Figure 2. *Mean performance and standard deviation of experimental and control groups on a critical thinking test about the transfer of thermal energy.*

The bar chart in Figure 2 illustrates the mean score and standard deviations of the experimental and control groups. The data indicate that the experimental group achieved a significantly higher mean score (M = 63.06, SD = 9.415) compared to the control group (M = 33.72, SD = 11.831). This shows that the experimental group outperformed the control group in the transfer of thermal energy critical thinking test [11]. Additionally, the experimental group displayed a lower standard deviation, indicating greater consistency in performance within the experimental group. This implies that the use of computer-based process simulations has positively influenced critical thinking skills in physics.

Testing hypothesis for H_0: To test whether the difference was merely a coincidence or significant, the researcher computed an independent sample t-test. In an independent sample t-test, it was assumed that: the groups are independent and variances are homogeneous. The decision rule: reject H_0 and if the p-value is greater than the significance level, fail to reject H_0. [$\propto$ =.05] The independent sample t-test output was computed through SPSS version 26 and summarized in Table 2:

Table 2. *Independent Sample t-test.*

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	T	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Score	Equal variances assumed	.381	.541	8.231	34	.000	29.333	3.564	22.091	36.576
	Equal variances are not assumed.			8.231	32.368	.000	29.333	3.564	22.077	36.589

Source: Field data (2024)

An Independent Samples t-test was conducted to compare the test scores between the experimental group, which utilized computer-based simulations, and the control group, which received traditional instruction. Levene's test indicated that the assumption of equal variances (homoscedasticity) was met, $F(1,34)=0.381$, $p=0.541$. The t-test results showed that there was a statistically significant difference in scores between the two groups, $t(34)=8.231$, $p<0.001$. The mean score for the experimental group was significantly higher (Mean Difference = 29.333, SE=3.564), with a 95% confidence interval for the difference ranging from 22.09122 to 36.57636.

The results of the t-test provided strong evidence to reject the null hypothesis, as indicated by the p-value of 0.000, which is below the conventional threshold of 0.05. The significant mean difference of 29.333 suggests that the experimental group performed markedly better than the control group. This finding implies that the use of computer-based simulations significantly enhances student learning outcomes compared to traditional instructional methods. These results support the effectiveness of innovative teaching strategies in improving student performance and highlight the potential for integrating technology into educational practices.

Effect size: The effect size was computed to quantify the magnitude of difference between the experimental group and the control group on the extent to which computer-based process simulations enhance critical thinking in Physics

$$\text{Effect size} = \frac{M_1 - M_2}{SD_{pooled}}$$

Where

M_1 and M_2 are the means of the two groups.

SD_{Pooled} Is the pooled standard deviation

Hake's learning gain factor was mathematically calculated as;

$$SD_{pooled} = \sqrt{\frac{(N_E - 1)\ SD_E^2 + (N_C - 1)\ SD_C^2}{N_E + N_C - 2}}$$

N_E and N_C = number of students in experimental and control groups, respectively

SD_E and SD_C = standard deviations of experimental and control groups, respectively

SD_{pooled} = 10.69

Effect size = 2.7

The effect size value (2.7) indicates that there is a strong effect (> 1) of introducing computer-based process simulations in enhancing critical thinking among students in the physics subject. 0 – 0.2 = Weak effect, 0.21 – 0.5 = Modest effect, 0.51 – 1 = Moderate effect and > 1 = strong effect [5]. The effect size of 2.7, as derived from the implementation of computer-based process simulations, provides compelling evidence of a robust enhancement in critical thinking skills among physics students. Effect sizes greater than 1 are indicative of a strong effect, signaling that the intervention effectively facilitates cognitive engagement and higher-order thinking.

Generally, the impact of computer-based process simulations on critical thinking was measured using a standardized achievement test, which included multiple-choice and fill-in-the-gap items focused on physics concepts. The significant mean score difference between the experimental group (M = 63.06) and the control group (M = 33.72) demonstrates that CBS can effectively enhance critical thinking skills [12]. There is a strong effect of introducing computer-based process simulations in enhancing critical thinking among students in the physics subject. It also enhances Piaget's cognitive constructivism theory by demonstrating that computer-based process simulations enable students to construct knowledge through interactive problem-solving and experimentation.

10. Conclusion and Recommendations

10.1. Conclusion

Based on the findings, the study concluded that computer-based process simulations to a high extent enhance critical thinking among students in physics concepts. There is a strong effect of introducing computer-based process simulations in enhancing critical thinking among students in the physics subject.

10.2. Recommendations

Based on the conclusions, the study recommends that secondary schools that computer-based process simulations should be integrated into teaching physics concepts to students in public secondary schools, as it enhances critical thinking. Also, the study recommends that the government, through the Ministry of Education Science and Technology should prioritize the provision of comprehensive in-service training for physics teachers, focusing on the effective integration of computer-based simulations and technology into their teaching practices. Finally, the government should ensure that secondary schools are equipped with the necessary technological resources that support the use of computer-based simulations regardless of the school's location.

Abbreviations

CBS	Computer-based Simulations
CSEE	Certificate of Secondary Education Examination
ETP	Educational Training Policy
MWECAU	Mwenge Catholic University
PhET	Physics Education Technology
ZPD	Zone of Proximal Development

Conflicts of Interest

The authors declare no conflicts of interest.

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