JOURNAL OF BALTIC SCIENCE EDUCATION

ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

STUDENTS' PERCEPTIONS OF MULTIMEDIA USAGE IN TEACHING AND LEARNING QUANTUM PHYSICS: POST-ASSESSMENT

Pascasie Nyirahabimana,
Evariste Minani,
Mathias Nduwingoma,
Imelda Kemeza

Abstract. *The research on students' perceptions after implementing a teaching style is recommended due to its potential to inform reformed education. The present study surveyed 319 students and revealed their perceptions of multimedia usage in teaching and learning quantum physics. Among these students, 156 were surveyed after learning quantum physics with a multimedia-aided method, while 163 were surveyed after learning with a lecture method. The piloting of the test used generated Cronbach alpha of .841 of internal consistency, and it contained quantitative Likert scale items and supporting qualitative items. The data were analyzed descriptively and inductively. Students taught by multimedia perceived quantum physics as easy, while those taught by lecture perceived it as difficult due to its abstractness and mathematics needs. Students preferred computer simulations, animations, and YouTube videos as interactive methods that fit quantum physics lessons. Students testified that a quantum physics course that uses visualization methods in some of its teachings is more interesting than a course taught without them. However, students in both classes concurred that their class was student-centered and full of demonstration. Recommendations related to teaching practices and future research foci were made.*

Keywords: *lecture method, multimedia-aided method, student perceptions, quantum physics, Rwanda*

Pascasie Nyirahabimana, Evariste Minani, Mathias Nduwingoma
University of Rwanda, Rwanda
Imelda Kemeza
Mbarara University of Science and Technology (MUST), Uganda

Introduction

The literature currently available on teachers' and students' experiences with quantum physics education primarily concentrates on the graduate level. It is asserted that the attitudes and approaches of university lecturers towards quantum physics are shaped by the belief that the main objective of quantum physics courses is to ensure that students acquire the mathematical formalism connected with quantum physics to prepare them for physics research (Siddiqui & Singh, 2017). While learning quantum physics, students met with difficulties such as the inability to differentiate between energy eigenstates and eigenstates of other physical observables. Students could not identify the measured value, the probability of measuring it, or the expectation value. In short, students struggled to determine the time evolution of wave function after the measurement (Zhu & Singh, 2012). Similarly, some researchers find that many students find quantum physics a challenging subject because it is abstract, counterintuitive, and heavily mathematical. They only take it as a requirement to pass the curriculum. Additionally, they have demonstrated that due to the nature of quantum physics, teachers struggle to teach it because it is difficult for students to understand (Prabavathi & Nilufer, 2015; Wattanakasiwich, 2005). Therefore, students do not have the qualities of being good at quantum physics since they are limited by the many calculations involved in this course. As the authors argue, this limitation may result in negative consequences for physicists and physics education in general (Johansson et al., 2018). Research conducted on the teaching and learning of quantum physics explored difficulties that students meet while learning this course. The abstractness of quantum physics was reported to be one of the factors that make this content difficult for undergraduate students (Bouchée et al., 2021). The quality of future professional training of physics teachers presumes its emphasis on the modern laws of physics and the instructional practices needed for an effective teaching and learning process within higher learning institutions (Matjanov, 2021).

https://doi.org/10.33225/jbse/23.22.37

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Educators and researchers carried out much research to convince the world that technology does not only contribute to delivering information but also to enhancing education (Bouchée et al., 2021; Senan et al., 2016). The importance of interactive multimedia in enhancing teaching and learning physics is well-known worldwide (Munfaridah et al., 2021). However, few studies critically evaluated students' perceptions toward these multimedia in terms of their importance, acceptability, and suitability to enhance students' achievement while teaching and learning physics in general and quantum physics in particular (Bennett & Brennan, 1996). Indeed, educating the generations of physicists goes hand in hand with attracting good students, using teaching methods that will ensure that they remain at the university and increase their enrolment within the institution (Johansson et al., 2018).

The students found quantum physics challenging to understand, necessitating the use of visualization methods and other media to fully grasp the complicated concepts and mathematical issues in quantum physics (Kohnle et al., 2015). Therefore, offering a different and most appropriate educational method while teaching quantum physics is crucial to help students understand the material. The most effective teaching method should accommodate the students' diverse needs. As a result, computers equipped with multimedia approaches can offer a different type of method that will help students better understand quantum physics content. However, studies have shown that students learn actively and get interested in computer-based teaching methods (Nzaramyimana et al., 2021). In addition, Nkurikiyimana et al. (2022) stressed that students increase their understanding of physics concepts through strong interactive activities and multimedia. Thus, there is a need to study strategies used while teaching quantum physics (Krijtenburg-Lewerissa et al., 2017), where students' perceptions about the teachers' used methods come in.

In recent years, educational sectors in Rwanda have been interested in knowing how computers and the internet can best be utilized to increase educational effectiveness and efficiency at all levels of education. Hence, multimedia has become a handmaiden for learning activities. Georgiou and Sharma (2015) reported that multimedia learning helps improve physics learners' achievement. Both teachers, as well as students, showed positive opinions toward using multimedia learning. In this context, this research was carried out to collect students' views about the teachers' use of multimedia in teaching quantum physics at the University of Rwanda College of Education (UR-CE). The findings from this study will shed light on how undergraduate students value the effectiveness of teaching methods exposed to them and how they are taught quantum physics under those methods. Thus, the findings from this study will help lecturers effectively use multimedia while teaching and learning physics in general and quantum physics in particular toward students' performance and interest in learning.

Literature Review

Quantum physics is a part of the physics curriculum that studies the physical phenomenon at microscopic and atomic levels and considers the dual behavior of matter. Different studies have identified that learning quantum physics is challenging for students (Chhabra & Das, 2016; Henriksen et al., 2014; Lin & Singh, 2010; Mason & Singh, 2010). The studies exhibit that students often have difficulties in understanding the nondeterministic nature of quantum phenomena. The research conducted by Akarsu on students' understanding of quantum physics shows that quantum physics challenges students' conceptual understanding. He argued that undergraduate students at Erciyes University in Turkey experience conceptual difficulties and misconceptions in quantum physics courses (Akarsu, 2010). Although the current teaching practices at UR-CE may not provide a holistic understanding of quantum physics concepts and principles (Nyirahabimana et al., 2022). The study done by Dokuz Eylül University in Izmir, Turkey on student ideas about some concepts in quantum physics and quantum phenomena shows that students manifest problem in the concepts of the electron, wave function, wave-particle duality and structure of atom (Bilal & Erol, 2007).

Today it is important to understand that visualization methods such as demonstrations, simulations, models, graphs, films, animations, videos, and other applets can help educators and students understand and study quantum physics concepts and phenomena much better. Different 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 (Akarsu, 2010; Jian-hua & Hong, 2012).

Effectiveness of Using Multimedia in Teaching and Learning Physics

Literature showed that multimedia positively impact physics education in general and quantum physics in particular (Bouchée et al., 2021) when class is conducted traditionally. For instance, Munfaridah et al. (2021)

https://doi.org/10.33225/jbse/23.22.37

conducted a systematic review of multiple representations in undergraduate physics education and found that multimedia can be used effectively in teaching physics at university. Munfaridah et al. (2021) added that multimedia could enhance students' understanding of the concepts and enable them to solve the general and individual problems. In the study conducted on physics when embedding multimodal representations, Gunel et al. (2007) compared the two writing formats; presentation format against summary report format. The authors used a quasi-experimental study with students in six pre-existing physics classes. After that, students were exposed to multimodal representations such as text, mathematical, graphical, and pictorial within the body of the presentation format (PowerPoint) for students in the control group; the results revealed that students who were exposed to multimodal representation outperformed their counterpart students who used summary report format. Similarly, while discussing the use of pedagogical technologies in teaching quantum physics, Matjanov (2021) argued that when students are exposed to the theoretical part of quantum physics, they should be taught based on the design of the technology in use.

Students' Perceptions of the Use of Multimedia while Learning Quantum Physics

The results from the study revealed that the use of multimedia was in a valid category for each category of pedagogy aspect (Widyaningsih et al., 2020). Students gave positive responses concerning enhancing students' HOT abilities in terms of analyzing, evaluating, and creating. It was therefore concluded that multimedia-oriented instructions could be used in physics education. Similarly, in the study on interactive multimedia learning physics, Bennett and Brennan (1996) used pre-and post-test questionnaires, using scaled and open answers for 35 students. For the results from the study, students showed high acceptability of interactive multimedia use.

In the study conducted on enhancing students learning of two-level quantum systems with interactive simulations, Kohnle et al. (2015) used a survey questionnaire after teaching students using simulations. The results analysis showed that students perceive simulation as a helpful tool that enhances their conceptual understanding and active learning. In addition, while investigating students' perceptions and behavioral intention to use multimedia teaching methods, Laosethakul and Leingpibul (2021) used three common multimedia teaching methods: the lecture, the video-based tutorial, and the paper-based tutorial. Laosethakul and Leingpibul (2021) intended to capture students' perceptions about using these three teaching methods. The feedback revealed that students perceived the instruction of video-based tutorials as enhancing their understanding and ease of following the lesson.

Furthermore, while carrying out a study on enhancing student learning of two-level quantum systems with interactive simulations, Kohnle et al. (2015) used a quasi-experimental study whereby the control and experimental groups were exposed to superposition states and mixed states simulation, respectively. Twenty students, in total, completed the pre-and post-test. The results analysis showed that the use of simulation improved students' performance in quantum mechanics of undergraduate students in favor of those students in the experimental group. Also, these students perceived that multimedia facilitated their learning of quantum physics.

Pospiech (2019) analyzed how students view the use of metaphors for describing the concepts of uncertainty and entanglement in teaching quantum physics. Students believe that quantum physics must be deeply explained and mirror as precisely as possible the physical relations to prevent the occurrence of students' misconceptions. Pospiech (2019) used an attitudinal questionnaire to collect data from 18 students. The results from the study showed that since quantum physics is linked to students' mathematical and physical experience, the teachers' use of unusual metaphors can be an added value in supporting the use of visualization.

Research Gap to be Filled

Few enrolments of students that take physics as a major subject in higher learning institutions may be linked to students' perceptions and attitudes. This assumption implies wondering how much students perceive and value the way they are taught quantum physics (Bennett & Brennan, 1996; Moraga-Calderón et al., 2020). Although studies showed that there are positive effects on the use of multimedia, a deep comprehension study about students' perception of the use of multimedia in physics education while learning quantum physics, especially for undergraduate students, is still missing (Krijtenburg-Lewerissa et al., 2017; Munfaridah et al., 2021). This gap in the literature motivated us to conduct this study to explore students' perceptions of multimedia usage in teaching and learning quantum physics at the University of Rwanda, College of Education (UR-CE).

https://doi.org/10.33225/jbse/23.22.37

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Building on a pre-assessment survey by Nyirahabimana et al. (2022), this study explored student teachers' perceptions regarding the effectiveness of the multimedia method on the teaching and learning of quantum physics. The study sought answers to the following research questions:

i. Which concepts of quantum physics are perceived to be difficult for students?
ii. What are students' perceptions regarding the effectiveness of the multimedia method in the teaching and learning of quantum physics?
iii. What are students' recommendations for teachers regarding using multimedia method in teaching quantum physics?

Research Methodology

Design

The present study is the third phase of a PhD research work which used a quasi-experimental and survey research design to study the use of multimedia in teaching and learning Quantum Physics at UR-CE. A baseline study of this PhD project was conducted in the first phase. It assessed the impact of current teaching methodologies and teaching staff and students' perceptions of quantum physics for a quality knowledge delivery system using a quantitative data collection method. The second phase used a quasi-experimental research design that targeted 385 second-year students who were taught quantum physics module using two different teaching methods. These students were allocated into two groups (control group or lecture class and experimental group or multimedia-aided class). Students in the control group (192) learned eight quantum physics topics using the lecture method. In contrast, the experimental group (193 learned the same topics using multimedia applications for six weeks. After learning quantum physics concepts, students participated in a study, which used a survey research design to assess students' perceptions of multimedia usage in teaching and learning quantum physics at UR-CE. This survey used a mixed (both quantitative and qualitative) data collection method.

Participants

The study focused on students from the Department of Mathematics, Science, and Physical Education at UR-CE. In this department, 385 undergraduate students studying quantum physics who were enrolled in Mathematics-Physics-Education (MPE), PhysicsChemistry-Education (PCE), and Physics-Geography-Education (PGE) combinations were purposively selected to participate in the study. These participants were randomly divided into two groups: a control group (n = 192) that attended lecture class and an experimental group (n = 193) that attended multimedia class. The UR-CE (Ethical Committee) provided ethical clearance and approved a formal informed consent form which was completed by every student participating in the study. A group of 319 out of 385 undergraduate students who have completed the learning of quantum physics using either lecture or multimedia application methods were accepted to sign a consent form and participated in post assessment. The participants for post assessment were also allocated to the experimental group with 163 and to the control group with 156 students. To collect data online attitude quantum physics test was administered, and each group had its own link for the test.

Instrument and Procedures

The evaluation Questionnaire for Computer Simulations (EQCS) developed by Chou (1998) was adapted to the context of this study and used in data collection. The questionnaire used was adapted based on the literature review, daily teaching experiences, and students' group discussions. A student survey questionnaire of 29 questions was adapted and formulated. Five university researchers, experts in science education, agreed to validate the content of this questionnaire. Based on the validation report, eight items were removed from the questionnaire, and the remaining questions represented the final Quantum Physics Attitude Test (QPAT) for students (see Appendix A). The researchers piloted the QPAT on a sample of 30 students from the University of Kibungo (UNIK), Rwanda, to establish whether the adapted instrument would give similar results in a Rwandan context. A medium level of reliability, with a coefficient alpha of .841 was found. The closed questions of QPAT used in the baseline study were conducted to determine the prime indicators of current teaching methodologies and students' perceptions of quantum physics

https://doi.org/10.33225/jbse/23.22.37

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

at UR CE (Nyirahabimana et al., 2022). To answer the research questions of this study, the researchers preferred to collect both quantitative and qualitative data. Therefore, the "why" question was added to QPAT to get opinions and ideas from respondents anticipated to support quantitative data collected using closed questions of QPAT. The next step consisted of data collection using an adapted QPAT. During this step, 163 students from the control group and 156 students from the experimental group participated in an online survey.

Data Collection Procedure

In this study, both primary quantitative (numbers) and qualitative (texts) data were collected using an online survey questionnaire composed of closed and open questions. The researchers used Google Forms to design this online survey questionnaire. Using a google drive form to administer the materials for this study had several advantages. It allowed many students (319 students) from authentic lectures and multimedia courses in quantum physics to be surveyed. All students completing the survey questionnaire studied eight topics: Blackbody radiation; the Photoelectric effect; the Compton Effect; the Bohr model of the atom; the De Broglie hypothesis; the Bohr correspondence principle; uncertainty relations, and Schrodinger equation using animations, simulations, and video or by using lecture method. Appendix B shows some examples of lectures and multimedia content. As these students were allocated to control and experimental groups, each group got its link and was asked to access it and answer the survey questionnaire. A consent form on the opening page informed students that the study took between 15 and 20 min to complete and was completed individually; answers to the survey would be kept confidential; anonymity would be used in data analysis as well as presentation, and participation in the study was voluntary and that they could withdraw at any time with no penalty. The researchers agreed with a participant who agreed to participate in the study on the date, starting and ending time for the survey, and data were downloaded as an excel sheet with responses to all questions of the survey. These data are available on the following link: https://data.mendeley.com/datasets/gm49fmx86t/5

Data Analysis

In this study, data were analyzed using MS Excel 2016. Data were transferred from a CSV file (from an online google form) to an EXLS file. Data were filtered by arranging data that had the same characteristics. For instance, the items related to the Likert scale were analyzed from one sheet, and test data (reason-based items) were analyzed on a separate sheet. "CountIf" function was used to compute the number of respondents that selected one of the scales. Since most of the items that were rated on the Likert scale had 5-point Likert scale (strongly agree, agree, neutral, disagree, and strongly disagree), the researchers opted to narrow down these levels to three during analysis to make numbers more readable. These levels became agreement (by combining) the first two levels, neutral (stayed as it was), and disagreement (by combining the last two levels). The same analysis can be found in Musengimana et al. (2021) study. To analyze supporting qualitative data, mostly on third research question, the paper-based method was used, and descriptive analysis was employed (Orodho et al., 2016).

Research Results

Students Perceived the Concepts/Components of Quantum Physics as Difficult

Students' perceptions of quantum physics concepts differed from those taught by lecture and multimedia-aided instruction. Most of the students in multimedia class perceived that all quantum physics concepts were easy because their lecturer used the visualization method. Some students still claimed that the Bohr correspondence principle, Uncertainty relations, and Schrodinger equation were difficult to understand because of abstractness and their mathematical needs. However, many students perceived all quantum physics topics as difficult in a lecture class. The utmost reason for this answer was the abstractness of these topics. Many students (84) also said that the Schrodinger equation was complicated because this topic is too mathematical (see Table 1).

https://doi.org/10.33225/jbse/23.22.37

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Table 1
Number of Students who Selected each Quantum Physics Topic as Easy or Difficult in both Multimedia and Lecture Class

	Students in Multimedia Class					Students in Lecture Class				
	Easy to understand	Difficult to understand	Easy, because my lecturer used visualization methods and explained them well	Difficult due to the abstractness of this topic	Difficult because this topic is too mathematical	Easy to understand	Difficult to understand	Easy, because my lecturer used visualization methods and explained them well	Difficult due to the abstractness of this topic	Difficult because this topic is too mathematical
Blackbody radiation	37	0	117	0	0	17	31	0	96	8
Photoelectric effect	31	0	124	0	0	20	37	14	86	1
Compton Effect	40	2	114	0	0	30	34	2	88	3
Bohr model of the atom	33	1	122	0	0	31	37	2	77	1
De Broglie hypothesis	36	4	114	0	0	25	42	3	79	9
Bohr correspondence principle	34	8	110	2	1	19	37	0	69	2
Uncertainty relations	27	11	103	5	2	17	53	0	73	13
Schrodinger Equation	22	18	91	8	10	1	29	0	48	84

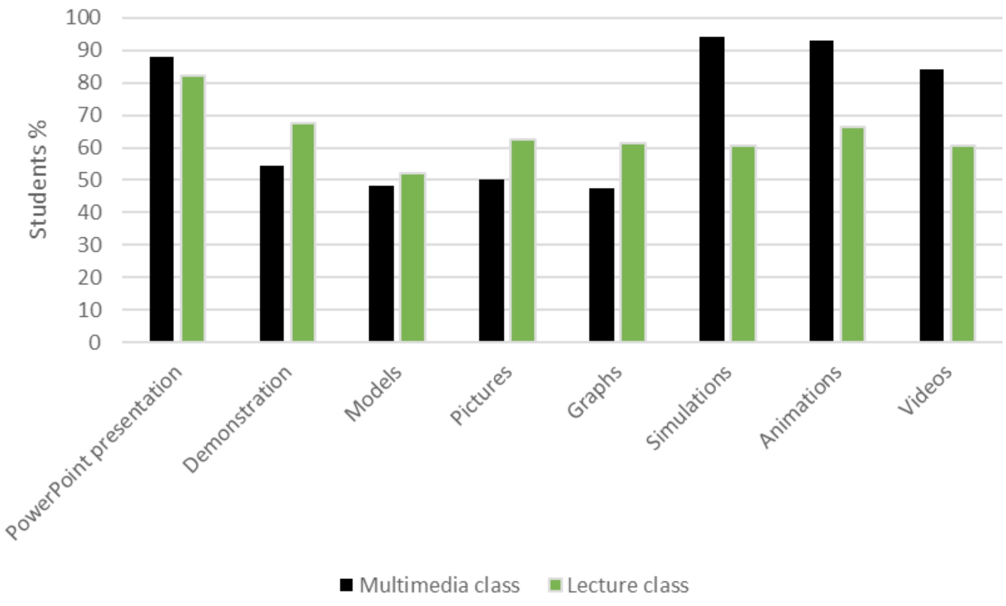
Students' Perceptions regarding the Effectiveness of the Multimedia Method in the Teaching and Learning of Quantum Physics

The visualization methods commonly used in quantum physics lessons noted by more than 50% of students in both multimedia and lecture classes were found to be PowerPoint presentations, demonstrations, pictures, simulations, animations, and videos. Surprisingly, students in lecture class noted that they learned with simulations, animations, and videos. They probably misunderstood the question or used multimedia tools and other online resources while revising their lessons in their spare time out of the classroom. This can be, for example, one of the reasons they testified about learning with simulations, animations, and videos. In fact, lecture classes did not use them. It can be noted that the multimedia class testified to the use of simulations, animations, and videos more than the lecture class testified. A PowerPoint presentation was used in both classes. Demonstration, models, pictures, and graphs were more testified by the lecture class than the multimedia class (see Figure 1).

https://doi.org/10.33225/jbse/23.22.37

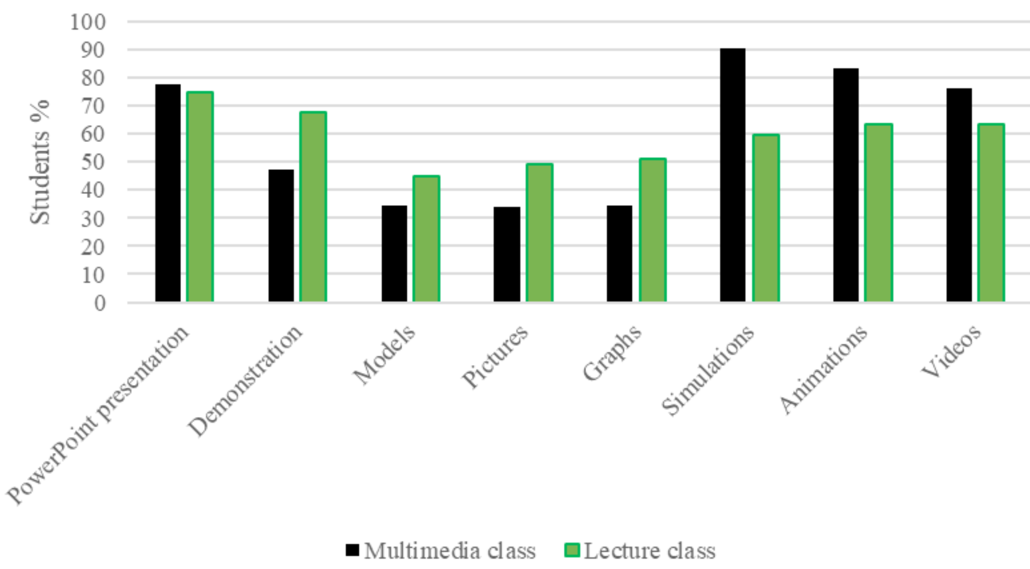
ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Figure 1
Visualization Methods Commonly Used in Quantum Physics Lessons



Likewise, the visualization methods in quantum physics lessons mostly preferred by more than 50% of students in multimedia and lecture classes were PowerPoint presentations, simulations, animations, and videos. Like methods used, the preferred methods were simulations, animations, and videos of the side of students that learned through multimedia. In contrast, students who learned through the lecture method preferred demonstrations, models, pictures, and graphs.

Figure 2
Visualization Methods Mostly Preferred by Students to be Used in Quantum Physics Lessons



https://doi.org/10.33225/jbse/23.22.37

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

College Students' Feelings toward Learning Quantum Physics

While most of the students that were taught using multimedia-aided method agreed on almost eight statements related to feeling toward learning quantum physics, students that were taught using lecture instruction disagreed (Table 2).

Table 2

Percentage (%) of Students from both Multimedia and Lecture Class Who Agreed and Disagreed with the Statements Related to Feeling of Learning Quantum Physics

	Students in Multimedia Class			Students in Lecture Class		
Statement	**Agreement**	**Neutral**	**Disagreement**	**Agreement**	**Neutral**	**Disagreement**
I enjoy learning QP concepts.	92	6	1	44	7	49
I feel I understand QP.	79	17	3	40	8	52
I use my free time to read books, do research, and do exercises related to QP.	89	8	3	40	7	53
If I am stuck on QP exercises, I usually try to figure out a different way that works.	80	15	4	36	12	52
Although QP is abstract in nature, the way my lecturer taught it, I found it easy to approach it.	91	6	3	39	12	49
Although QP is too mathematical, the way my lecturer taught it, I found it easy to approach it.	80	13	6	43	9	48
Due to how I learned QP, I am confident I will have to teach it in my future career.	93	6	1	45	1	54
As a future physics teacher, I will be able to answer student questions on QP while teaching this course.	95	4	1	37	8	55

Some of the questionnaire statements used for the qualitative part of the study are analyzed below:

1. I enjoy learning quantum physics/mechanics concepts.

Students in the multimedia class enjoyed learning quantum physics because the lecturer used computer simulation and animations to explain the concepts in the module. For instance, one student testified that he enjoyed it because it helped him to know the failure of classical mechanics, *"he said that animations and simulations helped me to think about the reality of small particles like atoms and then understand the origin of Quantum mechanics*. Another student said, *"I enjoyed learning QP because I totally like the way simulation and animation were used." "During lesson delivery, the lecturer solved all misconceptions which are in quantum physics by using some models, animations, and simulation; all these encouraged me to enjoy QP."*

While students in the multimedia class enjoyed learning quantum physics due to the method used, students in the lecture class claimed that quantum physics is still so hard, very difficult to understand, and it is too mathematical. Students compromised that the concepts such as the photoelectric effect, black body radiation, and Compton effect would be understood if the simulation had been used and the formula used would have been proved. Students said, *"I did not enjoy it because some topics, like the Schrodinger equation, are very difficult." "Teaching method of quantum is poor."*

https://doi.org/10.33225/jbse/23.22.37

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

2. I feel I understand quantum physics/mechanics.

Students in multimedia class confirmed that they mastered quantum concepts such as black body radiation, photoelectric effect, Compton effect, Bohr model of the atom, de Broglie hypothesis, and Bohr correspondence principle more than how they studied in secondary school. One student said, *"I really know where the atom comes from and different concepts related to atoms such as protons, electrons, nucleus, and neutrons! I understand well the blackbody and how it works, the Compton effect and the photoelectric effect; I really know how light behaves."*

While students in multimedia class testified that they understood the module, those in lecture class still hesitated that they did not understand it because some equations, including time-dependent and time-independent Schrodinger equations, are more complicated, and how it is being taught was not effective.

3. I use my free time to read books, watch videos, research, and do exercises related to quantum mechanics.

Students in multimedia became motivated to learn by doing research and reading books. Students research to understand quantum physics well and gain many skills about it. They tried to use online courses to search for more information related to quantum physics. Students know that a book is an extra source of information that helps them understand the lesson well. One student provided an example of a book: Optics and Introduction to Modern physics module which was written by Dr. Lakhan Lal Yadav and Dr. Evariste Minani" (Yadav & Minani, 2011). "Student said, *"because in my free time I was used to reading a different book of quantum physics, one of them is 'Optics and Introduction to Modern physics"*

4. If I am stuck on Quantum Physics exercises/problems, I usually try to figure out a different way that works.

Students in multimedia class appreciated using videos, animations, and simulations to overcome being stuck on QP exercises. Students in lecture class were reluctant to solve quantum physics exercises too. They said that the questions related to this module are complicated. They concur that many formulas and alternatives must construct answers in physics because some exercises seem complicated. However, some students got different strategies, such as working in groups. For instance, one student said, *"because some problems were very difficult. To handle this, I used to join with others to achieve the solutions." They also concur that m*any exercises help in more understanding, while others are discouraged. One student said, *"it is not easy to get the answer; sometimes I get bored due to its complexity." "I try to solve the related problem by referring to the other one I solved previously but do not have much capacity to solve new problems."*

5. Although quantum mechanics is abstract in nature, due to the way their lecturer taught it.

Contrariwise, students in lecture class claimed that quantum physics contains a complicated formula, especially Schrodinger equations. They said that some topics, like Schrodinger equations, are not applicable in real life, and the learning approach used was not effective. Students raided the following thoughts, *"I don't know if it's my low capacity, but the way he taught it didn't convince me to do it. Although quantum mechanics is abstract in nature, the way their lecturer taught it was not right because learners did not participate enough in delivering the lesson."*

6. Although quantum physics is too mathematical, the way my lecturer taught it, I found it easy to approach it.

Students in multimedia class concurred that the lecturer tried to make QP easy through some moving images and discussion in a class by sharing ideas with students. They believed that Mathematical calculation is still problematic, but they have confidence that it will be easy as they continue to read and do exercises. Students claimed that their lecturer quickly taught them mathematical concepts such as the Schrodinger equation. One student said, *"although she proved all formulas, Schrodinger's equation needs a lot of mathematics, which is very difficult to understand."*

Students in lecture class believed that the Schrodinger equation was not easy to calculate; they did not understand it well due to the lack of demonstration and because they don't have a good mathematical background

https://doi.org/10.33225/jbse/23.22.37

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

from secondary school. These students showed fear of mathematics. One student said, "when it is mathematical, everything becomes difficult." "Not easy to approach because I do not understand mathematics well; there are many calculations and formulas." However, other students contributed such failure to the instruction used. One student believed that without using concrete examples, methods of discovering, process approach, etc., he found QP difficult to approach.

7. Due to the way I learned quantum physics, I am confident that I will have to teach it in my future career.

Due to the way students in lecture class learned QP, they are not confident that they will have to teach it in their future careers. They are not satisfied with the Schrodinger equation; they do not score it at a higher level and are not good at this module.

8. As a future physics teacher, I will be able to answer students' questions about quantum physics while teaching this course.

As future physics teachers, students in the multimedia class will be able to answer questions about QP while teaching this course because they have been trained well and studied how to answer students' questions even when the context is hard. While students in multimedia do not fear answering quantum-related questions during its teaching in the near future, students in lecture class believe that they will not be able to answer students' questions about QP while teaching this course because quantum is complicated and its concepts present difficulties to tackle. However, few students believe they will allow their students to ask any questions related to quantum physics while teaching because they will do research.

Student Teachers' Recommendations Regarding the Usage of Multimedia Methods in Teaching Quantum Physics

While students that learned using multimedia-aided instruction appreciated the use of visualization, those who learned using lectures perceived it as low action; for instance, 97% of students from multimedia class, alongside 42% of students from lecture class, agreed that they liked and enjoyed learning from visualization methods. Contrariwise, students in both classes preferred that their lecturer would use a student-centric approach and demonstration in teaching QP. For instance, 93% of students from multimedia classes, alongside 84% of students from lecture classes, confirmed that their lecturer uses a student-centric approach to teaching QP (see Table 3).

Table 3
Percentage (%) of Students from both Multimedia and Lecture Class who Agreed and Disagreed with the Statements-related to Feeling of Learning Quantum Physics

	Students in Multimedia Class			Students in Lecture Class		
Statement	Agreement	Neutral	Disagreement	Agreement	Neutral	Disagreement
Student perceptions of multimedia usage in teaching and learning quantum physics (QP)						
I like and enjoy learning from the visualization methods	97	1	2	42	7	51
QP course that uses visualization methods in some of its teachings could be more interesting than a course taught without using them.	96	3	1	32	11	58
Learning with multimedia can improve my understanding of how theories of QP can explain the physical observation.	97	1	1	37	7	57

https://doi.org/10.33225/jbse/23.22.37

	Students in Multimedia Class			Students in Lecture Class		
Statement	**Agreement**	**Neutral**	**Disagreement**	**Agreement**	**Neutral**	**Disagreement**
Student perceptions of multimedia usage in teaching and learning quantum physics (QP)						
Learning multimedia can improve my ability to solve new problems in QP by using basic principles and concepts.	98	1	1	36	13	51
Visualization methods increase my understanding and appreciation of QP concepts.	99	1	0	39	13	48
The use of visualization methods increases my motivation and interest in learning the QP part.	94	3	4	35	18	47
Student perceptions of the teaching methodologies used in quantum physics (QP) teaching						
My lecturer used the teacher-centric approach to teach QP	3	4	92	13	1	86
My lecturer used a student-centric approach to teaching QP	93	4	3	84	2	14
My lecturer used the demonstration approach to teach QP	93	4	3	86	1	13
My lecturer used the conventional-cum-demonstration method to teach QP.	3	7	90	16	2	82

Discussion

This study provides students' perception of the usage of multimedia to learn QP. The study provides information on how QP is taught. The analysis compared students' views, those in a multimedia class and those in a lecture class. Through triangulating findings, students in multimedia class reported that they enjoyed learning QP when multimedia was used. However, students in lecture class claimed that learning QP remains abstract, thus making it difficult to learn it. The use of multimedia has been an effective tool since this learning technology makes a significant difference in making the QP concepts more understandable through visualization.

The study was not limited to valuing the usage of multimedia but also reported on students' perceptions about how these undergraduate students were taught. Exposing students to a different form of content delivery rather than relying only on lecture teaching methods enhances students' conceptual understanding. The visualizations include power point presentations, demonstrations, models, pictures, graphs, simulations, animations, and videos. For instance, Kohnle et al. (2015) found that students perceived the use of simulation to enhance their conceptual understanding and active learning. Similarly, Leingpibul (2021) emphasized the use of three common multimedia teaching methods: the lecture, the video-based tutorial, and the paper-based tutorial to his students' QP. However, Ndihokubwayo et al. (2020) reported that instructors still rely on textbooks and syllabi, and they forget the affordance of multimedia use, such as using PhET simulations and YouTube videos which would improve the teaching of physics. These results relate to ours in way that they compromise on the relationship between understanding of learned concepts and students' positive perceptions.

The quantum physics' abstractness makes this topic difficult for undergraduate students (Bouchée et al., 2021), as also claimed by undergraduate students in this study. However, multimedia has the potential to increase students' confidence, motivation, and performance through the visualization of QP concepts. The visualization of the concepts refers to the use of videos that clearly present physical phenomena. Indeed, Laosethakul and Leingpibul (2021) also argued that students perceived the teaching method of video-based tutorials as a tool to enhance their understanding and interest in following the lesson. Similarly, Kohnle et al. (2015) confirm that simulation improves

https://doi.org/10.33225/jbse/23.22.37

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

students' performance in quantum mechanics of undergraduate students. However, students have challenges related to mathematical calculations that may hinder their understanding. Pospiech (2019) also explained that since quantum physics is linked to mathematical and physical experiences, students should be equipped with mathematical skills to support visualization. The use of multimedia can potentially improve students' HOT skills since students taught through multimedia have abilities in terms of analyzing, evaluating, and creating (Widyaningsih et al., 2020). The multimedia teaching method effectively enhances students' conceptual understanding and ability to solve individual and other problems in general (Munfaridah et al., 2021). However, not only do teachers need to use multimedia, but also students must use multimedia while doing the given activities by their teachers. Students who use the presentation format are significantly advantaged compared to those who use the summary report format (Gunel et al., 2007). The findings are related to these studies in a way that they both compromise that multimedia-related instruction eases the learning of physics in general more than lecture does.

Not only do primary and secondary school students enjoy interacting with ICT tools, even undergraduate students enjoy interacting with ICT tools (Nzaramyimana et al., 2021). The affordance of interactive multimedia through videos, texts, and graphs makes the content more concrete, clear, precise, and reliable, enhancing students' retention of physics concepts (Demitriadou et al., 2020). This study concurs with Azid et al. (2020). They argued that the ICT integration in teaching and learning physics increased students' physics achievement and motivated learners to accomplish their classroom tasks. These and our results promise that multimedia enjoyment is not only from the secondary or university level but across the grades. This shows the power and need of using ICT-related teaching aids to remediate students' misunderstandings and increase their interest in learning. For instance, the use of multimedia is expected to support the traditional methods since when lecturing is used alone, it does not give students opportunities to construct their learning, leading to poor performance and lack of motivation. Indeed, poor motivation in physics is linked to poor introduction to physics concepts (Akiha et al., 2018; Glynn et al., 2011; Oliveira & Oliveira, 2013). The use of multimedia in teaching and learning physics contributes to students' performance. Features such as texts, audio-visual content, cartoons, images, and interactive content are used to attract students (Kareem, 2018). Thus, using multimedia in teaching QP will enable lecturers to transmit the content in different forms, fostering students' performance in turn (Oliveira & Oliveira, 2013).

An enhanced conceptual understanding also affects pre-service teachers' confidence to deliver the content related to QP in their future teaching careers. This is explained by the fact that these pre-service teachers are ready to answer the questions they will ask while teaching QP concepts. Dushimimana and Uworwabayeho (2020) reported that once pre-service teachers do not perform well in the subject and national exams, they are likely to teach that subject poorly. The research findings also concur with Karsenti (2016), who argued that multimedia makes it easier to present materials to the class and helps the teacher provide better content presentations. This is because ICT tools such as multimedia foster students' motivation, concentration, attention, engagement, and self-esteem (Azid et al., 2020; Schroeder & Schroeder, 2007). ICT is an effective tool that can be integrated to become an influential pedagogical tool (Tonui & Bornace, 2016). Therefore, and educators should employ multimedia when teaching physics concepts to improve their students' conceptual understanding (Gambari et al., 2016). The study's unique finding is situated in revealing students' perceptions of learning quantum via multimedia aids. Difficult topics and mathematical topics were all appreciated when learning using such visual approaches. The prime limitation in the proposed study is that it did not discuss how lecturers felt about teaching quantum physics using multimedia applications. Additionally, pre-service teachers from the College of Education were the subject of the study. It did not study the situation of learning quantum physics in other colleges of the University of Rwanda. The project also was limited to only focusing on quantum physics. It did not look at any other module to ease the comparison of branches of physics taught at the university level.

Conclusions and Implications

This study aimed to reveal students' perceptions of multimedia usage in teaching and learning quantum physics at the University of Rwanda College of Education (UR-CE). It surveyed 163 students after being taught by lecture method and 156 students after being taught by multimedia-aided instruction. It intended to answer four research questions related to (a) the easiness or difficulty of quantum physics concepts, (b) the visualization methods commonly used and most preferred to be used in quantum physics lessons, (c) the extent students agree or disagree with the feeling-related learning of quantum physics, and (d) the extent students recommend the actions (both tools and methods) to be taken in improving teaching and learning quantum physics.

https://doi.org/10.33225/jbse/23.22.37

De Broglie hypothesis, Bohr correspondence principle, Uncertainty relations, and Schrodinger equation rebelled as difficult topics for students among quantum physics concepts. At the same time, blackbody radiation and the photoelectric effect were perceived as easy by students who learned through multimedia. However, all quantum physics concepts were perceived as difficult by students that learned through lecture methods. While students in the multimedia class enjoyed learning quantum physics, students in the lecture class felt misunderstanding these concepts. All students concurred that a PowerPoint presentation was used. However, it was found that students preferred the tools that were used in their classes. For instance, students in a multimedia class preferred simulations, animations, and YouTube videos more than those in a lecture class, while students in a lecture class preferred demonstrations, models, pictures, and graphs more than those in a multimedia class did.

Multimedia induced the students to like and enjoy learning from its visualization compared to lectures. The students from this instruction testified that learning with multimedia improves their understanding of how theories of quantum physics explain the physical observation. However, students in multimedia and lecture classes compromised that their lecturer did neither use the teacher-centric approach to physics nor the conventional-cum-demonstration method to teach quantum physics. Based on the above findings, it can be proposed that lecturers adapt to the use of multimedia, an emphasis is made on mathematics clarification, and enough time is provided to perform quantum exercises. Further studies may focus on checking students perceived attitudes toward learning other modules at higher learning institutions.

Acknowledgment

The first author received financial support for data collection from the African Center of Excellence for Innovative Teaching and Learning Mathematics and Science (ACEITLMS). Students who participated willingly in this study are also appreciated.

Declaration of Interest

The authors have no relevant financial or non-financial interests to disclose.

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ISSN 1648–3898 /Print/
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Appendix A. Quantum Physics Attitude Test, QPAT [Post-testing after being taught QP]

Section I. Biographical Data:

(Please complete the following table, and where relevant, tick by √ in the second column)

Q1. Gender	
1. Male	
2. Female	

You have learned a module named Modern Physics, molecular and thermodynamics; the questions asked here below are related to the modern physics part of this module

Section II: College students' Perceptions of Quantum Physics Concepts:

Q2. Some topics in modern physics (quantum physics) seem difficult and not understandable to the students for different reasons. *Please indicate if the topic is easy to understand or difficult to understand and the reasons behind it by ticking (√) where relevant in the table below.*

You can tick either easy to understand or difficult to understand, not both			Reasons for being easy or difficult to understand You may tick more than one reason			
Topic	**Easy to understand**	**Difficult to understand**	**Due to the abstractness of this topic**	**This topic is too mathematical**	**My lecturer does not use visualization methods and does not explain them well**	**Lack of motivation and interest when learning this topic**
1.Blackbody radiation						
2.Photoelectric effect						
3.Compton Effect						
4.Bohr model of the atom						
5.De Broglie hypothesis						
6.Bohr correspondence principle						
7.Uncertainty relations						
8. Schrodinger Equation						

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Section III. Use of MULTIMEDIA in Teaching and Learning Quantum Physics.
(Technologies and the visualization methods such as demonstrations, simulations, models, graphs, films, educational games, animations, pictures, PowerPoint presentations, audio, videos, and different other applets are used in teaching physics. Please indicate what visualization method and technologies are used in teaching and learning modern physics or quantum physics at your college by completing the following table and, where relevant, tick in the appropriate box)

You may tick more than one box

Q3: The visualization methods commonly used in teaching and learning quantum physics at UR-CE are:	Tick all where appropriate by using √
1. PowerPoint presentation	
2. Demonstration	
3. Models	
4. Pictures	
5. Graphs	
6. Simulations	
7. Animations	
8. Video	
Q4: The visualization methods I prefer mostly to be used in my lessons on quantum physics are:	**Tick all where appropriate by using √**
1. Simulations	
2. Animation	
3. Video	
4. Graphs	
5. Pictures	
6. Models	
7. Demonstration	
8. PowerPoint presentation	

Section IV. Your Feelings towards Learning Quantum Physics
To what extent do you agree or disagree with the following statements about your feelings toward learning Quantum physics? *(please rate your level of agreement from strongly agree to strongly disagree on the statements in the table below)*

Statements	Strongly agree	Agree	Neutral	Disagree	Strongly Disagree
Q5. I enjoy learning quantum physics concepts.					
Explain your answer					
Q6: I feel I understand quantum physics.					
Explain your answer					

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Q7: I use my free time to read books, do research, and do exercises related to quantum physics.					
Explain your answer					
Q8: If I am stuck on quantum physics exercises/problems, I usually try to figure out a different way that works.					
Explain your answer					
Q9: Although quantum physics is abstract in nature, the way my lecturer taught it, I found it easy to approach it.					
Explain your answer					
Q10: Although quantum physics is too mathematical, the way my lecturer taught it, I found it easy to approach it.					
Explain your answer					
Q11: Due to the way I learned quantum physics, I am confident that I will have to teach it in my future career.					
Explain your answer					
Q12: As a future physics teacher, I will be able to answer students' questions about quantum physics while teaching this course.					
Explain your answer					

https://doi.org/10.33225/jbse/23.22.37

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Section V. Actions for Improving Teaching and Learning Quantum Physics concerning the Use of Multimedia. To what extent do you recommend the following statements about the actions to be taken in improving teaching and learning quantum physics *(please rate your level of agreement from strongly agree (5) to strongly disagree (1) on the statements in the table below).*

Facts	Strongly agree	Agree	Neutral	Disagree	Strongly Disagree
Q13: I like and enjoy learning from the visualization methods (demonstrations, simulations, models, animations, videos, pictures, and graphs).					
Q14: Quantum physics course that uses visualization methods in some of its teachings could be more interesting than a course taught without using them.					
Q15: Learning with multimedia can improve my understanding of how theories of modern physics can explain the physical observation.					
Q16: Learning with multimedia can improve my ability to solve new problems in modern physics by using basic principles and concepts.					
Q17: The use of visualization methods increases my understanding and appreciation of modern physics concepts.					
Q18: The use of the visualization methods increases my motivation and interest in learning modern physics part.					

To what extent do you agree or disagree with the following statements about your perception of the teaching methodologies in quantum physics/modern physics? Please rate your level of agreement from strongly agree (5) to strongly disagree (1) in one of the barriers listed in the table below.

Facts	Strongly agree	Agree	Neutral	Disagree	Strongly Disagree
Q19: My lecturer uses the teacher-centric approach to teach quantum physics/modern physics					
Q20: My lecturer uses a student-centric approach to teach quantum physics/modern physics					
Q21: My lecturer uses the demonstration approach to teach quantum physics/modern physics.					
Q22: My lecturer used the conventional-cum-demonstration method to teach quantum physics /modern physic.					

Q23. Do you consider the existing teaching practices (teaching methods used by your lecturer) efficient enough for you to understand Modern physics concepts? If yes, explain your answer/ If no, explain your answer

https://doi.org/10.33225/jbse/23.22.37

THANK YOU VERY MUCH FOR YOUR PARTICIPATION AND COLLABORATION

Appendix B. Examples of Lecture and Multimedia Content

<table>
<tr><th>Quantum Physics Concept Taught</th><th>Lecture method</th><th>Multimedia method</th></tr>
<tr><td>Photoelectric effect</td><td>

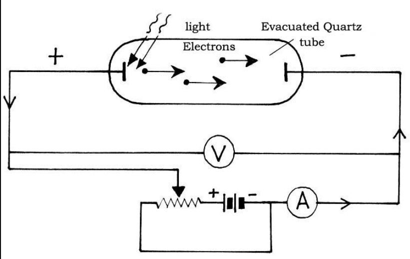
Introduction of the concepts

The instructor in the lecturer's class starts the lesson by providing the definition of the Photo-electric effect

Definition of photoelectric effect:

The photoelectric effect is a process whereby electrons are ejected from a metal surface when light strikes that surface.

The instructor explains the **experimental set-up of Photoelectric effect**



Instructors explain four experimental facts which have been observed concerning the photoelectric effect.

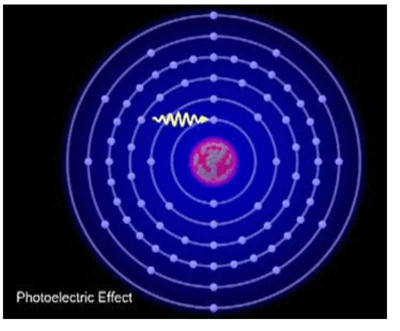
1. Up to an accuracy of no time interval was observed between the arrival of light at a metal surface and the emission of photoelectrons.
2. A bright light (Higher intensity) yields more photoelectrons than a dim one (low intensity), but the electron energies remain the same.
3. Photocurrent is proportional to light intensity (I), but extinction voltage Vo is the same for all currents.
4. The higher the frequency of the light, the more energy the photoelectrons have.

The extinction voltage Vo, and hence the maximum photoelectron energy, depends on the frequency of the light.

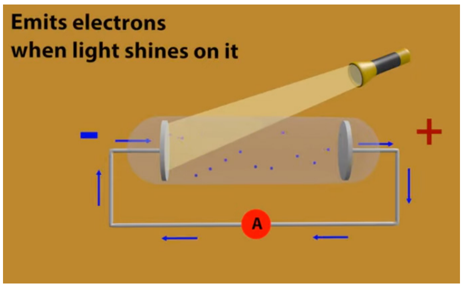
</td><td>

Introduction of the concepts

Instructors in multimedia classes start the lesson by asking the student to observe the animation and then, after using their observation to explain the phenomena observed
https://makeagif.com/gif/photoelectric-effect-FU7Kz5



https://www.youtube.com/watch?v=ubkNGwu_66s



After observation, students explain what the Photoelectric effect is

The instructor asks students to discuss in the group some questions and then present their findings

Some questions asked to students before playing the simulation

1.For the same monochromatic light source, would the photoelectric effect occur for all metals?
2.What does the photoelectric effect depend on?
3.Is visible light the only type of EM radiation that can cause the photoelectric effect?
4.What are the applications of the photoelectric effect?
5.Which law is conserved in the photoelectric effect?
6.Which photon is used in the photoelectric effect?
7.Is the photoelectric effect a consequence of the wave character of radiation, or is it a consequence of the particle character of radiation? Explain briefly.
The instructor gives students instruction to follow while playing the simulation
https://phet.colorado.edu/sims/cheerpj/photoelectric/latest/photoelectric.html?simulation=photoelectric

</td></tr>
</table>

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		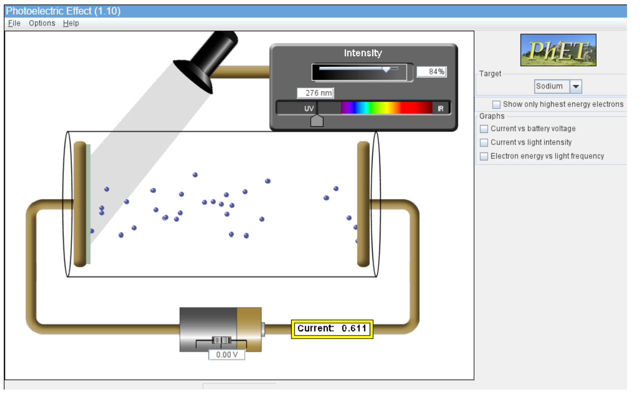 Questions not well answered before playing the simulation, students answer them after playing it This simulation helps students resolve some common problems, including: • thinking voltage rather than light takes electrons off the plate • thinking current increases with the speed of electrons • difficulty explaining the basic function of the experiment • difficulty explaining the classical model of light • difficulty explaining why PE experiment leads to photon model of light

Received: *October 13, 2022* Revised: *December 01, 2022* Accepted: *January 15, 2023*

Cite as: Nyirahabimana, P., Minani, E., Nduwingoma, M., & Kimeza, I. (2023). Students' perceptions of multimedia usage in teaching and learning quantum physics: Post-assessment. *Journal of Baltic Science Education*, *22*(1), 37-56. https://doi.org/10.33225/jbse/23.22.37

Pascasie Nyirahabimana *(Corresponding author)*
Master's Degree in Physics, Assistant Lecturer, University of Rwanda-College of Education (UR-CE), & PhD Student, African Centre of Excellence in Innovative Teaching and Learning Mathematics and Science (ACEITLMS) based at UR-CE, PO BOX 55 Rwamagana, Republic of Rwanda.
E-mail: pnyirahabimana@gmail.com
ORCID: https://orcid.org/0000-0002-3679-2586

Evariste Minani
PhD, Lecturer, University of Rwanda-College of Education (UR-CE), & Associate Member, African Centre of Excellence in Innovative Teaching and Learning Mathematics and Science (ACEITLMS), PO BOX 55 Rwamagana, Republic of Rwanda.
E-mail: evaminari@gmail.com
ORCID: https://orcid.org/0000-0001-7970-3056

Mathias Nduwingoma
PhD, Director of the Centre for Open Distance and eLearning (CODeL), University of Rwanda & Associate Member, African Centre of Excellence in Innovative Teaching and Learning Mathematics and Science (ACEITLMS), PO BOX 55 Rwamagana, Republic of Rwanda.
E-mail: ndumathias2001@yahoo.com
ORCID: https://orcid.org/0000-0002-2054-3518

Imelda Kimeza
PhD, Senior Lecturer, Department of Educational Foundations and Psychology, Mbarara University of Science and Technology (MUST), P.O BOX 1410, Mbarara, Republic of Uganda.
E-mail: ikemeza@must.ac.ug, imeldakemeza@yahoo.com
ORCID: https://orcid.org/0000-0002-0063-763X