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An integrative review of secondary school quantum physics curricula in Malaysia

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ABSTRACT

As a relatively new subject in the physics curriculum of Malaysian secondary schools, quantum physics (QP) raises questions about its relevance to students and the best approach for teaching it. This paper aims to analyze the content of the QP curriculum to provide students with a meaningful learning experience and expose them to the nature of science (NOS). To accomplish this, the Malaysian standard curriculum document known as *Dokumen Standard Kurikulum dan Pentaksiran* (DSKP) and the textbook were analyzed through integrative review. Frameworks and perspectives identified by Stadermann and co-workers on the common trust of the QP curriculum in 15 different countries were used as a benchmark for this analysis. It is found that the QP curriculum in Malaysia focuses on the fundamental principle of understanding the quantum energy of light and its interaction with matter. However, it is also found that there are specific NOS aspects that can be highlighted to help students develop their scientific literacy. These might include emphasizing the philosophy of complementarity in explaining the wave-particle duality principle, the ultraviolet catastrophe, and the contradiction of classical physics interpretation with QP. It is suggested that the QP curriculum be improved by including these and other relevant examples to be on par with other countries. Overall, this analysis provides insight into the relevance and content of QP in Malaysian secondary schools. The proposed changes may help improve students' learning experience and provide a more comprehensive understanding of the NOS.

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1. INTRODUCTION

Education in Malaysia has been evolving through curriculum transformation. One of the efforts was to revise and restructure the curriculum content to provide students with knowledge, skills and values relevant to current needs to face the challenges of the 21st century [1]. This transformation has to include quantum physics (QP) in the physics curriculum at the secondary school level as it is closely related to the technology that is significantly relevant to today's generations [2], and its exposure is important in bridging the gap that arises from the challenges of the 21st century [3]. Although there is no specific explanation to introduce QP to secondary school students in Malaysia, it is suggested that QP topics for secondary schools aim to develop students' physical worldview of the quantum part, build the skills of modeling the world that goes beyond classical models, and provide insight into the nature of science (NOS), particularly the ways knowledge is generated, which can bring the discussion on the scientific epistemology of QP [3].

While it is new in the secondary school physics curriculum in Malaysia, it is already common in other Asian countries like Bhutan [4], Indonesia [5], Western countries (Australia and Canada), and many parts of European countries (Denmark, Germany, Norway, and the United Kingdom) [6]. This topic was added to the the *Kurikulum Standard Sekolah Menengah* (KSSM), which was officially implemented in 2017 and was first taught to the first batch of upper secondary school students under KSSM in 2021 [1]. With the newly revamped curriculum, the Ministry of Education Malaysia (MOE) has enacted standard documentation of the physics curriculum and assessment, the *Dokumen Standard Kurikulum dan Pentaksiran* (DSKP), to guide teachers in delivering the instruction and achieving the national aspirations [7]. The selection of topics in the QP curriculum is guided by the scientific literacy aspects as a target to be developed in students apart from the QP knowledge [2]. In determining QP topic for secondary school, studies identified that the curriculum must cover at least one of the topics that are related to the fundamental principles: matter waves such as interference of electrons or the de Broglie relation, wave-particle duality, the probabilistic nature of QP, Heisenberg's uncertainty principle, or entanglement with the inclusion of several phenomena and application like blackbody radiation, line spectra and interaction between light and matter [6], which focus on the qualitative understanding of the QP concepts [2].

To the authors' best knowledge, the QP content and implementation in Malaysia's secondary schools have not been academically discussed and reviewed since its introduction and research related to secondary school QP in Malaysia is hardly found in the reliable literature sources as it is newly added in the curriculum. Furthermore, literature on QP for secondary schools area is still lacking, even at the overseas level [8]. Therefore, this study is carried out to analyze the relevance of the selected topics to Malaysia's secondary school students and to give insight into improving the content and learning approach so that the purpose of including this topic can assist relevant parties in delivering a meaningful purpose in physics education. Hence, this paper intends to critically review the QP content and identify the NOS included in the curriculum by referring to the curriculum and assessment standard document provided by the MOE, the DSKP, and the textbook for the physics curriculum. In reviewing the QP content in the physics KSSM, this study refers to the secondary school content standard for QP identified from the existing literature and gains insight into how the NOS can be practiced in teaching and learning QP. This paper also briefly discusses the important points in considering QP inclusion in secondary schools' physics curriculum and presents several recommendations for future possibilities that may improve the teaching and learning of QP at the secondary school level.

2. RATIONALE OF THE QP INCLUSION AT THE SECONDARY SCHOOLS' LEVEL

It has been found that research on QP at the secondary school level has been increasing since the topic was included in the syllabus. It is considered for secondary schools because it encompasses the fundamentals of modern physics [9] and is crucial in establishing the cognitive foundation for properly interpreting microscopic matter [10]. It has become a general understanding that quantum technology has benefited greatly and continuously advanced with QP knowledge, which has also gained significance in society [11]. Besides, previous research has proven and justified the significance of introducing QP in a secondary school [12]–[14].

Based on the reported analysis of the QP curriculum in other countries, most of the content of QP topics in secondary schools is equivalent to the introductory QP courses for non-physics majors at the college level. These topics focus primarily on the historical development of quantum theory, including significant experiments and essential topics such as the photoelectric effect, wave-particle duality, de Broglie wavelength, double-slit interference, probability interpretation, and the uncertainty principle [6], which students can learn qualitatively without complicated mathematical formulation [15]. As QP concepts contradict classical physics interpretations and offer many aspects of NOS, it can also provide students with the opportunities to learn how research is conducted and how scientific knowledge develops, which is useful in developing scientific literacy as it exposes students to making various interpretations that require critical thinking [6].

Based on the provided curriculum, there is no specific explanation for the QP inclusion in the KSSM physics curriculum. However, the DSKP generally emphasizes nurturing science literacy and technology-related skills through thoughtful learning that focuses on developing knowledge, skills and values through student-centered learning pedagogies [7]. This emphasis is in line with the inclusion of QP in the curriculum, as QP is considered a fundamental element to the advancement of technology that students experience today [16] and relevant to the thoughtful learning approach, which is also useful in discussing with students to help them realize and face the rapid technological development and various challenges of the

21st century like the Industrial Revolution 4.0 [7]. Therefore, this paper provides an integrative review to suggests on what aspects to be included in Malaysia's secondary school syllabus for QP based on a comparison with the expert recommendation in reference to their findings from other countries.

3. RESEARCH METHOD

This integrative review is conducted qualitatively by conducting a document analysis on the physics DSKP and the textbook to identify the content and learning standards of QP for physics KSSM. Document analysis is a type of qualitative research in which a systematic approach is used to assess or evaluate printed and electronic documents and interpret them to give their voice and meaning to a particular evaluation topic [17], [18]. The document analysis procedure is guided by Bowen [18]–[20], which describes it as analytical and comprises identifying, selecting, interpreting and synthesizing data in the documents. These data are extracted and organized into major topics and categories through content analysis [19].

Four factors were considered in selecting the documents for this study: authenticity, credibility, representativeness, and meaning [21]. Authenticity refers to the extent to which the document is genuine; credibility refers to freedom from error; representativeness refers to how typical the document is; and meaning refers to the significance of the document's content [18]. The document and the textbook are published by the MOE and developed based on Malaysia's education policy, which was retrieved from the official website of the curriculum development department. Government publications are often trustworthy as they involve experts in developing them. Thus, it reduces concerns regarding authenticity and credibility [18], [19]. The document is under MOE authorization, specially created as official guidance for teachers in teaching and learning [7]. Hence, it is common and significant to this study.

The content of the DSKP and the textbook were then analyzed using deductive thematic analysis [20], [22], [23] by referring to the themes identified by Stadermann and co-workers on the common trust of the QP curriculum in 15 different countries as the benchmark in determining the standard for QP topics for secondary schools. This analysis was conducted by adapting the six phases of reflexive thematic analysis [21], whereby the coding for the predetermined themes was gathered from the documents and compared with the QP content determined by Stadermann *et al.* [6]. From the analysis, this paper presents an overview and critical review of the QP topic in the Malaysian secondary school curriculum, including a discussion on the NOS included in the physics KSSM.

4. RESULTS AND DISCUSSION

This section discusses the findings of this study which include an overview of the QP topic in the Malaysian secondary school curriculum and a critical discussion of the QP topic in the DSKP and the textbook by comparing the findings with the contents in 15 countries [6]. The overview of the QP topic is based on the physics DSKP which is an official document provided by the MOE in Malaysia to the physics teachers in the government schools. This document in general includes the MOE aspiration, the purpose and direction of teaching and learning of physics, explanation of scientific skills and attitudes and several teaching and learning strategies for the 21st century. In detail, the document provides a guideline for teachers in conducting physics lessons by following the content organization, the content standard, the learning standard, and the performance standard. The QP content in the DSKP is then compared with the QP content discussed by Stadermann *et al.* [6] by discussing the comparison using integrative review method.

4.1. Overview of QP topic in Malaysian secondary school curriculum

The QP topic is the final chapter of the physics curriculum for upper secondary school students (17 years old) started in 2021. The addition is considered new compared to other countries like Indonesia, Nigeria, the United States, England, German, France and Italy, that has been taught for several years. This topic is organized under the Modern Physics theme in the DSKP and distributed into three standard contents as a learning area for the curriculum: Quantum Theory of Light, Photoelectric Effect and Einstein's Photoelectric Theory.

Table 1 presents the learning areas with learning standards in the physics DSKP that the students must achieve at the end of the lessons [7]. The learning areas cover three topics under the fundamental principle of understanding the quantum energy of light and its interaction with matter, which introduce the quantum theory of light, the photoelectric effect and Einstein's photoelectric effect theory, while the learning standards detail the key points that are classified based on the learning area. These learning standards guide teachers in determining the QP topic emphasis in their instruction, which includes the quantum energy, wave-particle duality, photons and photoelectric effect. They are the learning goals that the students must achieve at the end of the lessons. The DSKP also provide some activities suggestions and highlights important notes for each learning standard to guide teachers in conducting the lessons. For example, giving students a task to collect information and report on the background of the development of quantum theory from the classical theory towards the discovery of QP theory and discussing how the phenomenon of black body radiation that cannot be explained by classical theory has sparked the idea of QP. Further description of QP teaching and learning activities is available in the physics textbook provided by the MOE.

Table 1. The learning area and learning standard in Physics DSKP [7]

Learning area	Learning standard
1.0. Quantum Theory of Light	Pupils can: 1.1 Explain the initiation of the quantum theory 1.2 Describe the quantum of energy 1.3 Explain wave-particle duality 1.4 Explain the concept of photon 1.5 Solve problems using: (i) photon energy, $\mathbf{E}=hf$ (ii) power, $P=nhf$; n is the number of a photon emitted per second
2.0. Photoelectric Effect	2.1 Explain the photoelectric effect 2.2 Identify four characteristics of the photoelectric effect that cannot be explained using wave theory
3.0. Einstein's Photoelectric Effect	3.1 State the minimum work function needed by metal to emit an electron using Einstein's equation 3.2 Explain the threshold frequency, f_o, and the work function, W 3.3 Determine the work function of the metal, $W=hf_o$ 3.4 Solve problems involving Einstein's equation for the photoelectric effect 3.5 Explain the production of photoelectric current in a photocell circuit 3.6 Describe applications of the photoelectric effect

In discussing the quantum theory of light, the textbook first introduced the blackbody radiation and continuous energy concept before discussing the experimental findings of the blackbody radiation experiment, which reveals the failure of classical physics in explaining the relationship between radiation intensity and wavelength at higher frequencies which sparks the initiation of the quantum theory of light energy [12]. Several physicists involved in the formation of the classical theory of light properties were introduced, which began with Isaac Newton, who introduced the particle nature of light, followed by Thomas Young, who argued the existence of light properties as a wave through his Double-slit experiment. John Dalton and J.J. Thomson were also included to highlight their contribution to the atomic model, the discovery of the electrons, and their failure to explain the light spectrum of atoms.

In the era of modern physics, the physicists involved in the quantum theory revolution were discussed, which include the initiation of the quantum concept by Max Planck, Albert Einstein's quantum theory of light on explaining the photoelectric effect characteristics, Neils Bohr's explanation of the line spectrum production and Louis de Broglie's postulation of the wave-particle duality of subatomic particles. However, the official textbook only briefly discusses this developmental history and suggests a task for students to gather further information on this matter. As shown in the learning standard, the textbook provides a brief note on the quantum of energy concept and wave-particle duality with the introduction of the formulas involving photon energy and power before introducing the photoelectric effect concept as the second learning area for QP topics. This topic is discussed by applying an interactive simulation from the PhET sims for the photoelectric effect virtual experiment [24]–[26] to explain the characteristics of the photoelectric effect, which has been applied in several studies to improve students' understanding of the topic [5], [25], [27]. Apart from that, the textbook provides an experimental activity to determine the value of Planck's constant using Planck's constant kit and discusses the graph of activation voltage against 1/λ in determining Planck's constant.

In the final chapter of the learning area for the QP, Einstein's photoelectric theory is discussed by noting Einstein's success in explaining the photoelectric effect's characteristics by introducing the photon energy concept. His photoelectric effect equation is derived following the Principle of Conservation of energy and discusses the work function of metal and the threshold frequency of light in emitting photoelectrons with several problem-solving questions related to the equations [28]. The curriculum also highlights the photoelectric effect applications for QP concept applications, including a photocell circuit [29] at the end of the chapter.

4.2. Critical discussion of the QP syllabus in the Malaysian secondary school curriculum

This subsection compares the common trust of QP topics taught to Malaysia's secondary school students as appears in Physics KSSM with the contents in 15 countries [6]. Further review is also carried out by analyzing the QP content in the Physics KSSM using the theme generated in the study. The discussion of the syllabus in this integrative review is carried out by comparing the common trust of QP topics taught in the 15 countries as stated by Stadermann *et al.* [6] with the topics included in the physics DSKP. Overall, the topics included in the physics DSKP only cover the fundamental principle of QP topics as explained further.

4.2.1. QP content comparison

Table 2 compares the QP syllabus content in Malaysia's Physics KSSM with what is commonly taught in 15 countries [6]. The six common main topics based on Stadermann and her co-workers are discrete atomic energy, the interaction between light and matter, wave-particle duality, De Broglie wavelength, technical applications, Heisenberg's uncertainty principle and the probabilistic nature of QP [6]. Two of the six common main syllabi taught in the referred countries are not included in Malaysia's syllabus, which are Heisenberg's uncertainty principle and the probabilistic nature of QP, whereas the discrete atomic energy level, wave-particle duality and de Broglie wavelength with several examples of technical applications are only briefly discussed which neglected the explanation of the Bohr's complementarity. The focus of the QP topic in the DSKP is the fundamental principle of interaction between light and matter which is explained using the photoelectric effect concept and elaborated further by introducing Einstein's photoelectric effect theory. Thus, in terms of the actual syllabus content itself, it could be generalized that Malaysia's QP syllabus in secondary school is just around 50% of the syllabus in the mentioned countries.

Table 2. A comparison of the QP common trust topics of 15 countries and the Physics KSSM

The common trust of QP topics in 15 countries	QP topics in Physics KSSM
Discrete atomic energy levels include a discussion of absorption line spectra gases	A brief introduction to atomic spectra by introducing absorption and emission line spectra gases in understanding the concept of discrete and quantum energy, but a further explanation of energy level is not taught to the students.
Interactions between light and matter discuss the photoelectric effect or the Compton effect	The interaction between light and matter includes the photoelectric effect, Einstein's photoelectric effect theory, and a brief on its applications.
Wave-particle duality includes a discussion of Bohr's complementarity principle with the double-slit experiment or with a Mach-Zehnder interferometer. This topic is taught as the fundamental principle and as part of the philosophical aspect of QP	Wave-particle duality is taught with the double-slit experiment and does not include a discussion of Bohr's complementarity. The learning standard only introduces fundamental principles without discussing the philosophical aspect.
De Broglie wavelength discusses matter waves with a quantitative approach that includes calculations using the de Broglie to determine quantum system	De Broglie wavelength is included to explain the existence of wave-particle duality of matter with simple mathematical calculation.
Technical applications include scanning electron microscope, semiconductors, LED, laser	Technical applications include an electron microscope that is compared with an optical microscope. Semiconductors, LEDs and lasers are not discussed in the textbook. However, the learning standard highlights the application of photocell circuits to relate to the photoelectric effect concept.
Heisenberg's uncertainty principle	Not included
The probabilistic nature of QP	Not included

4.2.2. A critical review based on the thematic analysis

This section presents a detailed critical discussion of the current core curriculum of QP in Malaysia's physics KSSM by adapting the five central theme aspects of QP in secondary school education as pointed out by Stadermann *et al* [6]: i) fundamental QP principles, which suggest the fundamental concepts in QP field that should be taught to secondary school students; ii) phenomena and applications of QP, which relate the QP concepts with the phenomena and application in technological field that widely used in human's life; iii) atomic theory, which explain the theoretical concept of an atom; iv) wave function or other mathematical representations that analyzing and calculating a variable quantity to describe wave characteristics of a particle; and v) philosophical aspects that intended guide students to grasp the idea that particles do not just exist in one place at a time but they can exist in two different places at once. The following sub sections discuss these themes by comparing what and how the QP content in the physics DSKP is presented with the QP content [6].

a. Fundamental QP principles

The fundamental QP principles recommended for a secondary school level are wave-particle duality, Heisenberg's uncertainty principle, probabilistic, Pauli exclusion principle and entanglement [7], [9]. These topics have been taught in European countries [6], South Korea [30], China [31], [32], Indonesia [13], [33], Bhutan [4], and Nigeria [34]. In the KSSM, the fundamental principal aspects are mainly on wave-particle duality, clustered under the learning area of the quantum theory of light. The discussion of this topic includes de Broglie's hypothesis in explaining the wave characteristics of electrons through de Broglie's wavelength and a brief experimental finding of the double-slit experiments that confirmed the hypothesis. Stadermann *et al.* [6] pointed out that teaching the fundamental principle should highlight the discrepancies between classical physics views and QP principles because it is impossible for secondary school students to derive the wave-particle duality principle from familiar properties of physical reality or any previously learned physics syllabus. However, it is found that no specific learning standard is intended to recognize the disparity in Malaysia's KSSM. Therefore, as it is crucial to assist students in understanding the paradigm shift between classical physics and QP [35], it should be included as one of the objectives to allow students to compare and understand the contradiction between classical and QP [36].

b. Phenomena and application

Several phenomena and applications are highlighted for secondary schools in most other countries, including blackbody radiation, discrete energy levels or line spectra, the interaction between light and matter, and technical applications [6]. These phenomena and applications are valuable for demonstrating to students that QP is not only a theoretical construct but also explains real-world phenomena and has practical applications that are necessary to the life of secondary school students [14]. In this aspect, Malaysia's KSSM has included blackbody radiation in introducing the concept and discusses the beginning of the revolution of modern physics through Max Planck's idea of quantization of light energy, which leads to the discussion of line spectra [37]. The given textbook provides a brief discussion on the contradiction between classical theory and the experimental result of blackbody radiation but neglects to mention ultraviolet catastrophe in explaining the inconsistency between observations and the predictions of classical physics. This important event should be exposed to students to discuss the paradigm shift between classical physics and quantum theory, which is capable of giving insight into a better understanding of quantum theory [10], [38] by discussing the problems in classical physics that failed to explain the decreases in radiation intensity as the wavelength becomes shorter in the ultraviolet region which known as the ultraviolet catastrophe that led to the idea of the quantum theory [38].

In sequencing the learning standard, the quantum energy and wave-particle duality are introduced before discussing the interaction between light and matter, which discusses the photoelectric effect and Einstein's postulation of the photoelectric effect. The KSSM textbook explains the characteristics of the photoelectric effect by revealing the independence of the photoelectron kinetic energy from the light intensity but instead depending on the light frequency in emitting the photoelectrons from the metal surface. The existence of the threshold frequency and the instantaneous photoelectrons emission are also discussed, allowing students to compare the contradiction of the classical physics interpretation and the experimental result on the light properties [39].

The learning continues with Einstein's photoelectric effect theory, which discusses the derivation of his photoelectric effect equation, bringing students to understand the work function concept and relate it with the threshold frequency in producing photoelectron emission. The application of Einstein's photoelectric effect equation is also emphasized in problem-solving activities. The section on phenomena and application ends by exposing students to the applications of the photoelectric effect concept to connect with real-world applications. The learning standard for QP in the DSKP includes several applications like wave properties of electrons in electron microscopes and photoelectric effect concepts like photocell and solar cell but does not discuss a wider range of QP applications in other areas such as computers, smartphones, LCDs, magnetic resonance imaging and many other technological advancements that would not be discovered without QP. Besides, including modern perspectives and applications of QP to real simplified problems is important for understanding QP and will motivate students to continue their studies on this topic [40], [41].

c. Atomic theory

Experts have agreed that the atomic theory theme of QP should include the Bohr atomic model, discrete energy levels or line spectra, one-dimensional model or potential well, atomic orbital model, and Pauli exclusion principle for a fundamental QP [6], while the finding from the document analysis on the physics curriculum from several countries shows that most countries include energy levels, quantization, atomic structure, spectral lines, the hydrogen atom and the periodic table under atomic theory [2]. In comparison, Malaysia's KSSM textbook gives only a brief explanation of the contradiction between continuous and discrete energy by providing examples of line spectra comprised of emission and absorption spectra of some elements, such as mercury and hydrogen, to define quantum energy representation in an atom as an introduction to quantum energy and there is no further discussion on discrete energy levels or the Bohr atomic model that could explain the existence of the spectra. It is important to note that atomic theory is often taught under quantum chemistry, which usually includes the Bohr atomic and quantum atomic models in explaining spectra [42].

Apart from that, this topic involves complex mathematical formulation of the quantization of the electron energy in explaining the discrete energy levels [43]. Studies found that atomic spectra are difficult for students to understand as they could not relate spectral lines with energy levels [44] and the quantum model of emission and absorption spectra [43], [45]. Nevertheless, exposure to a qualitative understanding of the energy levels and the Bohr atomic model may help students understand how the spectra exist with the aid of visuals and multimedia in introducing and explaining this abstract topic [2] and should have been considered in Malaysia's QP syllabus.

d. Wave function and mathematical representation

The wave function and mathematical representation of QP found in several countries' secondary school curricula serve as an extension for preparing for upper-level or undergraduate studies, which include one-dimensional model or potential well, tunnelling, Schrödinger equation and detection probability as a square of the magnitude of the wave function or square of the phasor length in the sum over path approach [6]. It is also found that these items are not necessarily related to each other and occur independently in some curriculum documents. However, the wave function and mathematical representation of QP concepts are not discussed in Malaysia's KSSM. One of the possible reasons was due to some findings that this wave function and mathematical representation of QP are difficult and have caused misconception [46]. Even so, according to experts' consensus, wave functions that discuss the probability and one dimension potential well are key topics in QP for the secondary school level [2] and should be considered when revising the syllabus contents.

e. Philosophical aspects

This theme discussed the philosophical or epistemological consequences of the interpretations and thought experiments of QP theory like Schrödinger's cat, entanglement, wave-particle duality and complementarity, which should be explicitly mentioned as a learning outcome [6]. Researchers argued that the philosophical aspects are especially valuable as they can help students develop a qualitative understanding of QP if they are allowed to compare their interpretations with those of famous physicists [16]. Moreover, it is found that modern topics like teleportation and entanglement are fascinating for students because they need to modify their understanding of reality [47], and it implies many aspects of NOS that can improve students' understanding of QP [48].

In Malaysia's physics KSSM, the philosophical aspects of QP are not included in the learning standard, where the content focuses primarily on the fundamental principles, the phenomena, and a few applications. As previously pointed out, the philosophy behind wave-particle duality with Bohr's perception of complementarity might be valuable to be discussed as it is crucial for understanding its principle, which argues that the quantum entity, whether a particle or a wave, should be considered complementary to one another and does not exist simultaneously [49]. This discussion is not only important for students to understand the consequences but also useful to instill the understanding of the NOS; for example, the role of scientific models can be highlighted here, whereby a model only serves to show some aspects or particular phenomena as in this topic, it reveals that the quantum entity is represented by different models of light and matter for a different experiment [6].

4.2.3. NOS and history of science in QP

NOS in this paper refers to what students are expected to understand about the processes and methods involved in scientific study, particularly in QP [6], which is essential in developing students' scientific literacy and critical thinking [38], [50]. Therefore, teachers should not only provide the outcomes of scientific study as factual information but also guide students to conduct scientific research and facilitate them to gain knowledge of scientific knowledge development [30], [51]. Among NOS aspects is a methodology which involves experiments and making hypotheses, the role of scientific models, tentativeness of science, creativity in science and controversies in science, which are relevant to the context of teaching QP [6]. To the long-held hypothesis that light is a wave, Einstein added the photon hypothesis of light to explain the photoelectric effect. This theory was one of the many steps in a historical paradigm shift that eventually led to QP development. Different QP interpretations show that scientists question existing models and interpretations and that this is an ongoing process. More than in other parts of physics, the history of QP is regarded as relevant for education. Historical experiments illustrate why scientists had to change their mechanical worldview. For students, this can give science a more human image and bring theory to life [6].

In physics KSSM, the NOS is not explicitly informed in the learning standard. The given textbook only provides experimental activities, such as conducting a virtual experiment using interactive simulation and determining Planck's constant value using Planck's constant kit [39], that allow students to practice methodological aspects and inquiry learning, which is crucial in developing scientific literacy of the students [30], [51]. The learning standard of the physics KSSM has included the historical perspective of the QP development, which aligns with the necessity of including QP development history to expose students to the tentativeness of science [48]. However, it has been identified that the tentativeness aspect of QP is not explicitly discussed in the textbook.

As the MOE aspires to develop students' scientific attitudes and values, discussing this aspect in revealing the NOS is a good opportunity to instill awareness and appreciation towards science. In particular, students should know that knowledge is not definite and unalterable and that scientific processes do not provide definitive evidence. For example, students must realize that Newtonian physics cannot explain quantum phenomena and that scientific knowledge is always developing, transforming, and improving [48].

The experts believe that QP lessons should explicitly discuss the NOS to nourish creativity, whereby scientists do not simply follow a rigid method or procedure but instead use their creativity and imagination to develop a theory or solution [48]. For instance, developing QP theory is only possible by thinking out of the box, which leads to a creative thought experiment. It is also beneficial to discuss the controversies in science so students may understand how important debates and arguments over science theories are to developing knowledge, how difficult it can be to accept new scientific findings, and how interpretations might vary. In fact, the revolution of modern physics started with a controversial debate among physicists. For example, Einstein and Bohr's discussions illustrate how differing philosophical perspectives result in divergent interpretations. There is currently no consensus over QP interpretations, meaning the breakthroughs in QP are made possible only by an environment free of rigid standards [48].

Explicit inclusion of the NOS in the QP learning standard can guide and encourage teachers to discuss with students the related aspects to develop scientific literacy and critical thinking [30], [51], meaning teachers will be more aware of their commitment to not only share the facts but also facilitate students to develop the necessary skills through learning with NOS exposure. Hence, students can readily shift from classical physics to QP if they view science as ever-evolving and are aware that social and historical circumstances impact creative human endeavor. Thus, it may motivate them to learn more about QP [16]. Students who are unfamiliar with these facets of NOS would anticipate a single 'right' explanation for experimental outcomes, which would only lead to their confusion, while those who can view human endeavor may embrace the development of alternative interpretations for experimental data since it facilitates their understanding of complex concepts [48].

5. CONCLUSION

In general, two out of six common trusts and topics of QP for secondary school that is taught in other countries are not included in Malaysia's syllabus, whereas the other four are only briefly discussed. The two topics excluded are Heisenberg's uncertainty principle and the probabilistic nature of QP. Meanwhile, the wave function and the mathematical representation of QP are not discussed in the Malaysian secondary school as it uses complex mathematic formulation and may confuse students in understanding QP. Thus, it can be generalized that in terms of the actual syllabus content, Malaysia's secondary school QP is just around 50% of the syllabus in the mentioned countries.

From the thematic analysis point of view, the fundamental principal aspects of QP are confined only to wave-particle duality, provided with some simple applications of QP, a brief discussion on atomic theory, very limited on the formulation content, and no formal inclusion of its philosophical aspect. In addition, content that may assist students' exposure to the NOS is very limited. Nevertheless, the inclusion of QP in Malaysia's secondary school syllabus is a plausible move to expose the future scientists of the country on how everything might work in addition to the understanding of the real NOS. However, the contents and the theme are needed to be broadened to at least similar to other countries. Otherwise, the inclusion would only create extra difficulties for students with minimum benefit to the projected impact.

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