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Prime indicators of current teaching methodologies and students' perceptions in quantum physics

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ABSTRACT

With the growing revolution in the education system, imparting quality education has become a priority for instructors and students in any educational institution. The challenge grows high when it comes to teaching advanced subjects like quantum physics. The present study considered the case study of the University of Rwanda College of Education. It investigated the impact of current teaching methodologies and teaching staff and students' perceptions in quantum physics for a quality knowledge delivery system. It employed a quantitative method of data collection. About 300 students and ten lecturers participated in this study. Data obtained from this study were analyzed using descriptive quantitative analysis. Students suggested that multimedia tools in teaching and learning quantum physics can improve the understanding of concepts and help solve complex mathematical problems in quantum physics. Likewise, the teaching staff finds quantum physics more comprehensive and effective when appropriate multimedia tools are used. The investigation outcome is meant multimedia utilization can improve quantum physics' teaching and learning experience at Rwanda high educational institutions.

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1. INTRODUCTION

Quantum physics is an area of physics of immense importance in modern technology because lasers, diodes, transistors, and semiconductors are some of its applications. Unfortunately, quantum physics is a subject which most students traditionally find very abstract and challenging, and its teaching methodology has not changed much since its introduction in higher learning institutions [1]. Wattanakasiwich [2] found that many students consider quantum physics a challenging course since it has an abstract, counter-intuitive, and highly mathematical nature. Students attend the course because it is in the curriculum program. In addition to students' problems with learning quantum physics, the instructors have problems teaching it because of the nature of the quantum concepts [3]. Therefore, the process of teaching and learning quantum physics in higher learning institutions needs to be improved so that students do not perceive the subject as a problematic, incomprehensible, and uninteresting subject.

With the rapidly evolving technology, multimedia interactivity helps achieve higher-level thinking, reinventing, and improving the intellectual and developmental processes in our everyday lives [4]. Today, digital technology is part of students' daily lives and is expected to be used in academic courses [5]. The advantage of integrating multimedia learning in the school curriculum is extended to interesting possibilities for meeting the necessities of the 21st-century [6]. Multimedia in teaching and learning can be defined as the transfer of instructional content using audio, video, and other interactive features, which the students use to build their knowledge [7]. Multimedia offers a stimulating and interactive environment where quantum physics learning and retention improve. With multimedia learning, students understand the concepts and problems vicariously. Further, multimedia motivates students to provide more individualized learning experiences as the human brain processes new information using visual or auditory channels more quickly than other teaching techniques [8], [9].

Furthermore, multimedia aided technologies have various effects on students' interest and can help them improve academic performance. A higher learning curve is achieved when students can see the significance of the presented information in the classroom. In this regard, multimedia-aided tools have been an integral part of education and have multi-fold benefits in the teaching-learning process of quantum physics [10], [11]. This manuscript determines the prime indicators of current teaching methodologies and students' perceptions in quantum physics for quality knowledge delivery system at the University of Rwanda College of Education (UR-CE) focusing on multimedia utilization.

Quantum physics has been an imperative part of engineering education for a long time. A study by Olsen [12] has been conducted to understand the quantum mechanics concepts in Norway's upper higher secondary school. The study randomly selected 236 students with 18-19 years from twenty different schools. The study found that students face problems understanding quantum concepts. The study's analysis has been carried out in the qualitative approach considering a specific number of students. Most students traditionally find quantum physics very abstract and challenging to comprehend. Various research studies found quantum physics complicated due to its complex mathematical problems and abstract nature. Hence, students only learn this subject as it is included in the main course curriculum [13]. Didis [14] found that lecturers also face difficulties teaching the subject due to "complex quantum concepts." However, the study has not addressed the challenge of teaching staff concerning resources, which is essential to be considered.

Bungum *et al.* [15] investigated lecturers' challenges and found adequate resources to teach quantum mechanics in Norwegian schools. The study asserts that lecturers felt less confident teaching quantum mechanics than other subjects in the curriculum. It was also observed that lecturers felt insecure in teaching quantum mechanics as they lacked the skills-set to answer the complex quantum questions adequately. Previous researchers [16] carried out a similar research work concerning teaching quantum mechanics at the school level. It has been found that the teaching approach and the learning mode determine the knowledge transfer of a subject.

Teaching quantum physics is a difficult task as it is philosophically sensitive. The teaching approach and the learning mode determine the knowledge transfer of a subject. Betrancourt [17] found that the visual medium preserves information in the human brain for the long term to overcome the challenges. Thus, integrating technology in teaching orientation and the traditional lecture method will help the students understand the complex quantum physics concepts and mathematical problems more thoroughly. The research conducted by various researchers exhibited that multimedia-aided visualization methods such as demonstrations, simulations, models, graphs, films, animations, videos, and other applets help students and lecturers to understand quantum mechanics concepts and phenomena in a much better way [18], [19]. Shi and Liang [19] confirmed that multimedia technologies provide an effective, advanced, economical, and instructional method for teaching physics in universities. The multimedia illustrations and visualization make the quantum physics teaching process more understandable, motivating, enjoyable, and efficient. Therefore, multimedia technology can improve the quality of quantum physics in schools and universities [20]. As seen from existing approaches, studies are carried out in different countries. However, adopting similar approaches is very sparse in Rwanda's educational institutions. Therefore, the study asked the following research questions: i) Do Multimedia tools help faculty members teach quantum physics? and ii) Do Multimedia tools help students understand the complex concepts of quantum physics?

2. RESEARCH METHOD

This study investigated the current practice of teaching and learning quantum physics using a quantitative method. The quantitative study is a statistics-driven approach and provides a substantial analysis of the collected responses from the target respondents, whereas qualitative research assists in compiling the empirical representation of the facts and figures obtained from the study [21]–[23]. Moreover, adopting a quantitative technique result in more flexibility and reliability as large-scale populations can be considered for the study with statistical analysis assistance. This study was a non-experimental, descriptive research design. Ten lecturers and three hundred students from the UR-CE were purposively selected to participate in the research process. Data from this study were collected through the survey questionnaire and analyzed using descriptive quantitative. The analyses of survey data were done by using statistical package for the social sciences software (SPSS). Table 1 exhibits the research study parameters used in the study.

Table 1. Research study parameters

Total respondents	Software used	Statistical tool used
310	IBM Statistics SPSS 21.0	Frequency and percentage, Pearson correlation analysis

2.1. Reliability of the questionnaire items

The primary data consists of classroom observations and questionnaires. An evaluation questionnaire for computer simulations (EQCS) was adapted to our context and used in this research. The validity and reliability of the EQCS were done by Chou [24]. To ensure the validity of the research design, the research instruments, the survey questionnaire, and the interview guide was piloted before using them to collect data at one educational institution (The University of Kibungo, formerly known as the Institute of agriculture, technology, and education of Kibungo). There were four physics lecturers and 30 students participated in the pilot study. The piloting helped us identify questions that do not make sense to participants or problems with the questionnaire that might lead to biased answers, and it does hence help us to improve data collection tools.

The excellent idea of the test is to explore if there is a presence of any significant wrong item (out of the total items) that could cause potential declination of internal reliability and consistency within each other [25]. For lecturers**,** to assess the questionnaire items' internal consistency and reliability, Cronbach's alpha of all constructs (seven items) was examined. Theoretically, the value of Cronbach's alpha ranges from 0 to 1. However, acceptable values lie from 0.7 to 0.9. Cronbach's alpha value was found to be .841. The number is greater than the 0.7 benchmarks, which signifies that all the item scales used in this study had sufficient and satisfactory internal consistency and reliability. Hence, for students: Cronbach's alpha value was .801, which is once again greater than the 0.7 benchmarks. This indicates that all the item scales used in this study had sufficient and satisfactory internal consistency.

The next step consisted of data collection using improved data collection tools. At this stage, ten lecturers teaching quantum mechanics and modern physics (10 lectures) and 300 undergraduate students studying quantum mechanics and modern physics in UR-CE were informed about the research and use of findings. Confidentiality was granted to participants in the study, and a consent form was signed. Participants were also informed that the results were only used for research to improve the teaching and learning of quantum physics through multimedia at UR-CE.

3. RESULTS AND DISCUSSION

3.1. Lecturers' perception towards teaching quantum physics

3.1.1. Quantum physics related modules taught at UR-CE

Usually, the physics section of department of Mathematics, Science and Physical Education at UR-CE have 10 lecturers who teach physics. Figure 1 shows the lecturers who teach quantum physics related modules at UR-CE. Most lecturers teach modern physics (PHY2143), followed by very few of the lecturers who are teaching quantum mechanics (PHY2345) and introduction to modern physics (ISE3241). This means that eight lecturers out of ten teach modern physics related modules and two lecturers out of ten teach quantum mechanics related modules. Therefore, few lecturers can teach quantum physics related module at UR-CE.

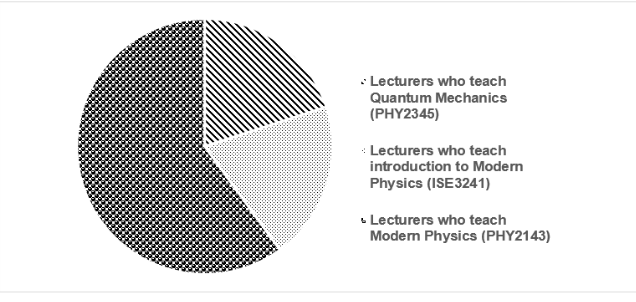

Figure 1. Lecturers who teach Quantum Physics related module at UR-CE

3.1.2. Problems in teaching quantum physics topics

Generally, learning advanced physics involves a tremendous amount of mathematics sophistication and building on the knowledge one has acquired at the introductory and intermediate levels. Furthermore, quantum physics may be particularly challenging since the paradigms are so different from general physics. Table 2 shows that most lecturers found the blackbody radiation, uncertainty relations and Schrodinger equations challenging to teach the students. According to the lecturers, these topics are complex, so multimedia tools will help demonstrate the topics more effectively.

Table 2. Quantum physics topics

Constructs	Problem faced	No problem
Blackbody radiation	6	4
Photoelectric effect	3	7
Compton Effect	4	6
Bohr model of the atom	4	6
Uncertainty relations	4	6
Bohr correspondence principle	4	6
Schrodinger Equations	6	4

3.1.3. Multimedia tools used in teaching quantum physics

Multimedia-aided technology helps students grasp and understand quantum physics concepts and laws swiftly. The advantage of multimedia applications in the classroom is a dynamic simulation, i.e., the students get interested in the subject through visual experiments and animations. The most commonly used multimedia tool is the demonstration method, followed by the simulation technique. Table 3 shows that all the lecturers use PowerPoint presentations, graphs, and pictures to teach quantum physics at UR-CE.

Table 3. Multimedia tools used

Constructs	Frequency
PowerPoint Presentation	10
Graphs	10
Pictures	10
Demonstrations	8
Simulation	2

3.1.4. Perception towards the use of multimedia in teaching quantum physics

Table 4 statistics show that most lecturers believe that multimedia technology can make quantum physics more exciting and help achieve the quantum physics module's learning outcome. The lecturers also perceive that multimedia technology can help them achieve the learning outcome of the quantum physics module. Most lecturers disagree that they understand what activities and outcomes are expected from multimedia in teaching quantum physics. Some of the lecturers believe they experience challenges when teaching quantum physics.

Table 4. Perception on the use of multimedia tools in teaching quantum physics

Constructs	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Using multimedia technology can make my lessons more interesting.	8	2	0	0	0
Using multimedia technology can help me to achieve the learning outcome in quantum physics	8	0	2	0	0
I understand what activities and outcomes are expected from the use of multimedia in teaching quantum physics	1	1	0	6	2
I experience challenges when teaching quantum physics	3	0	0	5	2

3.1.5. Lecturers' perception towards existing teaching practices

The teaching of quantum physics has not changed much since it was invented in the early twentieth century, and many students traditionally find it very abstract and challenging. Most quantum physics concepts are derived via theories and complex mathematical problems. Therefore, it is difficult for students to understand the concepts and mathematical formulas in a short time interval. Most of the lecturers (eight) believe that the existing teaching practices are inadequate for understanding quantum physics.

3.1.6. Benefits of multimedia tools in quantum physics

Table 5 statistics show that most lecturers believe that multimedia technology can help build a more interesting conceptual understanding of quantum physics. It will also increase the motivation and interest of students in quantum physics teaching and learning. The lecturers' perception shows that better knowledge delivery can be provided if the desired multimedia tools are considered concerning specific subjects in quantum physics. The teaching staff realizes the benefits of technological tools in imparting knowledge about quantum physics. According to the lecturers, different chapters in quantum physics have different distinct mechanisms to be taught, and the adoption of multimedia technology can boost this experience. Thus, it satisfies the first research question: Does Multimedia tools help faculty members teach quantum physics?

From the analysis of lecturers' perception of existing teaching practices, it can be interpreted that: i) Most of the lecturers use PowerPoint presentations, graphs, and pictures to teach quantum physics at UR-CE; ii) Most lecturers believe that using multimedia technology can make quantum physics more exciting and help achieve the quantum physics module's learning outcome; iii) Most lecturers believe that multimedia technology can help build a more interesting conceptual understanding of quantum physics. It will also increase the motivation and interest of students in quantum physics.

Table 5. Benefits of multimedia tools in quantum physics

Constructs	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Quantum physics module is perceived by the student as a difficult and not understandable module	10	0	0	0	0
The use of multimedia technology can increase student conceptual understanding of quantum physics	9	0	1	0	0
The use of multimedia technology can lead to students' motivation and interest in quantum physics	9	0	1	0	0

3.2. Students' perception towards learning quantum physics

3.2.1. Complexities of learning quantum physics topics

Table 6 shows that students find quantum physics contents such as Blackbody radiation, Photoelectric effect, Compton Effect, Bohr model of the atom, De Broglie hypothesis, Uncertainty relations, Bohr correspondence principles, and Schrodinger Equations challenging to understand due to abstractness and mathematical complexities of the contents. According to the students, the lecturers' lack of visualization techniques to explain these topics and lack of motivation and interest also adds to the complexities of learning quantum physics topics.

Table 6. Complexities of learning quantum physics topics

Topic	Abstractness (%)	Mathematical (%)	Lack of visualization methods (%)	Lack of motivation and interest (%)
Blackbody radiation	50.33	22.33	15.67	11.67
Photoelectric effect	47.00	11.00	21.67	20.33
Compton effect	47.00	17.33	18.00	17.67
Bohr model of the atom	62.33	10.67	13.67	13.33
De Broglie hypothesis	62.33	14.33	10.67	12.67
Uncertainty relations	50.33	22.33	15.67	11.67
Bohr correspondence principle	62.33	12.67	13.00	12.00
Schrodinger equations	10.33	62.33	14.67	12.67

3.2.2. Students' perception towards existing teaching practices

In traditional teaching of quantum physics, the main motive of teachers is to prepare students for exams than coach them and make them understand the concept and syllabus topics. This teaching approach has been found lacking in providing opportunities for students to develop their understanding of quantum physics concepts and a positive attitude towards it [26]. As a result, the approach is less encouraging for students to develop their level of thinking and understanding. Most students (61%) believe that the existing teaching practices are inadequate for understanding quantum physics. They indicated that in the current teaching practice their lecturers use both the teacher-centric approach and conventional-cum-demonstration method to teach quantum physics. Therefore, these lecture methods somehow hinder the development of conceptual understanding, practical skills among the students and they are not useful for developing scientific attitude.

3.2.3. Multimedia tools used in learning quantum physics

Table 7 shows that majority of the students believe that PowerPoint presentations, demonstrations, graphs, and pictures, followed by video, models, and simulation techniques, are used at UR-CE to learn quantum physics. The students' preference for multimedia tools for learning quantum physics can be seen on the right side of the table. All the preferred multimedia tools are already being used at UR-CE for teaching quantum physics. Students prefer PowerPoint presentations, demonstrations, simulations, animations, and video than other multimedia tools to be used in learning quantum physics.

Table 7. Multimedia tools used in learning quantum physics

Multimedia tools used in learning quantum physics		Student's preference of multimedia tools	
Constructs	Responses (%)	Constructs (%)	Responses (%)
PowerPoint Presentation	19.47	PowerPoint Presentation	15.05
Graphs	14.91	Graphs	10.65
Pictures	13.86	Pictures	9.32
Demonstrations	15.79	Demonstrations	14.05
Simulation	6.49	Simulation	8.69
Audio	4.91	Audio	4.59
Animation	3.68	Animation	7.54
Films	2.11	Films	3.85
Models	7.02	Models	8.88
Video	8.60	Video	10.95
Educational games	3.16	Educational games	6.43

3.2.4. Students attitude towards learning quantum physics

Table 8 reveals that most students think quantum is mathematical and abstract. They will not choose this course if it is an elective subject. Most students also assert that they do not understand quantum physics concepts due to how their lecturers taught the course. It can also be found that participants confirm that they will answer students' questions about quantum physics in the future when teaching this course. Others said they are not confident enough to teach quantum physics concepts in their future careers. These two different ideas are directly connected because someone can answer student questions without mastering course content and methodology to deliver the content. Further, it is unknown what kind of the answer is correct or wrong. The nature of the course, principles, teaching methods, resources, concept, and nature of the learner count more in teaching. Also, previous researcher defines pedagogical content knowledge as a type of knowledge that is unique to teachers and is based on the way teachers relate their pedagogical knowledge (what they know about teaching) to the subject matter knowledge (what they know about what they teach) [27].

The integration or synthesis of teachers' pedagogical knowledge and their subject matter knowledge comprises pedagogical content knowledge. Therefore, the fact that the participants can answer student questions but are not confident in teaching the course is a sign of incomplete or superficial levels of pedagogical content knowledge [28], [29].

Table 8. Student's attitude towards learning quantum physics

Constructs	Strongly agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly disagree (%)
Quantum classes/lessons are not interesting	51.00	15.67	9.67	12.00	11.67
I will not take the quantum course if it is an elective course	48.33	15.33	15.00	11.33	10.00
Quantum physics is too mathematical. I expect just to pass the course	47.00	36.33	5.67	6.33	4.67
As a future physics student teacher, I will be able to answer students' questions about quantum physics when teaching this course	51.00	15.67	12.00	11.67	9.67
Quantum physics concepts are difficult and abstract in nature	45.00	21.00	8.67	16.33	9.00
No matter how hard I try, I find the quantum physics module very difficult.	62.33	8.00	8.33	13.00	8.33
I worry that I will have to teach quantum physics concepts in my future career.	51.00	15.67	9.67	12.00	11.67
I do not understand quantum physics concepts due to the way my lecturers taught me.	53.67	15.67	8.00	11.67	11.00

3.2.5. Recommendations for improving teaching and learning quantum physics

Table 9 statistics show that most students recommended using visualization techniques to increase their motivation and understanding of quantum concepts. The students asserted that using technology in quantum physics would improve the comprehension of concepts. It also solves complex problems in quantum physics. Multimedia applications can make the teaching content intuitive inspiring enthusiasm among students and improving their learning efficiency [30].

Table 9. Actions for improving teaching and learning quantum physics

Constructs	Strongly agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly disagree (%)
I like and enjoy learning from the visualization methods	59.67	36.33	2.67	1.33	0.67
Visualization methods in teaching could be more interesting than a course taught without using them	56.67	39.00	2.33	1.33	0.67
Learning with the multimedia can improve my understandings of how theories of quantum physics can explain the physical observation	53.67	41.67	2.67	1.33	0.67
Learning with multimedia can improve my ability to solve new problems in quantum physics by using basic principles and concepts	53.33	36.33	8.33	1.33	0.67
Multimedia should be used more often in quantum physics learning and instruction	47.67	42.00	8.33	1.33	0.67
If my lecturers were using visualization methods in my classroom, I would be able to learn the subject matter of quantum physics more easily	43.67	41.00	10.00	4.67	0.67
The use of the visualization methods increases my understanding and appreciation of quantum physics concepts	63.00	29.00	6.00	1.33	0.67
The use of the visualization methods increases my motivation and interest in learning quantum physics module	53.67	32.33	5.33	4.67	4.00

3.3. Hypothesis test-1

To investigate the research question 2: Do multimedia tools help students understand the complex concepts of quantum physics? The study formulates hypothesis 1, which states that H_0: Multimedia tools help students understand the complex concepts of quantum physics. Null Hypothesis: H_0: Multimedia tools help students understand the complex concepts of quantum physics. Alternate Hypothesis: H_1: Multimedia tools do not help students understand quantum physics' complex concepts.

Table 10 highlights the relationship between multimedia tools and complex concepts of quantum physics. It can be analyzed that there is a significant link between the two factors as $p>.000$. Owing to the significant value of 'p', the outcome statistically shows a positive relationship between multimedia tools and understanding complex concepts of quantum physics. Therefore, the null hypothesis states that Multimedia tools help students understand the complex concepts of quantum physics.

It can be found that students shared positive feedback on the adoption of multimedia tools. Adopting visualization tools is highly assistive in better understanding quantum physics' essential concept with a better illustration. According to them, it improves their analytical capabilities too, and they are more motivated to adopt them in the future. From the analysis of students' perception of existing teaching practices, it can be interpreted that: i) Most students find quantum topics challenging to understand due to the abstractness and mathematical complexities of the contents. They also think the existing teaching practices are inadequate for understanding quantum physics; ii) Most of the students preferred PowerPoint presentations, demonstrations, graphs, and pictures, followed by video, models, and simulation techniques; iii) Multimedia tools help the faculty members in teaching quantum physics; iv) Multimedia tools help students to understand the complex concepts of quantum physics.

Table 10. Pearson correlation analysis-1

		Multimedia tools	Complex concepts and mathematical equations
Multimedia tools	Pearson correlation	1	.823
	Sig. (2-tailed)		.000
	N	10	10
Complex concepts and mathematical equations	Pearson correlation	.823	1
	Sig. (2-tailed)	.000	
	N	300	300

4. CONCLUSION

This paper brings out interesting findings in the form of contribution from the study: i) There is a big gap in adoption of ICT in the educational system of Rwanda in contrast to other countries where the usage of multimedia in teaching is not much found frequently being used mostly in case of quantum physics; ii) There is a greater deal of challenges encountered by the students in acquiring more in-depth knowledge about quantum physics because of various essential topics of quantum physics, which are not clear to them by adapting the existing teaching practices in Rwanda's educational institution; iii) The primary indicators of these challenges are owing to the approaches used by the existing teaching staff associated with tool usage, or styles of teaching, or giving illustration about solving mathematical problems in the core subject; iv) The secondary indicators of this challenge is the demand of the multimedia-aided tools for better understanding of concepts, demonstrations, ideas, and mathematical formulas of quantum physics.

The study's significant contribution is to prove that the multimedia tools' adoption significantly assists in teaching quantum physics in Rwanda Educational institutions. It is also proven that the student always treats quantum physics as a challenging subject, while the adoption of multimedia makes the task understanding relatively easier. A significant finding is that the mathematical approach is highly inconsistent in understanding various quantum physics topics. The improvement in teaching efficiency is not highly significant as the teachers lack prior experience in adopting multimedia in teaching quantum physics. Various information is obtained from most of the students' perceptions, signifying the need to adopt innovative approaches and multimedia tools. The prime limitation of the proposed study is that it does not consider or discuss more innovative approaches apart from multimedia tool adoption to improvise quantum physics training. The study also does not discuss the mechanism of curving multimedia tools to teach different quantum physics chapters. Further research will include developing and using a multimedia intervention to enhance UR-CE teaching and quantum physics modules.

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