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Teaching Quantum Physics at Secondary Schools: A Systematic Literature Review

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Abstract

Quantum Physics (QP) a topic that is dealt at the university level. However, QP is beginning to be introduced at secondary schools. The aim of this study is to analyse the extent to which QP has been applied at secondary schools, what teaching methods teachers used to teach QP and what challenges teachers faced when teaching QP. This systematic literature review focus on empirical studies published from 2017 to 2022 in English and in these three databases: SCOPUS, Web of Science and Google Scholar. Based on the PRISMA methodology, 24 articles were selected and thematically analysed. The themes identified on teaching methods were: 1) Using technology in teaching QP, 2) Experimental based learning and 3). Role of nature of science. Teachers faced three major challenges in teaching QP. First and second challenges are related to lack of laboratory equipment and related references respectively. The third challenge is on teachers' misconceptions of QP concepts. The study draws the conclusion that teachers require training that focuses on teaching methods relevant for secondary school students. Future research to overcome teachers' misconception for QP is imperative.

Keyword: Physics Quantum, Teaching Methods, Teachers, And Secondary School.

Introduction

Quantum Physics (QP) is usually studied at fourth year of physics undergraduate program at the university. QP is one of the many abstract topics in physics which students need a strong knowledge and skills in physics and mathematics to understand and solve problems based on QP. There are several reasons why quantum physics (QP), which is not just about mathematics calculation, should be included in secondary school curricula. First, QP must be taught in high school and should not be restricted to 19th-century physics because it is essential for our contemporary scientific worldview, (Kaur et al., 2017; Pospiech, 2009). Quantum-related studies of physics are on the rise in today's increasingly modern world, producing equipment such as solar cells, microchips, and lasers. To trigger students' interest in this field and quantum technology, QP is introduced at the secondary school. Based on Einstein's theory of relativity, teachers should take the opportunity to show interesting insight into physics especially in QP which not only personifies scientists but also students (Bungum et al. (2015) and Angell (2004)

The theoretical work by Bohr, Einstein, De Broglie, and many other notable scientists lay the groundwork for the development of a new theory of physics and quantum has been one of the most significant branches of physics. The theoretical developments in quantum physics have also had an impact on philosophy, biology, electrical engineering, health, and communication technology. Typically, the following major issues are covered in these courses, along with some historical advances in quantum theory and notable experiments: De Broglie wavelength, double slit interference, probability analysis, uncertainty principle, photoelectric action, wave, and particle behaviour (Wuttiprom et al. (2009) and Kragh (1992)). Heisenberg's uncertainty principle and other quantum physics principles are taught in high school textbooks in a qualitative manner without the use of complex mathematics.

Numan et al. (2022) has conducted a systematic literature review (SLR) on interactive teaching with the help of computers and challenges faced by teachers. Numan Ali et al. (2022) stated that virtual labs and simulation software allowed students to perform hands-on experiments in a digital environment. Nyirahabimana et al. (2022) in their research also stated that using multimedia technology in teaching quantum physics can improve the comprehension of concepts and solve complex problems. These interactive labs aimed to enhance students' learning experience by providing a more engaging and immersive way of learning physics concepts. The teaching method discuss in this SLR focussed only on one teaching approach. There for, more effort is needed in identifying others teaching approaches that would facilitate the teaching of QP. Based on research conducted by Simin et al. (2015), ICT resources offered in schools are insufficient and not in good condition; teachers receive insufficient training and professional development; technical help is offered but occasionally; and the school's computer lab is in poor shape despite having functional equipment.

Various teaching methods are used by lecturers at the university such as lecture, interactive learning, problem solving session and laboratory work. According to Hasan and Pervin's (2016) research, experiments, animations, visualisations, and other comparable techniques helped students at universities better understand the QP. Students can see quantum systems, wave functions, energy levels, and other abstract concepts with the aid of visualisation tools, computer simulations, and interactive software, (Hasan and Pervin (2016)). Although teaching methods using technology can help in teaching QP, university students still faced problems making the transition from classical physics to quantum physics, which was particularly noticeable in quantum physics topics like black body radiation, the wave-particle structure of light, and the uncertainty principle (Hasan and Pervin (2016)). Students conduct the experiment to learn QP in university, it helps students to understand QP especially for observation topics. Therefore, to what extent this approach is relevant at secondary schools at also relevant and in addition to understand what the challenges for teachers in secondary schools are, which is the aim of this systematic review Thus, the research questions are:

1. What are the teaching strategies in quantum physics?
2. What are the challenges in teaching quantum physics?

Research Method

In the process of conducting systematic literature review, it involves the process of identifying, selecting, evaluating, and collecting and analysing data from relevant and related past studies (Moher et. al.,2009). PRISMA guidelines and flowcharts are used in conducting this SLR study. All articles for review are obtained from the SCOPUS, Web of Science (WOS) and Google Scholar databases. The phrase searching function and the Boolean operators OR

and AND are used for combining keywords at the start of the advanced search procedure. Handpicking, backtracking, and forward tracking were used for manual author search. As for the eligibility criteria, pre-reviewed and published studies in a scholarly journal will be selected (Newspapers, proceeding and magazines were excluded).

The research question is based on references from earlier investigations by (Stephanie et al. 2021). All the articles sought are related to the teaching methods and challenges in teaching QP. The authors used mnemonics PICo which represents 'P' (Population or Problem), 'I' (interest) and 'Co' (Context) (Lockwood et al. 2015). Based on PICo, the authors selected secondary school teachers (Population), teaching strategy (Interest), and quantum physics (QP) (context) as the factors for this SLR. Therefore, the primary inquiry of this study is: "How does a high school teacher teach quantum physics?"

The study involves four steps: identification, screening, eligibility, gathering data and analysing the results. The author specifies keywords for the identification process, including teaching strategies, high school teachers, and quantum physics. The authors were able to develop these terms further by using an online lexicon, reviewing keywords from prior studies, consulting SCOPUS' suggested keywords, and consulting subject-matter experts. Several terms related to teaching strategy and QP, such as *teaching method, learning approach, learning strategy, teaching culture, pedagogy, quantum mechanics, quantum* dan *physics* were checked based on this procedure. Using Boolean operators, these keyword combinations were examined in the Web of Sciences and SCOPUS databases (Table 1), while the handpicking method is used to select studies from Google Scholar. The authors solely concentrate on quantum physics teaching strategies for high school students. After thorough scanning, 263 suitable articles were found from the selected databases.

Table 1
Search string in the advanced database

Database	String
SCOPUS	**TITLE-ABS-KEY ((*"PHYSICS"*) AND (*"TEACHER"*) OR (*"TEACH"*) AND (*"QUANTUM"*)) AND (LIMIT-TO (PUBYEAR , *2022*) OR LIMIT-TO (PUBYEAR , *2021*) OR LIMIT-TO (PUBYEAR , *2020*) OR LIMIT-TO (PUBYEAR , *2019*) OR LIMIT-TO (PUBYEAR , *2018*) OR LIMIT-TO (PUBYEAR , *2017*))**
Web Of Sciences	**TS= ((*"PHYSICS"*) AND (*"TEACHER"*) OR (*"TEACH"*) AND (*"QUANTUM"*)) AND (LIMIT-TO (PUBYEAR , *2022*) OR LIMIT-TO (PUBYEAR , *2021*) OR LIMIT-TO (PUBYEAR , *2020*) OR LIMIT-TO (PUBYEAR , *2019*) OR LIMIT-TO (PUBYEAR , *2018*) OR LIMIT-TO (PUBYEAR , *2017*))**

Sources: String are from SCOPUS and WOS.

The second process was screening, in which publications were either included or eliminated from the research based on a specific set of criteria manually or with the use of the database as shown in Table 2. Based on the idea of "research field maturity," Kraus et al. (2020) said that this review restricted the screening procedure to only include the papers published between 2017 and 2022.

This timeframe was chosen because there was enough published research to allow for a thorough review. The authors made the choice to evaluate a study that was exclusively published in scholarly journals and had a research design pertaining to QP teaching methods. Notably, only research articles written in English were taken into consideration to prevent confusion. 263 papers were disregarded because they did not adhere to the SLR's standards, which were to derive a QP teaching method from the studies that had been conducted. Therefore, 40 articles were left for consideration in the following step.

Table 2
Criteria for inclusion and exclusion

Criterion	Inclusion	Exclusion
Time interval	2017 - 2022	Less than 2015
Document format	Qualitative, Quantitative, Mixed Methods, or Meta-Analyses - Empirical research, Articles.	Magazines and newspaper, proceeding, conference paper.
Language	English	Non-English
Field of study	Science social	Studies in medicine, public health, and other fields of non-social science, quantum computing, quantum model.

The third process was eligibility, where authors need to review the articles manually by reading abstract, methodology, analysing data or overall, of the articles to see whether it met the predetermined inclusion criteria or not. During the title screening phase, 177 articles were disqualified, while 62 articles were eliminated during the abstract screening phase. From SCOPUS and Web of sciences only 19 articles can be used for this SLR, the authors add another 5 articles by handpicking in Google Scholar. Only 24 papers were ultimately selected for the quality assessment step (Figure 1).

Screening Process

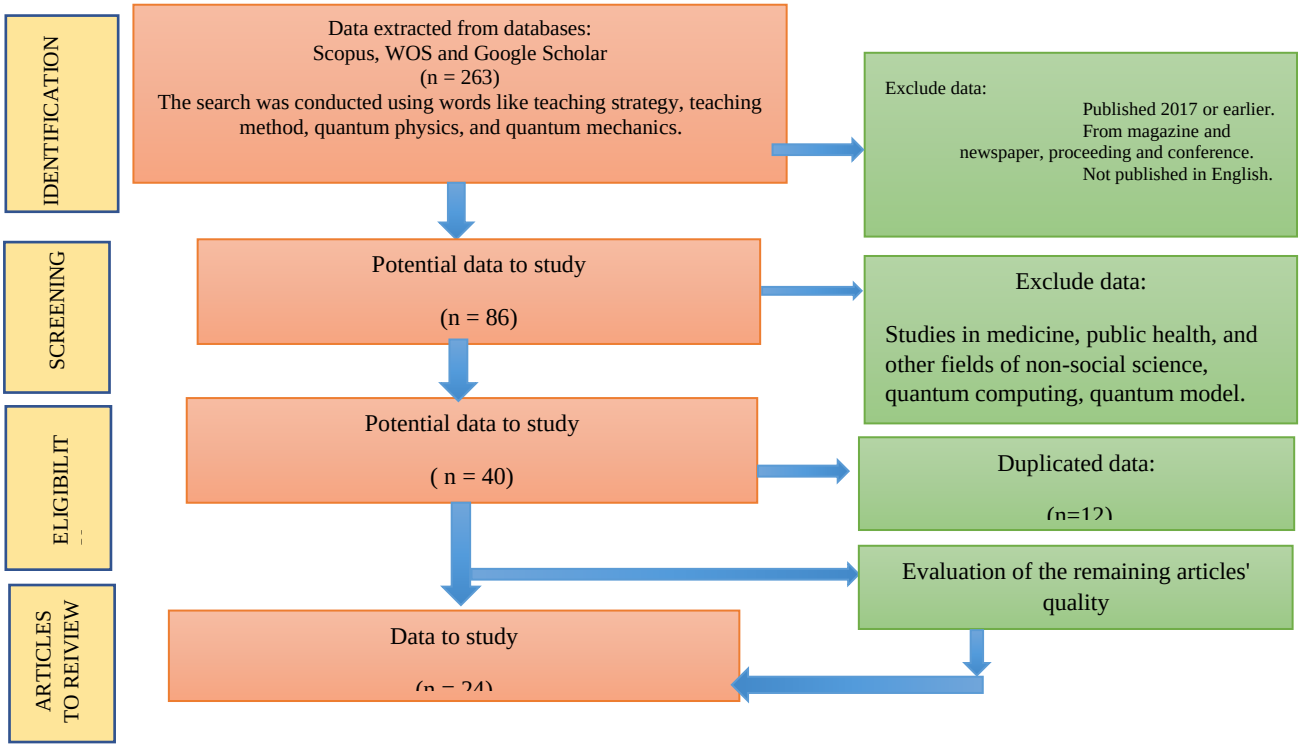

Figure 1: PRISMA Systematic Literature Highlights adapted from Page et al. (2021)

Data Analysis

The quality assessment stage was carried out to make sure the methodology and analysis of the chosen studies were adequately finished. The Mixed-Method Appraisal Tool (MMAT) developed by Hong et al. (2018) was employed for this purpose. The purpose of using MMAT is to evaluate the studies conducted are systematic and structured. For the qualitative research the articles were thematically evaluated to show the best ways to include the variations through qualitative synthesis (Whittemore and Knafl 2005). By identifying any similarities or links that may exist in the current data, thematic analysis seeks to find and alert the pattern of previous studies (Braun and Clarke 2019). From the analysis, there are 6 out of twenty-four articles using qualitative research. Based on the steps proposed by Kiger and Varpio (2020), thematic synthesis is carried out and each article will be reviewed based on pre-set themes. All the articles used interview as the instrument to get data from respondents. The analysis is shown in table 3.

Meta-analysis is a synthesis technique that focuses on the benefits and/or harms of therapy across several studies to provide the best estimate regarding the effect of an intervention (Morton et al. 2017). Meta-analysis is a quantitative synthesis of review data. Twelve articles used the quantitative method in the study, where the focus of the study was on pupils, teachers, and prospective teachers. Based on the analysis, two articles used test instrument and questionnaire with quasi experimental design. Meanwhile, nine studies used questionnaire. The result is shown in table 3.

Table 3
Summary of Country, Methodology, Instrument and Sample Size of 24 Selected Articles.

Author	Country	Methodology	Instruments	Sample size
Anggara et al. (2021)	Netherlands	Quantitative	Questionnaire	30 students
F pallott et al. (2022)	Italy	Mix method	Questionnaire and semi structured interview	29 teacher and 107 students
Massimiliano et sl. (2017)	Italy	Mix method	Questionnaire and interview	14 students
Philipp (2021)	Germany	Mix method	Questionnaire and interview	10 teachers
Putri et al. (2022)	Indonesia	Mix method	Questionnaire and interview	Not stated clearly
T. Bouchée, et al. 2021	Netherlands	Mix method	Questionnaire and interview	3 teachers and 15 students
Leonid et al. (2020)	Russia	Mix method-Experimental	Questionnaire and interview	35 teachers
Efraim Yehuda et al. (2022)	Israel	Qualitative	Interview	Nine expert
H. K. E. Stadermann et al. (2021)	Netherlands	Qualitative	Interview	10 teachers
H. K. E. Stadermanne et al. (2019)	Netherlands	Qualitative	Document analysis	15 syllabus QP
Kirsten et al. (2022)	Netherlands	Qualitative	Interview	Group of teachers
Marco et al. (2021)	Italy	Qualitative	Interview	Not stated clearly
Maria Luisa et al. (2022)	Italy	Qualitative	Open questions	20 students
F A Pradana et al. (2019)	Indonesia	Quantitative	Questionnaire	130 students and 4 teachers
Gregory T. Rushton et al. (2017)	USA	Quantitative	Questionnaire	k-12 schools
İlbilge et al. (2019)	Germany	Quantitative	Questionnaire-Experimental	Not mention clearly (State small group)
K. Krijtenburg et al. (2017)	Netherlands	Quantitative	Questionnaire	98 students
Luiza Vilarta et al. 2020	Netherlands	Quantitative	Questionnaire	114 students

M Di Mauro et al (2022)	Italy	Quantitative	Questionnaire	Not stated clearly
Meryem et al. (2018)	Turkey	Quantitative	Questionnaire	48 teaching students
Onah and Kingsley T (2022)	Nigeria	Quantitative	Questionnaire - Quasi experiment	85 students
Onah et al. 2022	Nigeria	Quantitative	Questionnaire	60 students
Philipp et al. (2020)	Germany	Quantitative	Questionnaire	30 students
Gregory A. DiLisi et al. (2020)	USA	Quantitative-Quasi experiment	Interview	18 pre-service teachers

To find, examine, and report on themes (or patterns) within the data, thematic analysis Braun and Clarke (2006) was utilised. The author analysis's themes from articles, each theme aims to summarise key facts regarding the data, Kelly et al. (2019). The thematic analysis is used to find, examine, and interpret patterns or themes in a dataset or text. To find repeating themes, concepts, or meaning patterns in data, it entails methodically classifying and categorising the information. Researchers can learn more about the participants' viewpoints, experiences, or social phenomena by using thematic analysis to examine and comprehend the underlying themes or issues that appear in the data, Braun and Clarke (2006).

To come up with a theme, the author read 24 articles and preset themes for QP teaching methods. Theme emerged for teaching strategies were: i) teaching method using computers technology; ii) Experimental based learning; and iii) teaching based on the nature of sciences (NOS). As for challenges the themes were: i) Infrastructure; ii) misconception in QP and iii) textbook.

Result and Discussion

Study-focused countries

The authors have identified the country that carried out the QP-related studies based on the 24 articles. The number of countries that have done a study of QP is shown in figure 1 and the authors for all the articles are shown in Table 3.

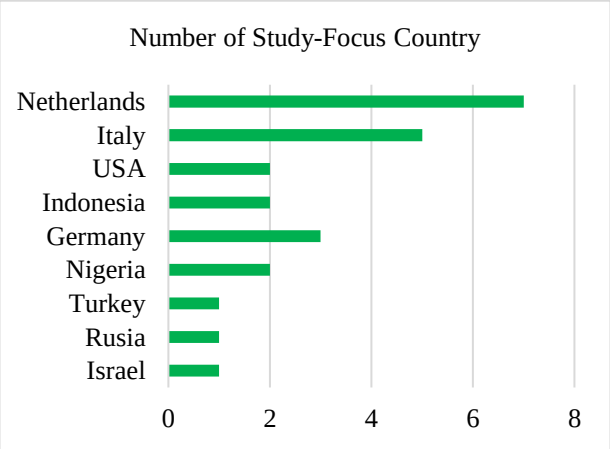

Figure 1: Number of studies based on the country.

Based on the number of studies focused by country, it shows that Netherlands is the most country studied about QP. Based on the research by Staderman et al. (2019),

Netherlands had implemented QP in the curricula since 2016. Staderman et al. (2019) also shows the country of the Netherlands included twelve subtopics in the QP curricula. Italy also conducted a lot of QP-related studies as the QP curricula has been included in secondary school since 2010 with ten subtopics introduced.

The results of the analysis of 24 articles showed that there is an increase in studies from 2020 to 2022. Figure 2 shows the number of articles published since 2017. The increase in studies occurred as more and more countries included curricula QP at the high school level. Staderman et al. (2019) has studied 15 curricula of QP in 2015, that only three countries namely Spain, Belgium, and Scotland out of 15 countries included curricula QP in secondary schools and in 2016 an increase of seven countries included QP in curricula. Figure 2 shows the number of articles published from 2017 to 2022.

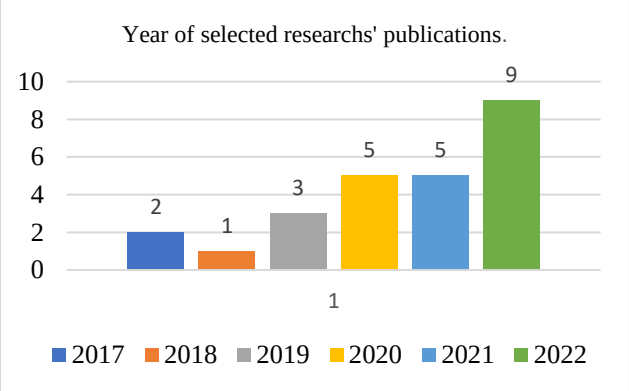

Figure 2: Year of selected research publication.

In 2017 only USA and Italy did research about QP. The focus was on the method of teaching QP and how to increase the ability of students to connect different ideas and experiments related to quantum theory (Massimiliano et al. (2017) The issue of QP became so important that the increase in studies every year and in 2022 a total of nine studies were conducted and four of them were reviewed by researchers from the Netherlands. Researchers began to focus the study on the most effective teaching methods and what challenges teachers face to teach QP.

Methodology, Instrument, and Sample Size

Soares et al (2013) and Hopia et al. (2016) claim that the mix method is the most effective for resolving problems by considering them from a variety of angles. Mixed methods research allows researchers to gain a comprehensive understanding of the research topic by integrating both qualitative and quantitative data. Qualitative methods provide in-depth insights, capturing rich contextual information and exploring complex phenomena, while quantitative methods provide numerical data for statistical analysis and generalizability. All seven articles used interview to collect data from small group and questionnaire to get more data in big group using questionnaire. The summarise for the methodology used in the research shown in table 3, twelve articles used quantitative method, six researcher used qualitative method and mix method respectively. For future research, it is suggested that researchers use qualitative methods because researchers will be able to gather information by focusing on exploring insights, meanings, experiences, and deep attitudes by using methods such as interviews, observations, text analysis, and case studies collected, examined, and interpreted.

Based on the systematic literature analysis, 12 articles used students as the sample in their research and six researchers focus on physics teachers as shown in table 3. This shows that more researchers focus on students as a sample and focused on understanding the concept of QP among students. Therefore, future studies should focus on teaching methods and what challenges teachers face. The focus should be on teachers first as teachers play an important role in introducing the QP fundamental to pupils using the effective and diverse teaching methods.

Table 4
Data analysis based on theme

No	Authors (Year)	Teacher competencies			Teacher resources		
		Using computer and technology	Experimental	Nature of Science	Infrastructure	Misconception	Textbook
1	Anggara et al. (2021)	√					
2	Efraim et al. (2022)		√	√	√		√
3	F A Pradana et al. (2021)	√	√	√			√
4	F pallott et al. (2022)	√	√				
5	Gregory et al. (2020)						√
6	Gregory et al. (2017)						
7	H. K. E. Stadermann and Goedhart (2021)			√	√		√
8	H. K. E. Stadermann et al. (2019)			√	√		√
9	İlbilge et al. (2019)					√	√
10	K. Krijtenburg et al. (2020)						√
11	Kirsten and Martin (2022)	√		√			√
12	Leonid et al. (2020)	√			√		
13	Luiza Vilarta et al. (2020)						
14	M Di Mauro et al. (2022)	√					√
15	Marco et al. (2021)		√				√
16	Maria Luisa et al. (2022)				√	√	√
17	Massimiliano et al. (2017)		√				√
18	Meryem and Huseyin (2018)		√				

19	Onah and Kingsley T (2022)				√			
20	Onah et al. (2022)					√		√
21	Philipp Bitzenbauer (2021)	√		√				
22	Philipp and Jan-Peter (2020)			√				
23	Putri and Irma (2022)			√		√		
24	T. Bouchée et al. (2021)	√						√

What are the teaching strategies in quantum physics?

Effective teaching methods and a strong understanding of a subject content are necessary for both teaching and learning physics especially in quantum physics. Despite the study's focus on electromagnetism, it offers insights into instructional approaches that also apply to the field of quantum physics. Along with the advancement of quantum physics in high school physics, the quantum physics teaching methodology is also advancing.

Teaching Methods using Computer and Technology

Using technology to teach quantum physics can be a successful and interesting method since it enables students to interact with simulations, visualise abstract ideas, and investigate complex phenomena more fully. The research investigates the effectiveness of various teaching approaches, including interactive simulations and visualisation tools, in promoting conceptual understanding and engagement among students. The impact of technology-enabled active learning on undergraduate students' comprehension of electromagnetic topics is examined in the study by Dori and Belcher (2005).The study of quantum physics teaching methods shows eleven articles mentioning using technology to teach QP, the data analysis shown in table 5.

Table 5

Teaching method using computer and technology.

Teaching Method: Computer aids or technology	Implementation	Authors and year
Power Point	Learning slides are provided in order by title, teachers can use QP notes to teach.	Donn Silberman (2022)
Quantum games and video.	Students watching videos on quantum physics, superposition, and entanglement, and introducing students to a formal description of quantum states, the students play Tiq Taq-Toe game application.	Maria Luisa et al. (2022) Philipp (2021)
Teaching sequence (Online resources).	Developed teaching material based on design principles from the literature and are revising and	

	optimizing it through feedback from teachers in the field (Online resources).	M Di Mauro et al. (2022)
	Introduce some fundamental concepts of quantum physics to high school teachers.	
Technological applications.	Interactive experiment: Single photons Conducts activities in classroom using technology.	F Pallotta et al (2022)
Used a simulation.	Digital worksheet with Phet simulation on quantum physics.	Anggara et al. 2021
	Simulations or visual representations related to the concepts of Quantum Physics.	Putri and Irma (2022)
Electronic book.	An electronic book on quantum phenomena was developed with a scientific approach as a revision for teachers and students.	F A Pradana et al. (2019)
Digital material.	Use of digital materials as an opportunity to support students' conceptual understanding of quantum physics.	T. Bouchée, et al. (2021)
Digital inquiry-based learning	Simulations, collaborative learning, and conceptual change. The sequence is composed of units, which are being developed using the Go-Lab ecosystem, a free online platform.	Luiza Vilarta et al. 2020

A lot of free digital materials are provided, and this is an opportunity for teachers to help students understand the concept of QP and students also could be directly involved in learning and helping improve their conceptual understanding (Bouchée et al. 2021). Based on Silberman's (2022) study, the PowerPoint slide have been prepared for teacher and they can used it in teaching QP as the teaching material or aids. Teachers can also provide QP teaching materials by using power points. The materials provided in a clear PowerPoint and with QP-based description examples will help facilitate students' understanding, Kirsten et al. (2022). A PowerPoint slideshow that starts with a question that allows students to make initial assumptions and this will be a simulation for students to delve deeper into the QP concepts to be learned. The display of videos and pictures in PowerPoint slides will also help the teacher to make it easier for students to understand QP.

When teaching quantum physics, computer games and videos can be used as a teaching approach. Based on Maria Luisa et al. (2022), teacher can show a video to students about QP, superposition, and entanglement, and introducing students to a formal description of quantum states. After watching the video, teacher can engage students and test their understanding with playing Tiq Taq-Toe game application. From the game students can used their understanding in QP and they can also identify any misunderstanding. Philipp (2021)

also stated that there are online sources that teacher can used to learn about fundamental of QP and teaching sequence.

Anggara et al. (2021) and Putri and Irma (2022) stated that computer simulations such as digital worksheet Phet simulation and simulation representation of QP will help teacher teach QP. One computer simulation developed by The University of Colorado Boulder's PhET Interactive Simulations offers a variety of interactive simulations for teaching quantum mechanics. The study also found that it was possible to improve high school pupils' high order thinking skill (HOTS) in quantum physics using a digital worksheet with a PhET simulation on quantum physics events Anggara Budi et al. (2021). Based on Anggara Budi et al. (2021), the research conducted by using digital worksheet only. Based on Wieman and Perkins (2005), it is important for interactive simulations, including those available on the Phet platform, in transforming physics education. To maximise the benefit of Phet simulation, teachers need to explore and use Phet simulation in class frequently, this will make students engaged with QP and make them understand QP easily.

Technology applications give students the opportunity to investigate quantum phenomena and carry out virtual experiments. Pallotta et al (2022) in their study stated that teachers can conduct interactive experiment of the photon in the classroom by using a technology to stimulate students and their understanding. By using digital material and technology, it can support students understanding, (T. Bouchée, et al. (2021)). They can understand the theory and concept in QP. There are many online resources for teaching quantum physics, including webpages, videos, and interactive platforms. To improve accessibility and engagement, these tools frequently use interactive simulations, visualisations, and computer aids.

Using a digital lab workshop, instructors may help students better comprehend quantum physics. The digital laboratory workshop is a virtual, interactive computer lab that simulates quantum physics physical phenomena that are challenging or impossible to explore using current laboratory apparatus, Leonid et a. (2020). The goal of the digital laboratory workshop is to establish a link between the mathematical formalism of quantum physics and its specific applications by focusing on the physical side of the issues being discussed. Teachers can use digital labs to help students understand QP despite not having enough tools to conduct experiments. The method of teaching using computer assistance is effective in helping students understand QP, but if teachers do not have knowledge related to Phet simulation and digital labs they will not be able to use this teaching method when teaching QP. Based on the studies conducted only discussed about the introduction of simulations and the application of learning using computers, but discussions on how to use simulations were not much studied. There is less discussion regarding workshops or courses conducted for teachers to learn this technology especially in simulation.

Experimental-based Teaching

Experiment-based QP instruction can be a very successful technique to engage secondary school students and aid in their understanding of the fundamental ideas behind quantum mechanics. The teacher can choose the appropriate sub-topics for conducting experiments. Most teachers choose to teach traditionally rather than conduct experiments, whereas according to Philipp and Jan-Peter (2020) idea avoids the conventional historical approach to address the dearth of contemporary concepts in quantum physics by offering an experimentally based guideway to various areas of contemporary quantum physics. F A Pradana et al (2019); Gregory et al (2020) in their studies also discuss that most of the teacher prefer to use traditional teaching method rather than another method. From this SLR, some

studies have been conducted based on teaching methods used experimental based learning. (see table 6);

Table 6
Analysis of teaching methods using experimental based learning.

Teaching method: Experiment based learning	Implementation	Authors and year
Laboratory experience	Use of laboratory experiments to help students understand the fundamental concepts of contemporary physics (QP).	F Pallotta et al (2022)
	Hands-on experiments.	Marco et al. (2021)
	Experiments are an important tool for studying quantum physics	Massimiliano et al. (2017)
	Experimental-based guideway to aspects of modern quantum physics.	Philipp and Jan-Peter (2020)
	Laboratory experiment.	Putri and Irma (2022)

Experimental-based learning in quantum physics is a highly effective approach to engage students in the subject matter and develop their understanding of quantum phenomena through hands-on exploration. By actively participating in experiments, students can directly observe and manipulate quantum systems, enabling them to develop a deeper appreciation for the fundamental principles of quantum physics, Hestenes et al. (1995). Four articles discuss experimental-based learning in QP in this SLR. When students conducted the experiment, they will used a laboratory tool and measuring instrument, this will help students to understands the fundamental of QP, F Pallotta et al (2022). Marco et al. (2021) and Massimiliano et al. (2017), in their studied found that hands on experiment are the important tools in studying QP, students can understand QP based on their observation. Putri and Irma (2022) mention in their studies, laboratory experiments are one of the methods that can be used in teaching QP but because of the lack facilities in school's lab, so the experiment cannot be conducted successfully.

An experiment such as Quantum Measurement Experiments: Measurement plays a crucial role in quantum physics, and conducting experiments related to quantum measurement can help students grasp its significance. Activities involving Stern-Gerlach apparatus, which demonstrate the quantization of angular momentum, or experiments related to the measurement of particle properties like spin, position, or energy, provide students with practical insights into the measurement process and its impact on quantum systems.

When implementing experimental-based learning in quantum physics, it is essential to provide students with guidance, scaffold their understanding, and encourage reflection on their observations. Connecting the experimental results to theoretical concepts and engaging students in discussions about the implications of their findings can further deepen their understanding of quantum physics.

Nature of Science

Teachers need a suitable teaching strategy by considering the nature of science (NOS) when instructing students in quantum physics to match their knowledge and cognitive capabilities. Teachers need to know the NOS of the students then choose a suitable method to teach QP because students need to develop a deeper understanding of the scientific process, the characteristics of scientific knowledge, and the ways in which scientific theories in QP. Based on the analysis, Leonid et al (2020); Kirsten and Martin (2022) stated that teachers need to mention and used NOS in QP (see table 7)

Table 7
Nature of Science

Challenges:	Implementation	Authors and year
Nature of science (NOS)	Teachers address the nature of science in their physics classrooms and how teachers use of nature of science aspects in teaching quantum physics.	Leonid et al. (2020) Kirsten and Martin (2022)
	NOS receives little attention in physics lessons because teachers lack the necessary teaching strategies, physics textbooks generally pay little attention to NOS, and teachers do not see it as their task to teach NOS.	Krijtenburg et al. (2020)
	Suggest discipline culture (DC)	Efraim et al. (2022)
	Explain basic principles of QP.	T. Bouchée et al. (2021)
	Discuss seven methods to teach based on NOS.	F A Pradana et al. (2021) Stadermann and Goedhart (2021) Onah et al. (2022) Stadermann et al. (2019)
	Different strategy based on NOS (Tiq Taq game)	Maria Luisa et al. (2022)

Based on nature of science (NOS) students, Efraim et al. (2022) suggest Discipline-culture (DC)'s approach to curriculum offers a solution for overcoming its substantial challenges. Stadermann and Goedhart (2021) discussed instructional activities such as narrative and explanation, explanatory video, concept questions, peer instructions, dialogic discourse, short written task, and role model can be used based on students' NOS.

Based on activities suggested teacher can create different lessons based on students need and available materials, reflecting their personal preferences. For future research, one can focussed on teaching methods based on NOS students and provide training to teachers.

What are the challenges identified in teaching strategy in quantum physics?

Teaching quantum physics presents several unique challenges due to its abstract nature and departure from classical physics concepts. As the QP is introduced at the secondary school level, many teachers face the challenge of teaching QP topics. From the analysed article the authors discuss themes related to challenges for teachers namely: i) Infrastructure; ii) misconception in QP and iii) textbooks.

Infrastructure

To support effective education and offer students hands-on learning opportunities, teaching QP requires specific infrastructure and resources. Based on Leonid et al. (2020) research, they stated that experiment is a very effective teaching technique for physics. To conduct the experiment, all the apparatus and material must be in a good condition and enough. Based on the analysis result as shown in table 8, three articles stated the important of enough infrastructure especially in laboratory.

Table 8
The infrastructure for teaching QP.

Challenges:	Implementation	Authors and year
Infrastructure	Teaching tools Experiment tools	Stadermann and Goedhart (2021) Stadermann et al. (2019)
	Games tools	Leonid et al. (2020) Efraim et al. (2022) Maria Luisa et al. (2022)

A study conducted by Maria Luisa et al (2022), games method to teach QP, but the tool must be provided in a good condition and adequate. Leonid et al (2020) stated high expense of experimental infrastructure and the expansion of safety regulations is the factor why effective experiment cannot be done. Efraim et al (2022) in their research stated that the concept of uncertainty may represent an experimental limit that might be reduced by applying better tools or techniques. Virtual simulation of a real-world experience is created by a computer experiment and can be used widely in teaching, but the lack of tools caused some of students cannot access the simulation and technology.

Misconceptions from a Quantum Perspective

Krijtenburg-Lewerissa et al (2017) have conducted research, and the result from a pilot test they did they reported that there are misconceptions in photoelectric, photoelectric is one of the subtopics of QP. Students are asked to predict the mechanism underlying the photoelectric effect, out of 42 pairs, four gave the answer "ionisation," four gave the answer "photons and electrons collide," and three gave the answer "voltage is needed for the effect." The results showed that some of the students have misconceptions, Krijtenburg-Lewerissa et al. (2017). So, this is a challenge for teachers where teachers need to address students' misconceptions and spend more time explaining. The results are shown in table 9.

Table 9

Challenges: Misconception	Implementation	Authors and year
Misconception about QP	Physics teachers are used to applying the wave approach, which can make it difficult for them to understand and teach the polarization approach.	Kristóf Tóth (2022)
Misunderstanding	Misunderstanding the relationship between the height of the barrier and the energy required for tunnelling.	K. Krijtenburg et al. (2020)
Misconception	Students had misconceptions about the photoelectric effect. For example, some students believed that the intensity of light affects the kinetic energy of electrons, while others believed that electrons are freed only above a certain value of intensity.	Maria Luisa et al. 2022

The teacher plays a role in explaining the concept of QP to students, but if the teacher explains incorrectly the photoelectric effect will also lead to misunderstandings in QP, Luiza Vilarta et al. (2020). Teachers who are poorly prepared in terms of QP content will cause them to misrepresent the concept of QP to students. Teachers also have forgotten the QP content since most likely the teachers last encounter with the QP at their undergraduate studies.

Kristóf (2022) discussed a few of the challenges that instructors may encounter when learning new approaches to quality improvement. Based on Kristof's research, s teachers need training programs with the expertise to avoid misconception. Teachers need a solid understanding of quantum physics concepts and principles. Participating in professional development programs, attending workshops, or pursuing advanced courses in quantum physics can help teachers deepen their content knowledge. Collaborating with other educators can provide insightful advice and supportive guidance. Not many studies were conducted on teachers participating in professional organisations to improve their understanding of QP and avoid misconceptions.

Textbook

Teachers use textbooks as guides and references during QP lessons. 15 articles as shown in table 9 state that textbook is used by physics teachers at the secondary school as a reference during teaching, problems solving and explain the applications of QP.

Table 9
Textbook as the resource

Challenges:	Implementation	Authors and year
Textbook	Electronic book. Textbook	F A Pradana et al. (2019) Efraim et al. (2022) Gregory et al. (2020) Stadermann and Goedhart (2021) Stadermann et al. (2019) İlbilge et al. (2019) Krijtenburg et al. (2020) Kirsten and Martin (2022) M Di Mauro et al. (2022) Marco et al. (2021) Massimiliano et al. (2017) Maria Luisa et al. (2022) T. Bouchée et al. (2021) Onah et al. (2022) T. Bouchée et al. (2021)

Based on Onah et al. (2022) textbook is use by teacher in QP class to explain the important concepts. From table 9, the articles stated most of the teacher used the textbook in conventional teaching method where teacher explain QP based on textbook. Teacher refers to the concepts, examples and application shown in textbook without providing other examples from different sources. Thus, one can conclude that concepts explained in textbooks should be free of misconceptions as teachers depend heavily on it. One possible recommendation is to conduct a content analysis of textbooks to identify various ways of presenting QP concepts in a comprehensible way to the students. In addition, ensuring that textbook explanation is free of misconceptions.

Conclusion

The recent literature review about QP in secondary schools showed that QP is included at the school curriculum in an increasing number of countries including Malaysia. The teaching of quantum physics is mostly done through experiments and computer assisted teaching. Both methods would require sufficient infrastructure thus schools need to be prepared in terms of its availability. In addition, the role of nature of science, is highlighted as an effective way of teaching QP. However, more research in needed in determining ways to integrate NOS meaningful when teaching QP. Finally, teachers understanding of QP is crucial for ensuring effective teaching and learning of QP at schools. With the assistance of misconception free textbooks and continuous professional development for the teachers- thus would lessen the challenges of teachers teaching QP at secondary schools.

Reference

Achufusi, N. N. (2022). Effect of Metaconceptual Teaching Approach on Students' Effect of Metaconceptual Teaching Approach on Students' Academic Achievement and Interest in Quantum Physics in Enugu Education Zone. *AJSTME*, *8*(1), 80–90. https://orcid.org/0000-0003-4075-8580

Ali, N., Ullah, S., & Khan, D. (2022). Interactive Laboratories for Science Education: A Subjective Study and Systematic Literature Review. In *Multimodal Technologies and Interaction* (Vol. 6, Issue 10). MDPI. https://doi.org/10.3390/mti6100085

Baybars, M. G., & Kucukozer, H. (2018). The effect of 7E learning model on conceptual understandings of prospective science teachers on "de Broglie matter waves" subject *. *European Journal of Educational Research*, *7*(2), 387–395. https://doi.org/10.12973/eu-jer.7.2.387

Bitzenbauer, P., & Meyn, J.-P. (2020). *A new teaching concept on quantum physics in secondary schools* (Vol. 55).

Bitzenbauer, P. (2021). *Practitioners' views on new teaching material for introducing quantum optics in secondary schools* (Vol. 56).

Bouchée, T., Thurlings, M., de Putter - Smits, L., & Pepin, B. (2021). Investigating teachers' and students' experiences of quantum physics lessons: opportunities and challenges. *Research in Science and Technological Education*. https://doi.org/10.1080/02635143.2021.1948826

Braun, V., & Clarke, V. (2019, June 13). Reflecting on reflexive thematic analysis. *Qualitative Research in Sport, Exercise and Health*, *11*(4), 589–597. https://doi.org/10.1080/2159676x.2019.1628806

Chiofalo, M. L., Foti, C., Michelini, M., Santi, L., & Stefanel, A. (2022). Games for Teaching/Learning Quantum Mechanics: A Pilot Study with High-School Students. *Education Sciences*, *12*(7). https://doi.org/10.3390/educsci12070446

Di Mauro, M., Esposito, S., & Naddeo, A. (2021). Introducing quantum and statistical physics in the footsteps of einstein: A proposal†. *Universe*, *7*(6). https://doi.org/10.3390/universe7060184

Di Mauro, M., Esposito, S., & Naddeo, A. (2022). Teaching quantum physics in the footsteps of Einstein. *Journal of Physics: Conference Series*, *2297*(1). https://doi.org/10.1088/1742-6596/2297/1/012036

Dilisi, G. A., Chaney, A., Mclean, S., & Rarick, R. (n.d.). *A Case Studies Approach to Teaching Introductory Physics A Case Studies Approach to Teaching Introductory Physics Part of the Physics Commons*. https://collected.jcu.edu/fac_bib_2020

Dökme, İ., & Koyunlu Ünlü, Z. (2021). The Challenge of Quantum Physics Problems with Self-Metacognitive Questioning. *Research in Science Education*, *51*, 783–800. https://doi.org/10.1007/s11165-019-9821-4

Garnaeva, G., Shigapova, E. D., & Nizamova, E. I. (2020). The Use of Digital Laboratory Work in Quantum Physics in the Process of Learning Physics Teachers. *VI International Forum on Teacher Education*, *1*, 1767–1777. https://doi.org/10.3897/ap.2.e1767

Ghavifekr, S., & Rosdy, W. A. W. (2015, March 2). Teaching and Learning with Technology: Effectiveness of ICT Integration in Schools. *International Journal of Research in Education and Science*, *1*(2), 175. https://doi.org/10.21890/ijres.23596

Kızılcık, H. A., & Yavaş, P. N. (2016, December 14). Pre-service Physics Teachers' Opinions about the Difficulties in Understanding Introductory Quantum Physics Topics. *Journal of Education and Training Studies*, *5*(1), 101. https://doi.org/10.11114/jets.v5i1.2012

Hong, Q. N., Fàbregues, S., Bartlett, G., Boardman, F., Cargo, M., Dagenais, P., Gagnon, M. P., Griffiths, F., Nicolau, B., O'Cathain, A., Rousseau, M. C., Vedel, I., & Pluye, P. (2018, December 18). The Mixed Methods Appraisal Tool (MMAT) version 2018 for information professionals and researchers. *Education for Information*, *34*(4), 285–291. https://doi.org/10.3233/efi-180221

Krijtenburg-Lewerissa, K., Pol, H. J., Brinkman, A., & Van Joolingen, W. R. (2017). Insights into teaching quantum mechanics in secondary and lower undergraduate education. *Physical Review Physics Education Research*, *13*(1). https://doi.org/10.1103/PhysRevPhysEducRes.13.010109

Krijtenburg-Lewerissa, K., Pol, H. J., Brinkman, A., & Van Joolingen, W. R. (2020). Secondary school students' misunderstandings of potential wells and tunneling. *Physical Review Physics Education Research*, *16*(1). https://doi.org/10.1103/PHYSREVPHYSEDUCRES.16.010132

Malgieri, M., Onorato, P., & De Ambrosis, A. (2017). Test on the effectiveness of the sum over paths approach in favoring the construction of an integrated knowledge of quantum physics in high school. *Physical Review Physics Education Research*, *13*(1). https://doi.org/10.1103/PhysRevPhysEducRes.13.010101

Morton, R. W., Murphy, K. T., McKellar, S. R., Schoenfeld, B. J., Henselmans, M., Helms, E., Aragon, A. A., Devries, M. C., Banfield, L., Krieger, J. W., & Phillips, S. M. (2017, July 11). A systematic review, meta-analysis and meta-regression of the effect of protein supplementation on resistance training-induced gains in muscle mass and strength in healthy adults. *British Journal of Sports Medicine*, *52*(6), 376–384. https://doi.org/10.1136/bjsports-2017-097608

Nyirahabimana, P., Minani, E., Nduwingoma, M. & Kemeza, I. 2022. Prime indicators of current teaching methodologies and students' perceptions in quantum physics. *International Journal of Evaluation and Research in Education (IJERE)* 11(3): 1134.

Numan Ali, Sehat Ullah and Dawar Khann (2022). Interactive Laboratories for Science Education: A Subjective Study and Systematic Literature Review. Multimodal Technol. Interact. 2022, 6, 85. https://doi.org/10.3390/mti6100085

Pallotta, F., Parola, A., & Bondani, M. (2022). Quantum physics at high school: a collaboration between physics researchers and teachers to design teaching - learning sequences. *Journal of Physics: Conference Series*, *2297*(1). https://doi.org/10.1088/1742-6596/2297/1/012019

Paransucia, P., & Amalia, I. F. (2022, November 16). Physics teachers' difficulties in teaching introduction to quantum physics in senior high school. *Research in Physics Education*, *1*(1), 14–24. https://doi.org/10.31980/ripe.v1i1.2095

Pradana, F. A., Suyatna, A., Ertikanto, C., & Herlina, K. (2019). The Development of an Electronic Book on Quantum Phenomena to Enhance Higher-Order Thinking Skills of the Students. *Journal of Physics: Conference Series*, *1155*(1). https://doi.org/10.1088/1742-6596/1155/1/012012

Rushton, G. T., Rosengrant, D., Dewar, A., Shah, L., Ray, H. E., Sheppard, K., & Watanabe, L. (2017). Towards a high-quality high school workforce: A longitudinal, demographic analysis of U.S. public school physics teachers. *Physical Review Physics Education Research*, *13*(2). https://doi.org/10.1103/PhysRevPhysEducRes.13.020122

Silberman, D. M. (2022). *Quantum education and pathways: an open-source modifiable presentation to high school and college students*. 38. https://doi.org/10.1117/12.2641537

Solmaz Khodaeifaal (2017). Curriculum, Pedagogy, and the Practical: From Waves to Quantum Physics. Simon Fraser University. Spring

Stadermann, H. K. E., & Goedhart, M. J. (2021). Why and how teachers use nature of science in teaching quantum physics: Research on the use of an ecological teaching intervention in upper secondary schools. *Physical Review Physics Education Research*, *17*(2). https://doi.org/10.1103/PhysRevPhysEducRes.17.020132

Stadermann, H. K. E., Van Den Berg, E., & Goedhart, M. J. (2019). Analysis of secondary school quantum physics curricula of 15 different countries: Different perspectives on a challenging topic. *Physical Review Physics Education Research*, *15*(1). https://doi.org/10.1103/PhysRevPhysEducRes.15.010130

Susila, A. B., Chanifah, A., & Delina, M. (2021). Development of Digital Worksheet with PhET Simulation on Quantum Physics to Enhance Students' HOTS. *AIP Conference Proceedings*, *2320*. https://doi.org/10.1063/5.0039417

T. Kaur, D. Blair, J. Moschilla, W. Stannard, and M. Zadnik, Teaching Einsteinian physics at schools: Part3, review of research outcomes, Phys. Educ. 52, 065014 (2017).

Tóth, K. (2022). Introducing Quantum Mechanics through light polarization: Experiences in Hungary. *Journal of Physics: Conference Series*, *2297*(1). https://doi.org/10.1088/1742-6596/2297/1/012016

Velychko, V., & Zyma, G. (2021, December 15). Virtual laboratory workshops in the process of training future physics teachers. *E-Learning TeXnology*, *5*, 73–78. https://doi.org/10.31865/2709-840052021247378

Vilarta Rodriguez, L., van der Veen, J. T., Anjewierden, A., van den Berg, E., & de Jong, T. (2020). *Physics Education Designing inquiry-based learning environments for quantum physics education in secondary schools Designing inquiry-based learning environments for quantum physics education in secondary schools*. www.golabz.eu

Weissman, E. Y., Merzel, A., Katz, N., & Galili, I. (2022). Phenomena and Principles: Presenting Quantum Physics in a High School Curriculum. *Physics (Switzerland)*, *4*(4), 1299–1317. https://doi.org/10.3390/physics4040083

Whittemore, R., & Knafl, K. (2005, December). The integrative review: updated methodology. *Journal of Advanced Nursing*, *52*(5), 546–553. https://doi.org/10.1111/j.1365-2648.2005.03621.x