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Effectiveness of PhEt Simulations on Conceptual Understanding of Protein Synthesis in Selected Secondary Schools in the City of Kigali

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Abstract: *This study investigated the effectiveness of PhEt simulations on protein synthesis conceptual understanding and effects of PhET simulation-based instruction towards protein synthesis in senior four secondary students. The study was a quasi-experimental pretest-posttest with a control group design. The sample of the study consisted of 107 senior four students doing biology in their subject combination in selected secondary schools in Kicukiro and Nyarugenge Districts. Over the course of a week, the experimental group (n=57) received instruction using PhET simulations whereas the control group (n=50) received teaching using traditional methods. The pretest-posttest and a protein synthesis attitude scale were used to collect data. The data were analyzed using the independent samples t-test in R core Team 2022. The study's findings showed that the PhET simulation-based instruction had a favorable effect on students' protein synthesis conceptual understanding as well as their attitudes towards protein synthesis. Students in the experimental group (M=79.23, SD=6.75) had a higher level of conceptual understanding of protein synthesis than those in the control group (M=55.88, SD=5.18). In terms of attitudes, the experimental group presented higher levels of positive attitudes towards protein synthesis than the control group.*

Keywords: *Effectiveness, PhET, simulations, Conceptual understanding, Attitudes*

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1. Introduction

Learners find complicated science topics that are taught in an abstract way without a link to their daily experience(Ramma et al., 2018). Generally, science classes from basic to university schools fail to provide a conceptual understanding of science to students. These classes quite often suppress any interest students may have in the subject (Perkins et al., 2006). To address this issue, a new aspect of technology has been tried out: Online interactive simulations. This is the way students can build and enhance their scientific conceptual understanding through semi-guided discovery (Perkins et al., 2006).

In a study conducted by Wieman et al., (2010) it is found that simulations enable the students to overcome a non-scientific conception, hence they promote the development of clear and common understanding. This is emphasized by Kotoka and Kriek (2014) who found that computer-based simulations are more effective to help students to better understand abstract science concepts.

Since 2016, Rwanda started to implement a competence-based curriculum in secondary schools to prepare competent citizens who will be able to satisfy the society needs and expectations (Nsengimana et al., 2021). This competence-based curriculum replaced a former learner centered curriculum based on knowledge instead of skills, attitudes, values and competencies introduced in 2006 (Nsengimana et al., 2021).

Physics Education Technology (PhET) is a suite of research based interactive simulations developed by PhET project at University of Colorado since 2002 to provide powerful learning simulations to students and teachers all over the world. PhET offers enjoyable, free of charge, interactive, research-based mathematics and science simulations. The project has created a number of interactive simulations for science teaching and learning, all of which are freely available on the PhET website (http://phet.colorado.edu) (Perkins et al., 2010).

To determine the effectiveness of PhET simulations on students 'achievement of the greenhouse effect, the PhET simulations were found to have a statistically significant positive contribution to the conceptual understanding of greenhouse effect. The study revealed that PhET simulations are simple to use and made the lesson quite enjoyable. The students need to experience PhET simulations at home and they had no difficulties using them. Therefore, the study concluded that despite its use of constructive teaching approaches, PhET, simulations provide a significant contribution to the learning process by empowering the instructional strategies (Hasan & Koştur, 2008) .

Salame and Makki (2021) conducted a study in United States of America intending to examine the students' impact of PhET simulations on their learning and attitudes, as well as to recognize the most advantageous properties of PhET. It has been found that PhET simulations were simple to follow, and they provide an enjoyable experiential learning that were not available in traditional laboratory settings. Not only that, but also the study revealed that PhET simulations improved conceptual understanding and made a significant contribution to grade improvement as well as being an ultimate valuable learning experience (Salame & Makki, 2021).

Ndihokubwayo et al., (2020) discovered that PhET simulations and YouTube videos-based instructions are far more effective than traditional teaching in improving conceptual understanding of geometric optics in Rwandan secondary schools. As a result, they concluded that PhET simulations and Youtube video-based instructions are immensely helpful for Rwandan secondary school students doing physics in general, and optics in particular.

The competence-based curriculum has shown a significant impact on classroom management and student learning (REB, 2018). Teachers are required to read more books and enrich their knowledge about various subjects and teach most updated lessons. In their teaching, teachers are expected to act as facilitators by applying learner-centered teaching approaches where students are engaged and participate actively in the lesson (REB, 2018).

Though the CBC implementation has provided significant opportunities in Rwandan education, there is insufficiency of teaching materials due to limited time to develop teaching aid, lack of some material in the surrounding environment as well as the high cost required to develop required instructional material (REB, 2018). This supported by the study conducted by Nsengimana, (2020) which revealed that CBC content especially in science subjects are taught theoretically due to lack of appropriate teaching materials for teaching abstracts.

However, Biology, being one of the science subjects to be taught in secondary schools, is not an exception to other science subjects such as chemistry and physics that are taught theoretically. Protein synthesis, in particular, is one of the science subjects that students struggle to understand when taught without adequate instructional materials. Therefore, to solve this problem, new teaching approaches based on technology integration strategies are highly needed to reach the intended learning outcomes and improve conceptual understanding of sciences. PhET simulations, being free of charge, more interactive and attractive to the learners, are suggested for teaching protein synthesis as well as other biological topics to secondary students in Rwanda.

Through this study, the following hypotheses were tested:

1. Students taught using PhET simulations are more likely to understand the concepts of protein synthesis.
2. Students taught using PhET simulations are more likely to present positive attitudes towards protein synthesis.

This study aims at answering the following questions:

1. How do PhET simulations affect conceptual understanding of protein synthesis in Rwandan secondary schools' students?
2. How do PhET simulations affect learners' attitudes towards protein synthesis?

2. Literature Review

2.1 PhET Simulations and conceptual understanding

Simulations refers to the computer-based animations of events that are difficult to monitor directly, dangerous, costly or happening slowly or fast (Hasan Özcan & Koştur, 2008). They are considered as one of the educational technologies that can easily be used in education since the introduction of computers in classrooms. It is very clear that computers and simulations play a major role in everyday scientific life, just as the microscope and telescope were in the history of science(Hasan & Koştur, 2008).

PhET simulations were created for two main goals: increased student interest and improved learning. Students learn through exploration in the animated, interactive, and game-like environments (Wieman & Perkins, 2006). They focus on the connections between real-world phenomena and the underlying science, and strive to make expert scientists' visual and conceptual models accessible to students, often by making the invisible visible (Wieman & Perkins, 2006).

The PhET simulation project aims at proving the way science is taught and learned around the world through the use of free interactive simulations which are well-known throughout the world for significantly improving science teaching and learning (Banda & Nzabahimana, 2021a). These simulations are mainly developed for the purpose of increasing student engagement and improving learning of sciences (Perkins et al., 2006). They are specifically designed to engage students in active learning to construct and enrich their knowledge as well as creating an upscale environment in which they will construct a strong conceptual understanding of sciences through exploration (Wieman et al., 2008).

PhET simulations offer an animated, interactive, and game-like environment that students find enjoyable and encourage them to interact and explore in an interactive play area (Wieman et al., 2008). Through this environment, learning becomes a construction of effective organizational framework that requires significant cognitive work on the part of students. Therefore, PhET simulations arise curiosity and a sense of challenge encouraging students to interact and explore in depth through enjoyment (Perkins et al., 2012)

The term “conceptual understanding” refers to the ability of students to think critically in situations or conditions that necessitate the careful application of concept meanings, relationships or representations (Balka et al., 2016). According to (Banda & Nzabahimana, 2021b), conceptual understanding refers to the ability of students to extract information and knowledge from known concepts and apply it in a new setting.

Students with conceptual understanding are aware of more than just isolated facts and methods. They clearly comprehend the significance of science concepts as well as the various contexts in which it can be applied. They organize their skills and knowledge into a coherent manner allowing them to learn new concepts by connecting them to their prior knowledge (Kilpatrick et al., 2002).

To ensure the development of science conceptual understanding in students, teachers are advised to advocate for the incorporation of active learning techniques into the classroom. Furthermore, teachers should create a learning environment allowing modern teaching strategies, by using appropriate learning materials in order to meet the expectations and satisfy the needs of a competitive labor market. Technology in form of interactive simulations including PhET simulations is one of the available resources to be used for developing science conceptual understanding in students (Banda & Nzabahimana, 2021a).

PhET simulations have been found to be more effective in developing students' conceptual understanding of physics (Banda and Nzabahimana, 2021). Some instructional methods of using PhET simulations to improve conceptual understanding include inquiry-based activities, virtualized experiments, problem-based learning activities, and scaffolded learning activities. This is based on a number of studies conducted in various countries and educational systems (Banda and Nzabahimana, 2021).

2.2 Effects of PhET simulations on Learners’ attitudes towards learning sciences

A well-designed computer simulation learning environment can improve students' knowledge and performance in a biology course, and attitudes towards the subject (Kiboss et al., 2004). For a long time, animations and simulations have been considered as significant tools in the teaching and learning of sciences. Therefore, with greater access to technology in schools, the interactive simulations have become an effective tool for transforming science education (Moore et al., 2014).

PhET interactive simulations have a favorable impact on students' attitudes and perceptions about learning (Salame & Makki, 2021). The tools provided by PhET simulations assist students in developing a conceptual understanding of chemistry and content to be covered in lectures. Not only that, but also PhET simulations appear to promote and facilitate abstract concept learning and understanding. Moreover, PhET simulations provide clear instructions that are simple to follow, as well as learning opportunities that would not be possible in a traditional laboratory setting (Salame & Makki, 2021).

When comparing PhET simulations based instructional tools to traditional teaching, it is found that PhET are extremely beneficial for Rwandan secondary school students learning physics in general, and optics in particular. This is found after investigating the effectiveness of PhET simulations and Youtube videos as instructional tools to improve geometric optics conceptual understanding (Ndihokubwayo et al., 2020b). To be more effective for PhET, the teacher demonstrates all simulation features and students are given time to explore them. Students are encouraged to use computer and manipulate simulations.

According to Banda and Nzabahimana (2021), PhET simulations have been found to be more effective in developing students' conceptual understanding of physics. Some instructional methods of using PhET simulations to improve conceptual understanding include inquiry-based activities, virtualized experiments, problem-based learning activities, and scaffolded learning activities. This is based on a number of studies conducted in various countries and educational systems.

2.3 Theoretical framework

The present study is framed by Dual-coding theory developed by Allan Paivio and cognitive theory of multimedia learning.

2.3.1 Dual coding theory

The dual-coding theory states that a person can learn through audiovisual information for effective learning. This theory elaborates the idea of using visual and verbal stimuli to enable the effective encoding of information in students' memory and to ensure the easy retrieve of stored information. The mental codes associated with these audio and visual representations are used to arrange and organize incoming information so that it can be saved and recalled later (James & Paivio, 1991).

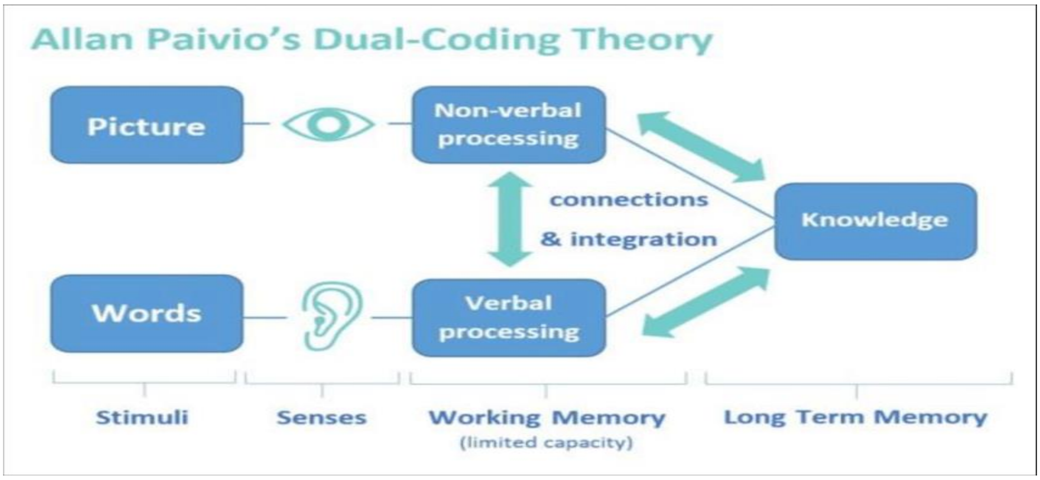

Figure 1: Dual coding theory by Allan Paivio (1971)

2.3.2 Cognitive theory of multimedia learning

This theory investigates how people learn from multimedia. Wittrock's generative theory and Paivio's dual-coding theory serve as the foundation for this theory. It goes beyond these two theories, moreover, by assigning the student the role of "knowledge constructor who actively chooses and relates pieces of verbal and pictorial knowledge." The theory backs up the idea that learners construct meaningful relationships between images and words and actively process them in long-term memory (Kanellopoulou & Kermanidis, 2019).

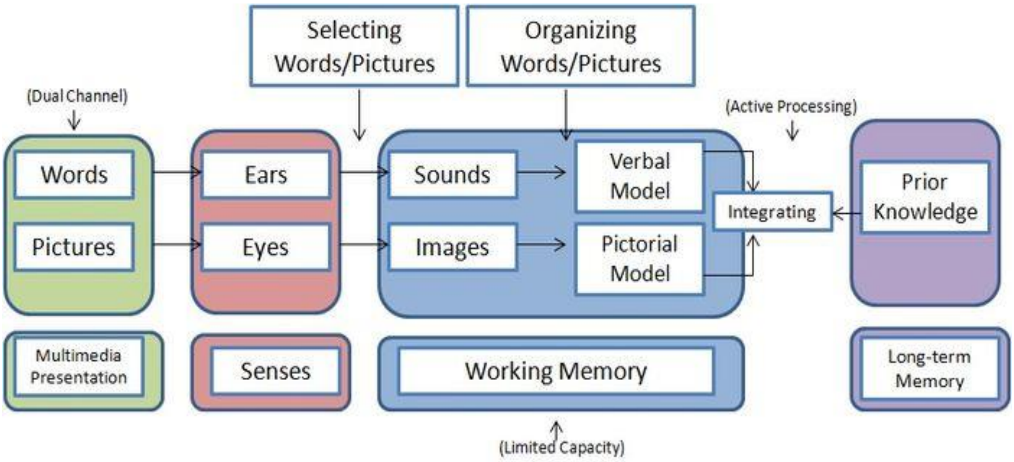

Figure 2: Cognitive theory of multimedia learning

3. Methodology

3.1 Research design

This study was conducted using a quasi-experimental design and pragmatic paradigm. The pragmatic paradigm prioritizes and looks at the research problems "what" and "how" as well as applying all approaches for solving it. Thus, pragmatism paves the way to multiple methods, different perspectives, and different assumptions, as well as different forms of data collection and analysis for the mixed methods researcher (Creswell, 2009).

The intervention focused on providing treatment and collecting data on the study's variables. Prior to the intervention, all groups received a pretest, and filled out the attitude scale form. Biology teachers received a specific training on the effective use of PhET simulations-based instructions before delivering a lesson, as PhET simulations would be manipulated by teachers rather than students. The researcher facilitated the training for two days, and teachers were exposed to PhEt simulations throughout the training and given an explanation of what they are, how to access them, and how to use them to effectively teach abstract subjects.

The experimental group (n=57) received the intervention, which was the incorporation of PhET simulations in the teaching and learning of protein synthesis. By use of computer and projector, biology teacher played the simulations, then after stopping the simulation he/she asked some questions to students, and students answered basing on their prior knowledge and what they were observing on the screen.

For control group (n=50) a traditional teaching approach was used, where teachers used student books, blackboard or whiteboard and chalks or markers. Practical demonstrations were done using manual drawings and some laboratory materials where applicable. Moreover, PhET simulations-based instructions were given to experimental group students. In order to determine whether the applied intervention had resulted in a significant change in terms of conceptual understanding of protein synthesis and attitudes towards protein synthesis, students from both the experimental and control groups were given a posttest and asked to complete the attitude scale form once again.

3.2 Sample and Justification of area of study

A sample of senior four students enrolled in four schools having biology in their subjects' combinations located in Kicukiro and Nyarugenge districts have been selected purposively. The choice of study area and participants was influenced by the research objectives, availability of infrastructures, availability of financial resources, the time, and the nature of the problem to be investigated. Kicukiro and Nyarugenge districts were purposively chosen as research area because they have a significant large number of secondary schools among Kigali's districts. Furthermore, given their advantageous location, it was quite convenient for the researcher to conduct the study in these areas with the available time and resources.

The participating schools were visited and inspected prior to the start of the main study. Furthermore, records of schools' achievement in standardized tests were examined, and it was determined that the four schools that took part in the main study had equivalent academic performance.

3.3 Data collection tools

To collect data on protein synthesis conceptual understanding, participants were given pretest prior to treatment and posttest after treatment. The test consisting of 25 Multiple Choice Questions (MCQs) which were created for the current study. The concepts of genetic code, transcription, amino acid activation, translation, and the impacts of changing nucleotide sequences were all taken into consideration when creating the questions, which all focused on the protein synthesis unit. Since the pretest and the posttest were identical, the maximum security would be guaranteed to make sure that no copies left to students before posttest. As a result, the computer used to create the test was password-protected. The test was graded on a scale of 100, with a higher score indicating a higher level of protein synthesis conceptual understanding. The test was found to have a high level of reliability with a Cronbach's Alpha of 0.86.

The protein synthesis attitude scale was developed based on biology attitude scale (BAS) developed by Rusell and Hollander (1975). The BAS developed by Rusell and Hollander consists of 22 questions. Therefore, some changes were made to meet the current study's objectives. The attitude scale consisted of 14 Likert scale questions and 6 semantic questions.

3.3.1 Part A. Likert-type scale

This part consisted of 14 questions. Eight of the statements were favorably organized and were used to measure positive attitudes towards protein synthesis, while six were adversely constructed and were used to measure negative attitudes towards protein synthesis. Students were asked to rate their agreement or disagreement on a scale of 1 to 5, with 1 denoting "strongly disagree", 2 "disagree", 3 "undecided", 4 "agree", and 5 "strongly agree".

3.3.1.1 Positive attitudes

The positive attitude scores were calculated using eight statements that were positively designed. The lowest possible score was 8, and the highest conceivable score was 40. The more points received, the more favorable attitudes regarding protein synthesis are prevalent. The following statements were used to measure the positive attitudes:

Table 1: Likert-type scale positive attitudes statements

No	**Statement**
1	Protein synthesis is very interesting to me
4	Protein synthesis is interesting and enjoyable.
5	Protein synthesis make me feel secure, and at the same time, it is stimulating.
7	Generally, I've good feeling toward protein synthesis.
10	I really like protein synthesis.
11	I enjoyed studying protein synthesis.
13	I feel happy with protein synthesis and like it very much.
14	I feel a definite positive reaction to protein synthesis, it is enjoyable.

3.3.1.2 Negative attitudes statements

Six negatively structured statements were used to measure the negative attitudes towards protein synthesis. The possible lowest score was 6 and the possible highest score was 30. The lower the score, the higher the positive attitudes towards protein synthesis.

Table 2: Likert-scale negative attitudes statements

No	**Statement**
2	I don't like protein synthesis, and it makes me nervous to learn it.
3	I am always under intense stress in a protein synthesis lesson
6	Protein synthesis makes me feel uncomfortable, restless, frustrated, and impatient
8	When I hear the word protein synthesis, I have a feeling of dislike
9	I approach protein synthesis with feeling of hesitation.
12	It makes me nervous to even think about doing a protein synthesis experiment.

3.3.2 Part B: Semantic scale

The semantic part consists of questions, which are graded on a bipolar scale with opposing adjectives defining each pole.

Table 3: Semantic scale statements

No	*Protein synthesis is*						
1	Good	5	4	3	2	1	Bad
2	Clean	5	4	3	2	1	Dirty
3	Useful	5	4	3	2	1	Useless
4	Kind	5	4	3	2	1	Unkind
5	Pleasant	5	4	3	2	1	Unpleasant
6	Fair	5	4	3	2	1	Unfair

To obtain the total score for every participant, the attitude scores of likert type scale and semantic scale were added up to generate a total score. To test the tool's reliability, Cronbach's Alpha Coefficient was calculated and found to be 0.77 indicating that the scale was within a reliable range.

4. Results and Discussion

4.1 Pretest scores

Pre-tests revealed that students from the control group and experimental group had similar conceptual understanding of protein synthesis. The average score was **26.9±5.9 %** and **27.7±6.23 %** for the control and experimental group, respectively (Figure 3A). The p-value of an independent sample t-test was 0.455, which was greater than the significance level alpha = 0.05. As a result, there is no statistical difference between the mean pretest scores from the control and experimental groups. This demonstrates that students in the control and experimental groups were on the same level prior to intervention.

4.2 Posttest scores

Posttest scores were compared to investigate whether the treatment had the same impact on control and experimental groups. The independent sample t-test results revealed that the experimental group had a higher mean score than the control group. The average score was **55.88±5.18%** and **79.23±6.75%** for the control and experimental groups, respectively. This is confirmed by the computed p value (p-value 2.2e-16), which is lower than the significant alpha (0.05). Therefore, there is a significant statistical difference between the mean scores of posttests in control and experimental groups (Figure 3B).

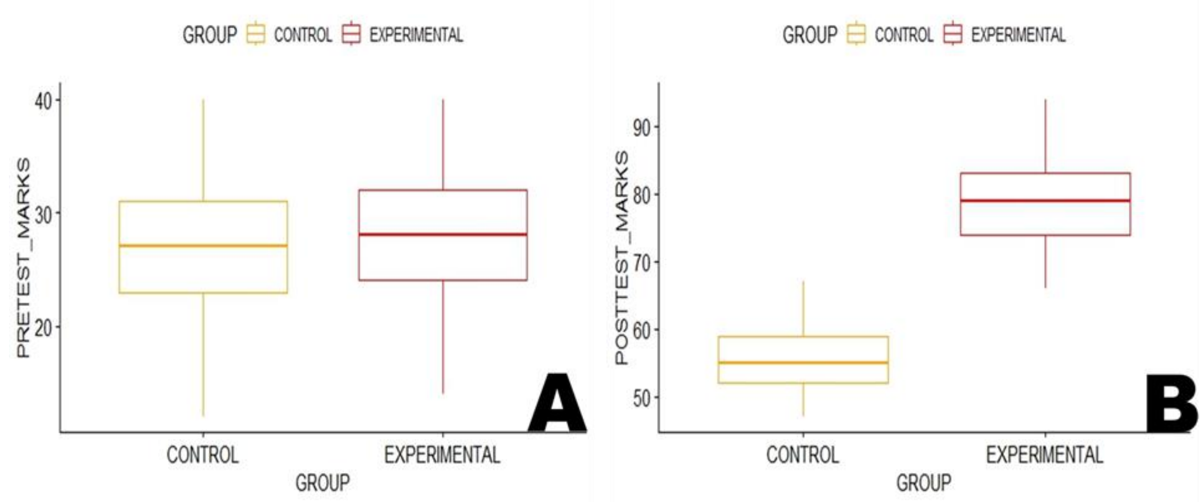

Figure 3: Comparisons of pretest and posttest scores

4.2.1 Positive attitudes

The independent sample t-test results (p-value 2.2e-16) revealed a statistically significant difference in positive attitude scores between the control and experimental groups. The experimental group's positive attitude scores (M=34.84, Sd=2.71) were significantly higher than the control group's positive attitude scores (M=28.08 Sd=3.02). This indicated that the experimental mode of instruction applied in experimental group had a positive effect on learners' positive attitudes towards protein synthesis (Figure 4A).

4.2.2 Negative attitudes

Negative attitude scores were compared to investigate whether the treatment had the same impact on control and experimental groups. The independent sample t-test results revealed that the experimental group had a lower mean score than the control group (Figure 4B).

The average score was M=**16.76, Sd=1.95** and M **9.95, Sd=2.02** for the control and experimental groups, respectively. This is confirmed by the computed p value (p-value 2.2e-16), which is lower than the significant alpha (0.05). Therefore, there is a significant statistical difference between the mean scores of negative attitudes towards protein synthesis in control and experimental groups.

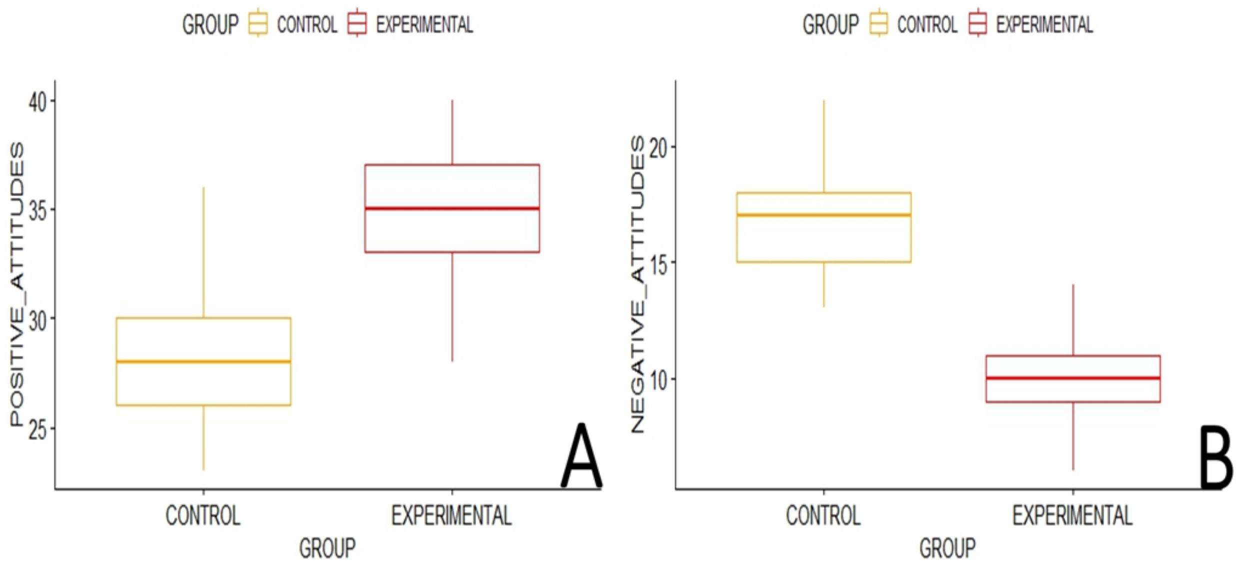

Figure 4: Comparison of positive and negative attitudes towards protein synthesis

4.2.3 Semantic scale attitudes scores

x assertions that are based on bipolar adjectives make up this section. The lowest possible score was 6, while the highest possible was 30. The higher the score, the higher the attitude levels towards protein synthesis. The independent sample t-test, revealed that experimental group had higher attitude scores (M=25.68, Sd=4.5) than the control group (M=11.02, Sd=3.8). This indicates that PhET simulations-based instruction has a favorable impact on students' attitudes toward protein synthesis.

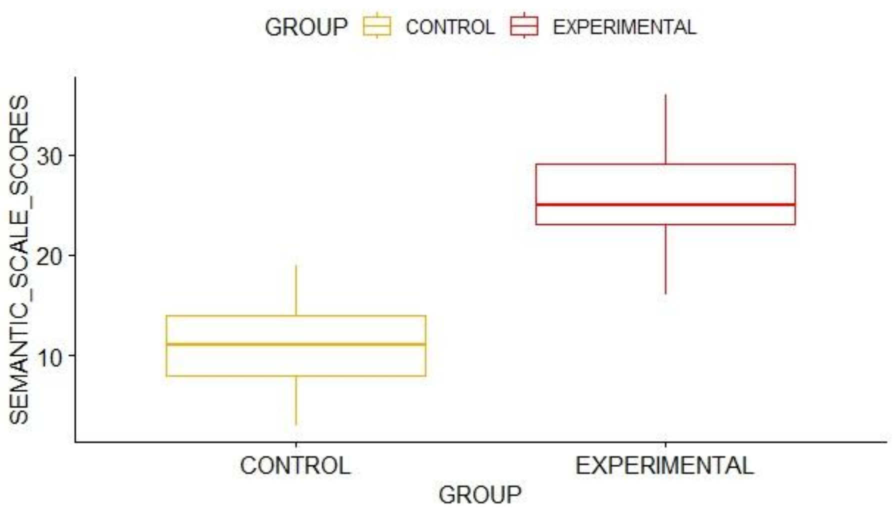

Figure 5: Semantic scale attitude scores

4.3 Discussions

4.3.1 Effects of PhET simulations on conceptual understanding of protein synthesis

The analysis of pretest scores revealed that all learners in the study had a similar level of conceptual understanding of protein synthesis prior to treatment. According to the independent sample t-test results, there is no statistically significant difference in pretest scores across all groups. This could be attributed to the fact that the schools chosen were on the same level.

The pretest scores analysis results showed a low conceptual understanding of protein synthesis in both groups. The applied treatment had significantly increased the level of conceptual understanding in both control and experimental group. Students taught using PhET simulations, (experimental group) showed a higher increase in conceptual understanding than students taught using traditional teaching methods (control group). Therefore, the use of PhET simulations-based instructions had a favorable influence on learners' conceptual understanding of protein synthesis. This study's findings are consistent with previously conducted researches (Wieman et al., 2008; Salame & Makki, 2021) that discovered the beneficial effects of PhET simulations on students' conceptual understanding. This is completely in line with Allan Paivio's Dual Coding Theory, which states that a person can learn through audiovisual information for effective learning. This theory elaborates the idea of using visual and verbal stimuli to enable the effective encoding of information in students' memory and to ensure the easy retrieval of stored information. The mental codes associated with these audio and visual representations are used to arrange and organize incoming information so that it can be saved and be reminded later (James & Paivio, 1991).

The results are also in accordance with cognitive theory of multimedia learning, which supports the idea that students actively integrate images and words in long-term memory by creating meaningful associations between them.(Kanellopoulou & Kermanidis, 2019).

4.3.2 Effects of PhET simulations on learners' attitudes towards protein synthesis.

The differences in attitude scores before and after intervention indicate that the two study groups' attitudes towards protein synthesis changed during the intervention. Both the control and experimental groups experienced a positive shift in their attitudes, with the experimental group experiencing a greater shift than the control group. As a result, PhET simulation-based instructions appeared to improve students' attitudes toward protein synthesis significantly.

This backed up the findings of a study conducted by (Salame & Makki, 2021), who discovered that PhET simulations positively affect students' attitudes because they are simple to use and provide enjoyable experiential learning that is not available in traditional teaching methods.

5. Conclusions and recommendations

5.1 Conclusion

The present study investigated the effectiveness of PhET simulations on protein synthesis conceptual understanding in selected schools in the Kicukiro and Nyarugenge Districts. When comparing PhET simulations-based instructions results to traditional teaching results, a statistically significant difference was found. As a result, it is concluded that PhET simulations-based instructions are extremely helpful in teaching biology, particularly protein synthesis.

Furthermore, the results showed that PhET simulations positively influenced students' attitudes toward protein synthesis. After intervention, the experimental group's attitudes toward protein synthesis changed significantly more than the control group. As a result, since PhET simulations influence students' conceptual understanding of protein synthesis, they also have a significant positive influence on students' attitudes towards protein synthesis. A further significant finding from this study is that PhET simulation-based instructions can significantly improve learners' motivation, engagement, and enjoyment while also making teaching - learning of scientific abstract topics much easier. This is due to the interactive nature of PhET simulations, which can easily change the invisible to visible for better comprehension.

5.2 Recommendations

1. Education policymakers are recommended to educate teachers and provide training on the integration and effective use of technological tools, including simulations, to promote active learning.

2. Schools, on the other side, are strongly advised to create a supportive environment that encourages the use of technological tools in schools, including allocating sufficient time for students to access computer laboratories and internet connectivity.

3. Science teachers should integrate PhET simulations into their lessons, particularly when teaching abstract topics that seem to be difficult for learners to understand.

4. The current study looked into the efficacy of PhET simulations on protein synthesis conceptual understanding in biology, specifically protein synthesis. This has created a void, as the PhET simulations should be used in other scientific topics. As a result, more research on the effectiveness of PhET simulations in other science subjects is recommended.

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