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Multimedia-Aided Technologies for Effective Learning of Quantum Physics at the University Level

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Abstract

Physics education has been identified as one of the public sectors that are mostly influenced by technological developments. This paper adopted the quasi-experimental pre- and post-test design to assess the effects of multimedia-aided technologies (MAT) on undergraduate students' performance in quantum physics (QP) at the University of Rwanda College of Education (UR-CE). The researcher used purposive sampling to get 385 undergraduate students. Participants were randomly allocated into experimental (group A) and control (group B) groups. Group A (187 students) students were taught selected topics of quantum physics (black-body radiation, photoelectric effect, Compton effect, wave aspects of particles, De Broglie's hypothesis, diffraction, interference and double-slit experiment, model of the atom, uncertainty relations, wave function, and Schrodinger equations) for 6 weeks using multimedia-aided technologies and engage, predict, observe, and explain (EPOE) method, whereas group B (187 students) was taught same topics during the same period with a lecture method. The results of ANCOVA revealed that the group's performance was the same ($p > .05$) before learning with no effect size (.000), while they diverged after learning with different teaching interventions. The significance was very high and statistically different ($p < .001$) with a large effect size ($> .5$). This implies that students taught with multimedia-aided technologies (experimental group) outperformed those students taught with lecture teaching methods (control group). Thus, the study recommends that educators should adapt teaching using MAT and EPOE strategy not only in QP but also in other domains of physics to improve active engagement, understanding levels, and academic achievement.

Keywords Physics education · Lecture method · Multimedia-aided technologies · Quantum Physics · University students

Introduction

Quantum physics demonstrates to be a special field in physics education due to its abstract formalism, the differences from classical physics, the lack of practical experiments usable in the classroom, and the strong traditions in teaching that are partially a result of the long unclear history of interpretation (Pospiech & Schöne, 2011). Many students viewed quantum physics (QP) as an abstract subject separate from everyday life. The traditional ways of teaching and learning physics, commonly known as lecture teaching methods, have been dominated by mathematical problem-solving rather than critical thinking, discussion of ideas, and qualitative understanding of the subject concepts (Bungum et al., 2018). To this end, various studies have identified that learning QP is challenging for students (Chhabra & Das, 2016; Henriksen et al., 2014; Lin & Singh, 2010; Mason & Singh, 2010). Research conducted by Sadaghiani (2005) showed that many students consider QP difficult since it is abstract, counter-intuitive, and highly mathematical. Students study this course only as a compulsory course in the curriculum to be completed. The traditional way of teaching QP is to prepare students for exams rather than teaching them to understand the concept and syllabus topics. This teaching approach was found to lack the potential to provide opportunities for students to develop their understanding of

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QP concepts (Wuttiprom et al., 2009). As a result, this traditional approach is less encouraging for students to develop their level of thinking and successfully perform the subject. In addition to students' problems with learning QP, the instructors have problems in teaching it because of its nature. However, one of the key challenges in teaching QP is to find a way to introduce its concepts, as quantum theory is both technically and theoretically subtle (Prabavathi & Nilufer, 2015). The same case was observed in teaching and learning QP in Rwanda's higher institutions (Nyirahabimana et al., 2022).

The study conducted by Ndihokubwayo et al. (2020) shows that the best way to assist students in understanding and to perform abstract physics topics is to use various engaging instructional tools. The same study investigated the effect of PheT simulations and YouTube videos and found that Rwandan students perform better in optics due to these tools. Teaching physics concepts using technology can improve learning and motivate students to grasp them more easily (Uwamahoro et al., 2021). Belay et al. (2022) found that teachers' teaching methods positively influenced students' performance in learning physics. Education systems still struggle to determine which teaching methods will be most effective in the twenty-first century. However, there is evidence that students persistently perform poorly in QP (Uwizeyimana et al., 2018). Hence, it is imperative to promote contemporary teaching and learning strategies that encourage student's creativity, imagination, and innovation. In addition, this provides a solid foundation for developing strategies for teaching and learning that are effective, efficient, and innovative, thereby overcoming barriers to poor QP understanding. The research conducted by Verawati et al. (2022) on enhancing the reasoning performance of STEM students in modern physics courses using virtual simulation shows that using simulations to teach modern physics in a classroom has proven to be an effective and valuable tool for facilitating student performance. Using simulations can also enhance learning experiences by creating interactive and engaging opportunities. Studies show that visualization methods such as demonstrations, simulations, models, graphs, films, animations, videos, and other applets can help students better understand physical concepts and phenomena (Stadermann et al., 2019). It is essential in QP since its concepts are abstract and counter-intuitive. Using multimedia can also facilitate a more active and hands-on classroom learning approach. In addition to conducting virtual experiments, students can explore concepts from various views and angles using multimedia resources. As a result, the material will be more engaging and understandable, allowing them to perform better. Also, students are more likely to find the material relevant and interesting if they understand the real-world applications of QP (Stadermann & Goedhart, 2020; Stadermann et al., 2019). According to Mason & Singh (2010), the teaching and learning of QP, in particular, as well as other science subjects, can be enhanced by using multimedia methods such as demonstrations, simulations, animations, videos, and other applets. However, using animations, PhET simulations, and YouTube videos combined to improve QP teaching and learning, particularly in Rwanda's higher education institution, has not been the subject of any research (Table 1).

A study by Ilhan & Oruc (2016) on the effect of multimedia on students' performance found that multimedia lessons motivated students to learn and improved students' performance in difficult topics. According to all the above findings, multimedia tools such as animations, simulations, and videos that support traditional teaching approaches can be used in teaching and learning with technology. Technology-aided instruction is a powerful tool to help students understand subject content more efficiently and in detail. Thus, with the emergence of technologies available for use in education, it is important to integrate technology into the teaching and learning process to improve student's critical thinking, concept-building, and motivation (Byusa et al., 2022; Lai & Bower, 2019) in learning different physics subjects such as QP. Therefore, the present study focuses on animations, YouTube videos, and PhET interactive simulations

Table 1 Legend of acronyms in this paper

Acronym	Description
ACEITLMS	African Center of Excellence in Innovative Teaching and Learning Mathematics and Science
ANCOVA	Analysis of covariance
CBC	Competence-based curriculum
MAT	Multimedia-aided technology
MSPE	Mathematics, science, and physical education
MPE	Mathematics-physics-education
PCE	Physics-chemistry-education
PGE	Physics-geography-education
PhET	Physics education technology
UR-CE	University of Rwanda College of Education
STEM	Science, technology, engineering, and mathematics
SPSS	Statistical Package for the Social Sciences
QP	Quantum physics
QPCS	Quantum Physics Conceptual Survey
QPAT	Quantum Physics Attitude Test
QMFPS	Quantum Mechanics Formalism and Postulates Survey
QMS	Quantum Mechanics Survey
QMCA	Quantum Mechanics Concept Assessment
POE	Predict-observe-explain
POEA	Predict-observe-explain-apply
POEE	Predict-observe-explain-explore
EPOE	Engage-predict-observe-explain-explore

as examples of multimedia instructional tools. Kunnath & Kriek (2018) discovered that students performed well using computer-simulated instruction. The PhET simulations are helpful for teachers and learners in gaining a better understanding of something otherwise not apparent. A study by Chinaka (2021) found that PhET simulations were useful in teaching students how waves work simply by showing the motion of a string. According to Krijtenburg-Lewerissa et al. (2017), PhET simulations changed students' attitudes and performances after practicing quantum mechanics. Students can experience scientific concepts virtually with the help of computer simulations. Simulations are, therefore, effective at helping students understand complex topics more quickly (Nkemakolam et al., 2018).

Simulations enable the development of explicit and shared understandings that overcome non-scientific conceptions (Wieman et al., 2010). Simulations are also practical for exploring gravity, nuclear fission, nervous systems, lighting, and explosives and replacing difficult or hazardous experiments with doing in laboratories (Astutik & Prahani, 2018). The use of computer simulations can provide a meaningful explanation of all of these concepts (Akuma & Callaghan, 2016). Rusanganwa, (2013) and Shah & Khan (2015) argued that multimedia in teaching and learning physics through simulations and visualizations are the most widely used multimedia tool in the instructions of sciences and physics. Also, students' performance in many subjects has been found to improve using YouTube videos rather than lectures alone. A YouTube video can, for example, be an effective teaching method to make physics more appealing to learners and to dispel misconceptions about it (Bhukuvhani et al., 2010). YouTube videos enhance learning motivation and conceptual understanding. In addition to adapting more diverse strategies and deepening their understanding of the content, these tools have allowed teachers to adapt more diverse teaching strategies.

YouTube videos can be used in many different ways. Resources like these can be used as standalone content, as supplements to other course activities, for just-in-time instruction, or as teacher research guides (Mukumba & Shambira, 2022). Students benefit from YouTube videos when directed to them and are allowed to discuss their ideas, and their ideas are contextualized. These videos have been shown to enhance student engagement and learning (Pattier, 2021). Despite QP's widespread application, studies have revealed that university students have faced difficulties learning its concepts (Hendawati et al., 2019; Kapngero, 2018; Politis et al., 2007). According to Akmam et al. (2019), one reason is the poor teaching methodology used by teachers. An effective learning environment poses a significant challenge to stakeholders in the education sector, particularly teachers. Learner-centered techniques that promote active learning are embraced by all countries implementing a competency-based curriculum (CBC) (Lin et al., 2021). These techniques will benefit students interested in physics and QP, particularly in their future careers. Also, the importance of interactive multimedia in enhancing teaching and learning physics is well-known worldwide. However, very few studies critically evaluated students' learning of multimedia in terms of their importance, acceptability, its combination to other active strategy like EPOE, and suitability to enhance students' achievement.

Therefore, the present study assessed the effectiveness of MAT on students' performance in QP at the UR-CE. To accomplish the goal of the present study, the following research question was considered: To what extent does MAT affect students' performance in QP at UR-CE? In order to accomplish the above objective, the following hypothesis is formulated (Ho): There is no statistically significant mean score difference between students taught with lecture teaching methods and those taught with MAT while learning QP.

Research Methodology

Research Design

The study adopted quasi-experimental pre-and post-test methods (Cresswell, 2012) with control and experimental groups. The control group students were taught selected topics of QP (blackbody radiation, photoelectric effect, Compton effect, wave aspects of particles, De Broglie's hypothesis, diffraction, interference and double-slit experiment, model of the atom, uncertainty relations, wave function, and Schrodinger equations) for 6 weeks using the lecture method, while the same topics were taught to the experimental group, during the same time interval, using MAT (Appendix A) combined with another active teaching strategy defined with the steps of the engage and predict-observe-explain technique (Erdem & Uyanık, 2022). Quantum Physics Conceptual Survey (QPCS) consisted of 32 multiple-choice questions (provided in Appendix B) and was used for both pre-and post-tests.

In this study, the experimental group instructor was trained to use the engage-predict-observe-explain strategy while teaching with animation, simulation, and YouTube video to help the students learn the concepts of QP (Appendix A). The pre-test was given to all students from both groups before the instructors started teaching QP using the methods above. After 6 weeks of teaching, the post-test was also given to all participants to examine if MAT had some effect on students' performance in QP. To minimize the effects of the study design that advantage participants of the experimental over participants of the control group, remedial sessions using MAT were provided to all students who underwent into lecture method after data collection. This delayed treatment was offered to all participants of the control group by the instructor who taught the experimental group, and it took 2 weeks with 12 h of teaching per week.

Research Sample

This study was conducted in Rwanda at UR-CE, especially in the department of mathematics, science, and physical education (MSPE). In this department, the QP course is delivered to year two students from three different combinations, mathematics-physics-education (MPE), physics-chemistry-education (PCE), and physics-geography-education (PGE) combinations. The population of this study was second-year physics students from the above combinations. These students have already learned the course of modern physics in their secondary school and have prior knowledge in some topics of quantum physics, including blackbody radiation, photoelectric effect, Compton effect, wave aspects of particles, De Broglie's hypothesis, diffraction, interference and double-slit experiment, model of the atom, uncertainty relations). These concepts are also included in quantum physics courses which they study at a university. As the study was aimed at improving QP's teaching and learning, the study participants have been selected purposively by considering all undergraduate students who study QP in the department of MSPE. A group of 385 undergraduate students from MPE, PCE, and PGE combinations enrolled in the QP module was selected and later divided into two sub-groups, i.e., the experimental group (group A) with 193 and the control group (group B) with 192 students. The allocation of students in a group was done based on student registration numbers for each combination. For instance, in the MPE combination, a class list had 124 students; from number one, 62 students were allocated to group A, and students from number 63, up to 124, were allocated to group B. In the same line, in the PCE combination, a class list had 184 students; from number one, 92 students were allocated to group A, while from number 93, 184 students were allocated to group B. Also, in the PGE combination, a class list had 91 students, from number one up to 41, allocated to group A, while from number 42, up to 91 were allocated to group B. Furthermore, the available financial resources enabled obtaining data from the selected sample through analysis to interpretation.

Intervention Delivered

In this study, QP was delivered in two different classes named "traditional" and "multimedia" classes. In the traditional class, students were taught QP using conventional methods such as lectures, drawing, PowerPoint slides, writing explanations, and teacher demonstrations of laws or equations. The emphasis was on developing an understanding of the theoretical concepts of QP through explanation and solving exercises. Overall, both the multimedia and traditional techniques focused on developing a conceptual understanding of QP, but the methods and tools used to achieve this understanding differed. Students in the traditional stream had fewer opportunities to manipulate variables and interactively observe the outcomes. However, they still had the chance to discuss their understanding of the concepts with their peers and instructors.

In contrast, students in the multimedia class were engaged in learning the same QP topics using various multimedia tools, such as animations, simulations, and YouTube videos. They were able to manipulate variables and observe the outcomes more interactively and engagingly. Figure 1 shows the multimedia technologies used during instructions.

Active learning and knowledge development require the use of various strategies and techniques. The Predict-Observe-Explain (POE) strategy is one of the strategies. This POE method is widely used for effective concept teaching and improvement of academic outcomes (Boo & Watson, 2001; Ayvaci, 2013; Venida & Sigua, 2020). The study conducted by Furqani et al. (2018) show that POE has limitations, but they can be fixed by modifying the steps in POE by adding, removing or replacing one or some steps in POE to better suit the subjects. During its implementation, the teacher might want to consider what concept to be taught with POE strategy. In this line POE technique such as, Predict-Observe-Explain-Apply (POEA), Predict-Observe-Explain-Explore (POEE), Predict-Observe-Explain-Elaborate(POEE), Predict-Observe-Explain-Reflect and Predict-Discuss-Explain-Observe-Discuss-Explain (PDEODE) and Predict, Observe, Explain, Elaborate, Write, And Evaluate (POE2WE) have been regarded as a powerful teaching technique in science as well as physics education (Nana et al., 2014; Hilario, 2015; Abdullah et al., 2017; Supriatna et al., 2019). However, in this study, the researchers have improved and add another domain on POE, "engage," making a new name Engage-Predict-Observe-Explain-Explore (EPOE). The EPOE was used in multimedia classes where animation introduced a concept and engaged students in the lesson. Then, before manipulating the simulation or a video, students were given prediction questions to help them predict the experiment's outcomes. Then, the students manipulate the simulation, observe its results, and explain the lesson concept using their observations. Appendix C shows an example of multimedia class and lecture class content related to the photoelectric effect as one of the QP concepts taught during our intervention.

Instrument and Data Collection

Four conceptual surveys/tests relating to quantum physics and quantum mechanics courses were chosen from PhysPort Assessments to create the Quantum Physics Conceptual Survey used in this study. These comprised Quantum Mechanics Formalism and Postulates Survey (QMFPS), Quantum Mechanics Survey (QMS), Quantum Physics Conceptual Survey (QPCS), and Quantum Mechanics Concept

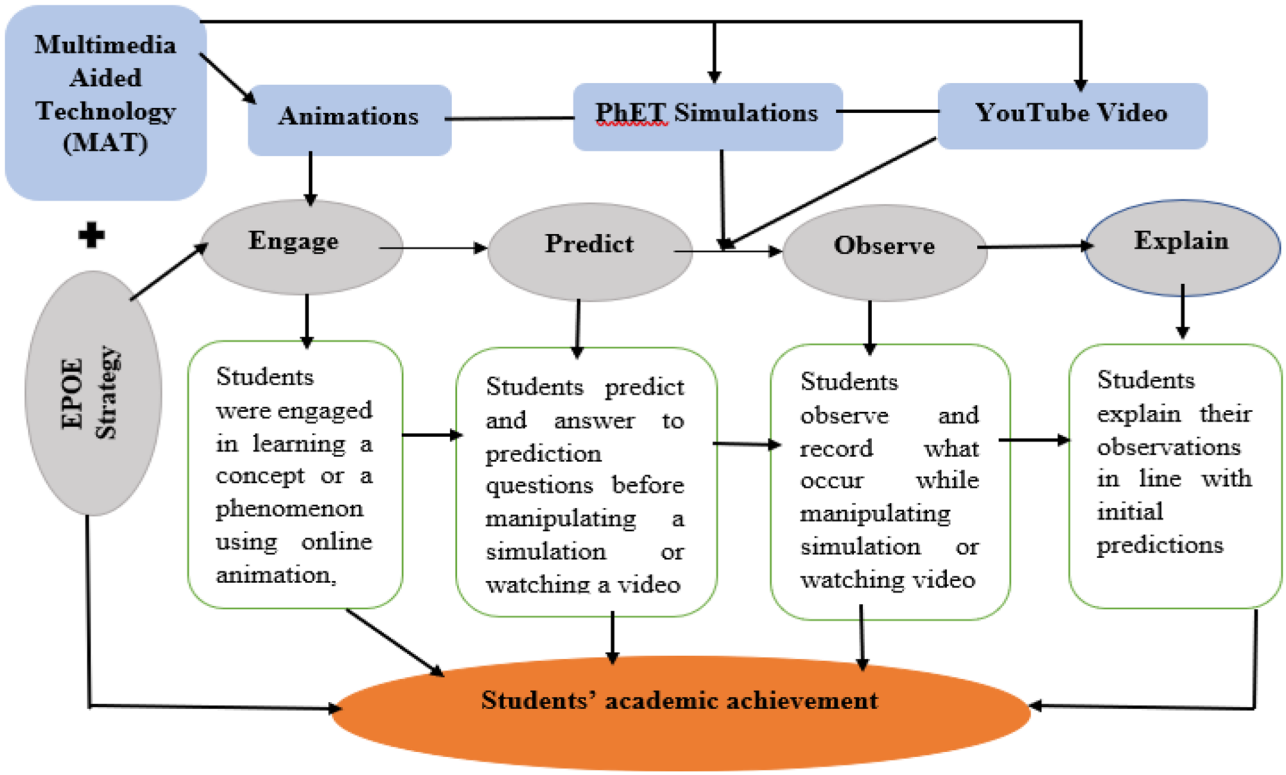


Fig. 1 Used intervention in multimedia group

Assessment (QMCA). Ten university academics teaching QP-related modules validated the test after being selected. Based on the validation report, one QPCS test was selected to cover 80% of the QP content taught at UR-CE. We created 36 items for the QPCS after adding six questions from the module to the QPCS questions to cover the remaining 20%. Four university physics educators who were not part of the study once again validated the content of this 36-item QPCS. We used a test–retest method to check the reliability and got a low Pearson correlation coefficient ($r = 0.280$) and a medium internal consistency (Cronbach alpha = 0.652).

We then checked the reliability of items and found that some items were invalid (the statistical significance to the total score was above the 0.05 alpha level). After removing four questions, we obtained a high Cronbach alpha coefficient (0.718) of 32 QPCS items (Smith et al., 2014). Therefore, from 36 questions, the pre-and post-tests consisted of 32 multiple-choice questions taken to the real study and analysis.

Analysis and Results

The Statistical Package for the Social Sciences (SPSS) software was used to compute the collected data. The study employed descriptive statistics to analyze the mean, median, variance, and standard deviation parameters. The researcher also used inferential statistics to test the formulated hypothesis. In this work, analysis of covariance (ANCOVA) was employed to analyze dependencies. It was used because it serves as a test to prove a presumed cause-effect relationship between the independent variables (MAT and lecture methods) and the dependent variable (students' performance). The first step of the analysis was data filtration, where all participants who missed either the pre-test or the post-test were removed from the control group (15 participants were removed) and the experimental groups (5 participants were removed). The total number for control group was 193, out of which 178 participants were considered for the analysis phase. The total participants for the experimental group was 192, out of which 187 were considered for the analysis phase. The test was marked on 32, after which the scores were calculated to percentages. The table shows the students' distribution in the pre-and post-test score range for both the control and experimental groups. The pre-and post-test columns indicate the percentage of students who scored within a specific range of scores. Please refer to Table 2 for more details.

It can be seen from Table 2 that the majority of students, 100% in both groups, are in the 0–30 score range before a teaching intervention (pre-test), while the situation changed after a teaching intervention (post-test), whereby 0% and only 14% students in both groups respectively are in 0–30 score range. While most students (96%) in the experimental

Table 2 Frequency distribution of scores in pre-and post-test for experimental and control groups

Scores	Multimedia group MAT and EPOE method		Control group lecture method	
	Pre-test (%)	Post-test (%)	Pre-test (%)	Post-test (%)
0–10 score	49	0	49	1
11–20 score	48	0	49	3
21–30 score	3	0	2	10
31–40 score	0	0	0	18
41–50 score	0	4	0	37
51–60 score	0	11	0	17
61–70 score	0	20	0	13
71–80 score	0	29	0	1
81–90 score	0	29	0	0
91–100 score	0	7	0	0

group are found in the 50–61 range score and above, only 31% are in the 50–61 score range for post-test. While students with the lowest score in the experimental group scored between 41 and 50%, the distribution in the control group showed that some students still got scores ranging between 0 and 10%. Thus, the MAT and EPOE gathered students between 41 and 100%, while the lecture technique gathered them between 0 and 80%. The preliminary analysis of score distribution confirmed that the assumptions to use ANCOVA were fulfilled. Our sample was above 30 participants, and the frequency distributions for our pre-test scores look plausible as their skewness (−0.3 to + 3) and kurtosis (−0.10 to + 10) fall in the standard range, as well as they both look reasonably normally distributed (see Fig. 2).

In a compromise, Levene's test of equality of error variances revealed a non-statistically significant difference ($p > 0.05$) between lecture and multimedia groups before learning QP. Therefore, parametric tests such as ANCOVA were appropriate to be used. Taking these into account homogeneity (the variance of the dependent variable must be equal overall sub-populations), Fig. 3 displays a homogeneity of regression slopes among all subpopulations.

Table 3 displays both groups' descriptive and inferential results before and after learning QP using multimedia and lecture methods. Sample, average score (mean), standard deviation, *p*-value, and partial eta squared are presented in both pre-and post-test columns.

The overall computed comparison revealed a statistical significance in *p*-values and effect sizes in partial eta-squared. One can see that the group's performance was the same ($p > 0.05$) before learning with no effect size (0.000), while they diverged after learning with different teaching interventions. The significance was very high and statistically different ($p < 0.001$) with a large effect size (> 0.5). Figure 4 exhibits the performance of QP among students in group A (multimedia group) and group B (lecture group).

Figure 4 highlights the change in average pre-test and post-test scores of students' performance in QP. The average score for both the lecture and multimedia groups was almost similar in the pre-test stage, while it significantly increased in the post-test stage. However, the average post-test score drastically increased for the multimedia group compared to the lecture group. Results clearly show the effectiveness of the MAT and EPOE techniques, which helped the experimental group students perform well in QP. As a result, the multimedia group had superior results than the lecture group students. However, the EPOE used in multimedia class allowed the students to be engaged with the use of animation, make predictions before running a simulation or a video, observe results after running a simulation or a video,

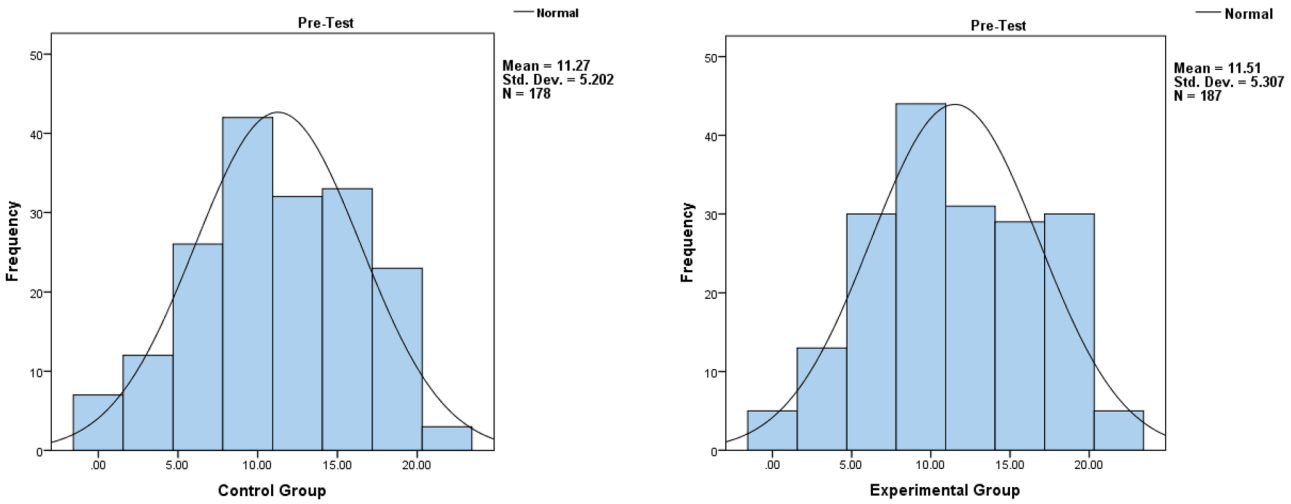


Fig. 2 Histogram of the pre-test score distribution of experimental and control groups

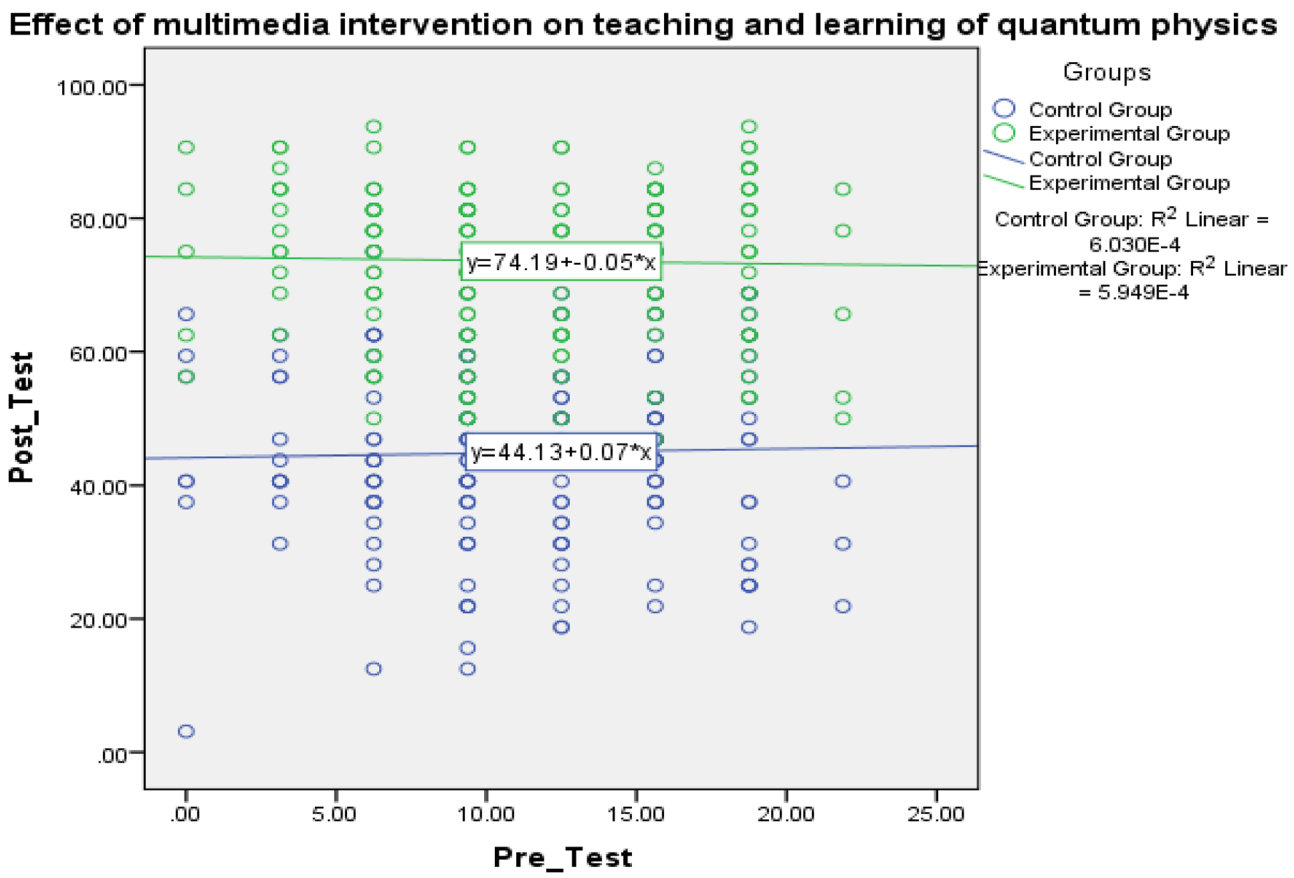


Fig. 3 Test for homogeneity of regression slopes

and explain them (an example was provided in Appendix B). This technique used in multimedia class provided opportunities for students to collaborate and discuss their understanding of the concepts with their peers and instructors. It also helps to resolve some common problems (misconceptions) among students while learning QP.

Table 3 Descriptive and inferential statistics results before and after intervention

Groups		Pre-test	Post-test
Group A (multimedia group)	Mean	11.5140	73.5963
	N	187	187
	Std. deviation	5.30679	11.15558
Group B (lecture group)	Mean	11.2711	44.8736
	N	178	178
	Std. deviation	5.20200	13.89424
Overall	Mean	11.3955	59.5890
	N	365	365
	Std. deviation	5.25014	19.08279
	p-value	>0.05	<0.001
	Partial eta squared	0.000	0.524

Discussion

Table 2 shows the output of test scores for lecture and MAT interventions. The test outcome exhibits a quiet improvement in the scores for the experimental group. The majority of the students in the control group got below-average scores compared to the experimental group students. Therefore, it can be analyzed that the combination of MAT and EPOE strategies helped the experimental group students achieve better QP academic achievement. As we wanted to know whether our groups were significantly different in their scores on the dependent variable (post-test), the *t*-test value calculated is $p<0.001$, which is less than 0.05. Therefore, we rejected our null hypothesis in favor of the alternative hypothesis. This implies that students taught with MAT and EPOE strategy (experimental group) outperformed those taught with lecture teaching methods (control group). Thus, our results showed that MAT and EPOE strategies positively affect students' performance of QP. Similar studies showed a positive effect on student performance due to animations (Mukagihana et al., 2021), web-based discussion (Iyamuremye et al., 2021), and computer simulations (Ndihokubwayo et al., 2020).

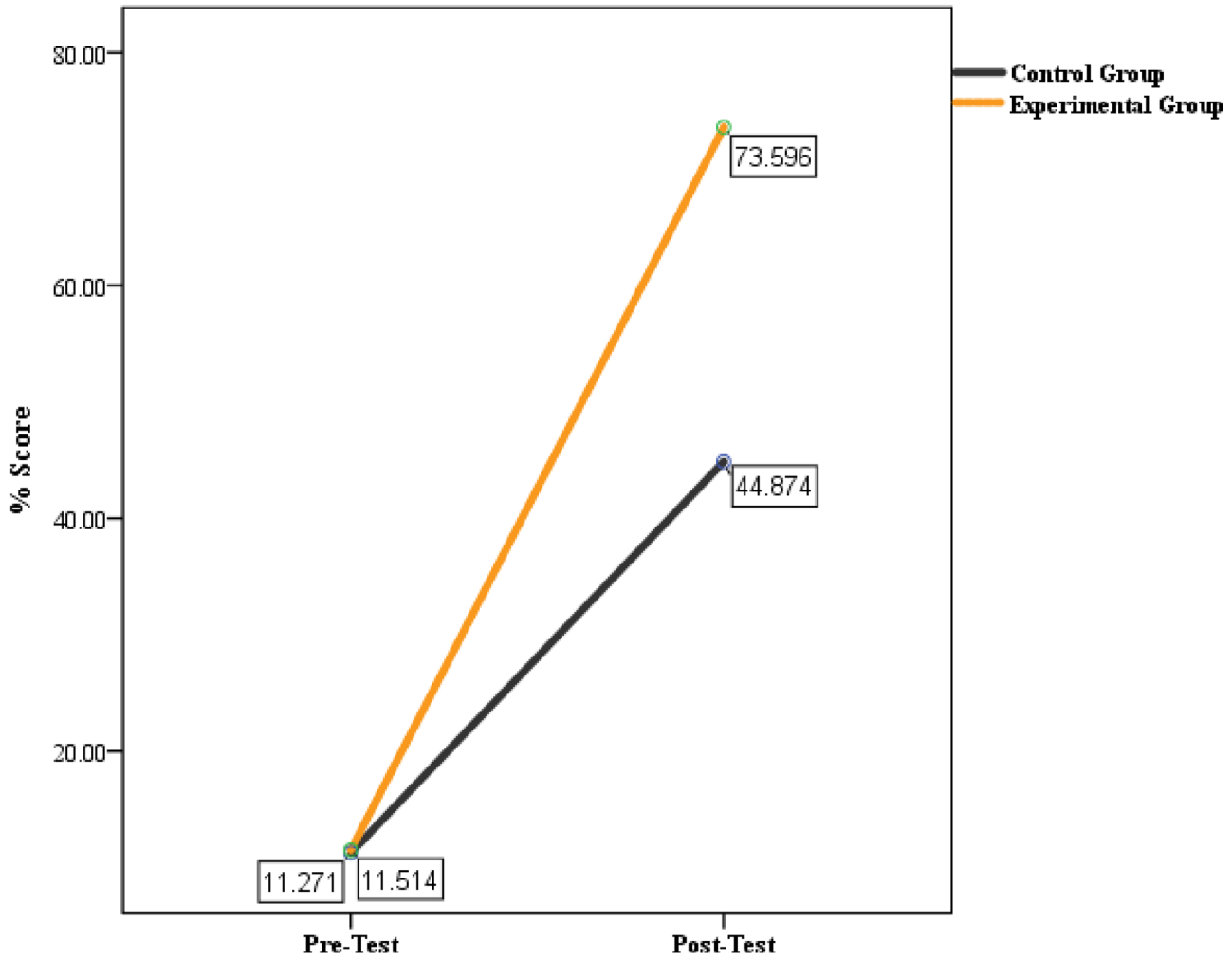


Fig. 4 Visualization of students' performance in both groups

Although the already carried out studies were conducted on elementary and secondary educational levels, our results agree with other researchers' findings (Čubrilo et al., 2014; Khan, 2015; Rusanganwa, 2013). For instance, Kohnle et al. (2014) conducted a study to understand multimedia resources for teaching QP in the classroom. They found that using animations in classrooms improves the conceptual understanding of the subject.

Also, Rusanganwa (2013) investigated the use of multimedia learning to explore the classroom environment in understanding physics and found that multimedia learning significantly impacts recalling the physics concepts taught in the classroom. Similarly, Khan (2015) demonstrated the effectiveness of multimedia-aided teachings on the students' academics and attitudes at the elementary school level. The study showed that multimedia-aided teaching is more effective than traditional teaching. Furthermore, Čubrilo et al. (2014) examined the influence of multimedia applications on the quantum theory and retention of concepts by students. The findings indicated that MAT increased students' quantum knowledge and recall of subjects compared to the conventional teaching method. The results showed that MAT enhances understanding of physics concepts and enhances teaching physics efficiency in the classroom. Thus, combining multimedia-aided teaching with the teachers' subjective and pedagogical knowledge helps in physics teaching and enhances the classroom's teaching positive effect on subject conceptual understanding and academic achievement (Jian-Hua & Hong, 2012).

A combination of MAT and EPOE strategies has proven effective in enhancing students' performance in QP, a complex subject that often requires visualizations and simulations. MAT helped students to visualize abstract concepts and see the behavior of subatomic particles, making the subject less intimidating and more engaging. Additionally, MAT can provide interactive learning experiences that allow students to manipulate variables and observe the outcomes, giving them a deeper understanding of the subject matter. MAT has also increased students' motivation and interest in QP, leading to better performance and a more enjoyable

learning experience. However, the obtained statistical parameters proved that MAT is more student-centric and can be combined with other teaching approaches to better understand concepts, demonstrations, and ideas and improve students' performance in QP.

Conclusions and Implications

This study assessed the effects of MAT on undergraduate students' performance in QP. The study employed a quasi-experimental study involving pre-and post-tests given to students in the control and experimental groups before and after the intervention. The study's results showed that MAT positively affects students' performance in QP. Students exposed to MAT and EPOE methods outperformed others in learning QP. It was also found that there is a significant difference between their performances. Various scholars have underscored the significance of the combination of the MAT and the EPOE approach in fostering improved scholastic performance (Radlović-Čubrilo et al., 2014; Hilario, 2015; Harman & Yenikalayci, 2022; Ilhan & Oruc, 2016). Understanding the fundamental principles of knowledge acquisition is crucial for effective pedagogy and optimal learning outcomes, particularly among students. These principles encompass the significance of prior knowledge, wherein new information is assimilated and integrated with existing cognitive frameworks to enhance comprehension and retention. Active engagement through problem-solving, discussions, and practical experiences promotes deeper understanding and the practical application of knowledge. The meaningfulness and relevance of information contribute to enhanced learning outcomes by establishing connections with personal experiences and recognizing practical value. Feedback plays a vital role in learning by providing timely and specific guidance for students to assess their understanding, rectify misconceptions, and refine their knowledge. Lastly, motivation and interest fuel effective learning, as students' enthusiasm and engagement drive them to invest effort, persist in learning, and achieve superior outcomes. Educators can optimize instructional strategies and foster an engaging learning environment by recognizing and applying these foundational principles.

This study is more important as it adds to the existing knowledge that combining MAT with the EPOE method contributes to better academic achievement in QP. Therefore, it provides insight to higher education and educators on the effectiveness of MAT usage in Rwanda and how it can be combined with other active teaching methods like EPOE to improve teaching and learning physics. Thus, we recommend that physics instructors adapt teaching using MAT and EPOE in QP and other domains of physics to improve active engagement, understanding levels, and academic achievement. In addition, Rwandan university instructors should be encouraged to use MAT in the education system. The prime limitation of the proposed study is that it did not discuss how lecturers felt about teaching QP using MAT and EPOE. Additionally, pre-service teachers from the College of Education were the subject of the study. It did not study the situation of learning QP in other colleges of the University of Rwanda. The study also was limited to only focusing on QP. It did not look at any other module to ease the comparison of branches of physics taught at the university level. The study only focused on the use of MAT combined to EPOE strategy. It did not look at other POE techniques such as predict-observe-explain-apply, predict-observe-explain-explore, predict-observe-explain-elaborate, and predict-observe-explain-reflect. Further studies may also look into effects brought by gender differences, school environment, students' attitudes, and instructors perceptions of using MAT and EPOE in teaching other branches of physics.

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Author Contribution All authors are major contributors to this study. The corresponding author conceived the study, designed the research instruments and conducted data analysis and manuscript writing. All co-authors revised and polished the manuscript. All authors read and approved the final manuscript.

Data Availability The datasets generated during and/or analyzed during the current study are available from the Mendeley repository: dataset from the UR-CE during learning QP (https://data.mendeley.com/datasets/gm49fmx86t/5, https://doi.org/10.17632/gm49fmx86t.5). Readers can view the raw data, replicate the study, and re-analyze and/or reuse the data (with appropriate attribution).

Declarations

Ethical Approval Trained masters students from the UR-CE supported in data collection from the participants. The research project successfully passed through the UR-CE ethical committee by following the established ethical process (University of Rwanda, 2022): (1) presentation of the research proposal, (2) submission of the application and tools to be used for ethical research clearance, and (3) review and approval of the application by the ethical research committee. Before data collection was initiated, ethical clearance was applied to and provided by the UR-CE research ethical committee.

Statement Regarding Research Involving Human Participants and/or Animals All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in this study.

Consent to Participate The ethical principle of informed consent was upheld for all research involving participants in this study. Before participation, all participants were provided with clear and comprehensive information regarding the study's purpose, procedures, and benefits. They were given ample time to ask questions and clarify any concerns before providing their voluntary and informed consent to participate. Participants were assured of their right to withdraw from the study without penalty. The consent form also specified the study results to be used in the publication. Confidentiality and privacy were maintained throughout the study, and all data collected were used only for the purpose of the study.

Consent for Publication Not applicable.

Competing Interests The authors declare no competing interests.

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