

ARTICLE

Physics teachers' difficulties in teaching introduction to quantum physics in senior high school

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Abstract

The High School Physics curriculum would not be complete without some basic concepts of Quantum Physics. The basic concepts of Quantum Physics are attractive to students, but the material is challenging to teach. This is because the phenomenon of Quantum Physics experienced by students is different from the real world and many principles of Quantum Physics may not be in accordance with the ideas that students know. Although the results of previous studies revealed a lot of research on the context of students' understanding of the concepts of Quantum Physics. However, limited empirical data regarding the difficulties of high school teachers in teaching quantum physics are still rarely encountered in physics education research. This study aims to explore data on the difficulties of high school physics teachers in teaching quantum physics concepts. This research design uses quantitative and qualitative case study methods. To get three participants, namely 3 twelfth grade high school physics teachers, the researcher used a purposive sampling technique. The age range of participants is between 45–55 years while the teaching experience of teachers ranges from 10 to 30 years. The instruments used in this study were a questionnaire and a semi-structured interview protocol. In this study, the questionnaire analysis used descriptive statistical analysis, while the interview data analysis used thematic analysis. The results of the study revealed that high school physics teachers had difficulty understanding the concept of quantum physics, had little difficulty in determining the right pedagogical approach, conducting laboratory activities, and building an evaluation system.

Keywords: Quantum Physics, high school physics teachers, teaching concepts of quantum physics

1. Introduction

The High School Physics curriculum would not be complete without some basic concepts of Quantum Physics. Quantum Physics has been one of the most important fields of Physics since the early 20th century when theoretical work by Bohr, Einstein, De Broglie, and many other famous scientists laid the foundation for the development of a new theory of physics. The theoretical insights from Quantum Physics have opened new possibilities and new ways of thinking not only in physics but also in philosophy, biology, electrical engineering, health, and communication technology.

High school Quantum Physics materials, concepts such as wave-particle dualism and Heisenberg's uncertainty principle are taught qualitatively without complicated mathematics (Stadermann, Berg,

and Goedhart 2019). Quantum Physics theory is interesting for students (Bungum, Bøe, and Henriksen 2018) but also this material is challenging to teach in teaching and learning activities in class (Krijtenburg-Lewerissa et al. 2017). This is because the phenomena of Quantum Physics experienced by students are different from the real world and many of the principles of Quantum Physics may not be in accordance with the ideas that students know. For example, when students are introduced to the concept of quantum mechanics which is quite complicated, students must express opinions in a realistic physics world view and must be able to predict and explain the results of Quantum Physics experiments (Johnston, Crawford, and Fletcher 1998; Ke, Monk, and Duschl 2005).

Several previous studies have shown that students do not easily understand the new quantum atomic model and still adhere to the learning model of the Bohr model (Adbo and Taber 2009; Griffiths and Preston 1992; Petri and Niedderer* 1998). Even after studying the Quantum Physics of atomic matter, many students still find it difficult to describe the electron as a classical particle (Mannila, Koponen, and Niskanen 2001) and the atom as a Bohr model (Müller and Wiesner 2002). Other empirical studies have found that to study Quantum Physics, students must understand the reasons for developing models and learn to handle different models in appropriate contexts (McKagan, Perkins, and Wieman 2008). The results of this study indicate that the concept of quantum physics is still a big challenge for students to understand.

Although the results of previous studies reveal many studies regarding the context of students' understanding of the concepts of Quantum Physics, the limitations of empirical data regarding the difficulties of high school teachers in teaching quantum physics are still rarely encountered in physics education research (Niaz and Rodriguez 2002). Whereas knowing several empirical facts regarding this issue encourages teachers to develop appropriate creative methods to be used in teaching abstract concepts of Quantum Physics. Therefore, this study aims to explore empirical data regarding the difficulties of high school physics teachers in teaching quantum physics concepts.

2. Literature Framework

2.1 The concepts of quantum physics in Indonesian science education curriculum

In most of these countries, curriculum changes in high school are carried out by integrating quantum physics (Stadermann, Berg, and Goedhart 2019). This curriculum change aims to provide opportunities for high school students to learn about quantum physics (Bøe, Henriksen, and Angell 2018). Topics in quantum physics include black body radiation (Henriksen et al. 2018), atomic spectra (Savall-Aleman et al. 2019), photoelectric effect and Wien shift (Krijtenburg-Lewerissa et al. 2017). In these concepts, students experience conceptual difficulties because they are required to map abstract mathematical models to experiences in the physical world, accept counterintuitive phenomena and concepts, make the transition from a deterministic worldview to a probabilistic view, and understand language to express phenomena and concepts. concept of Quantum Physics (Bouchée et al. 2021).

Quantum physics is now a standard subject in the high school curriculum. Several reasons why Quantum Physics deserves a place in the high school curriculum. First, Quantum Physics is essential to today's scientific worldview. Second, Quantum Physics presents several applications such as lasers, solar cells, and microchips that are indispensable for modern life. Other research in Quantum Physics also presents DNA decoding, Cryptography, and quantum computers. Finally, Quantum Physics is believed to be a topic that attracts students' interest and makes physics more attractive (Stadermann, Berg, and Goedhart 2019; Ke, Monk, and Duschl 2005).

2.2 Physics teachers' experiences in teaching quantum physics

The results of the science education research revealed that high school teachers felt uncomfortable and lacked confidence in teaching Quantum Physics. Teachers also reported that it was difficult to

support the conceptual understanding of high school students because teachers were unable to discuss the details of the mathematical formalism of Quantum Physics. The teacher said that they rely more on textbooks to teach Quantum Physics. In contrast, some high school students are more interested in Quantum Physics material than other topics in physics because of its philosophical implications (Bungum *et al.* 2015).

Another difficulty for teachers in teaching Quantum Physics is that they see the abstract and counterintuitive nature of quantum physics as opposed to various pedagogical issues, such as which philosophical stance on the interpretation of Quantum Physics should be taken, whether to avoid references to classical physics, and whether the conceptual aspects Quantum Physics should be considered (Akarsu 2010). As a result, students experience a loss of interest in Quantum Physics material when problem solving activities are too prioritized (Johansson 2018). Meanwhile, the lack of problem-solving exercises can also cause students to experience difficulties in conceptual understanding of Quantum Physics. Students struggle to develop self-efficacy because they need to modify previously acquired learning strategies centered on problem solving to develop their understanding (Bøe, Henriksen, and Angell 2018). There is a lot of literature on the conceptual difficulties of students learning Quantum Physics. However, little is known about the challenges of teacher and student experiences for teaching and learning Quantum Physics (Bungum *et al.* 2015).

2.3 Pedagogical content knowledge of physics teachers in teaching quantum physics

Teachers need to know how people learn, how memory operates, and how the brain develops with age. This knowledge is called general pedagogical knowledge or knowledge of how people learn. Most importantly, teachers of certain subjects must have a special understanding and ability to integrate their knowledge of the content of these subjects and students' learning of this content. This specific knowledge is called PCK pedagogical content knowledge, which distinguishes the science knowledge of teachers from scientists (Loughran 2019). However, research shows that teachers tend to teach in a way that has been taught such as the lecture method (Sundstrom, Phillips, and Holmes 2020).

In the last 20 years many teacher educators have concluded that the most important aspect of teachers' practical knowledge, especially for high school teachers, is their knowledge of pedagogical content (Loughran 2019). In describing PCK's pedagogical content knowledge about Quantum Physics material in teaching and learning activities in the classroom, it is important to have knowledge of students' difficulties, and previous conceptions in studying the material. This knowledge becomes the basis for teachers to have knowledge of representation, instructional strategies, and knowledge of assessment methods.

The teacher's PCK pillar is specifically divided into three main pillars: pedagogical content knowledge, pedagogical knowledge, and content knowledge. Knowledge of pedagogical content includes several indicators: orientation towards teaching, knowledge of physics curriculum, knowledge of students' ideas, knowledge of effective, instructional strategies knowledge, and about assessment methods. Meanwhile, pedagogical knowledge includes knowledge of brain development, knowledge of cognitive science, knowledge of collaborative learning, knowledge of classrooms, and management and school laws. Finally, content knowledge includes indicators such as knowledge of quantum physics concepts, the relationships between them, and methods of developing new knowledge.

3. Research Method

3.1 Research design

The research design used in this research is quantitative and qualitative case study methods. A case study is an exploration of a system that is bound over time through in-depth data collection and involves a variety of strong information sources in a context. A case study is research in which the researcher explores a certain phenomenon (case) in a time and activity (program, process, institution,

or social group) and collects detailed and in-depth information using various data collection procedures over a certain period (Gordy et al. 2021).

The case study method is more in demand for both quantitative and qualitative approaches (Gordy et al. 2021). The quantitative approach is a research approach that aims to measure data and generalize the results from the sample to the population and focuses on numerical data (Gordy et al. 2021). For a quantitative approach, researchers can use data collection methods in the form of tests, questionnaires, or observations (Gordy et al. 2021). In this study, researchers used a questionnaire to determine the level of difficulty of physics teachers. While the qualitative approach aims to obtain research data from a case or issue and requires a long and extensive time in digging up rich information to build an in-depth picture of a case (Braun, Clarke, and Hayfield 2022). The qualitative approach in this study uses semi-structured interviews (Semi structured Interview). When conducting semi-structured interviews, researchers need to listen carefully and take notes on what the informants say (Braun, Clarke, and Hayfield 2022).

3.2 Participants

The population of this study were all physics teachers in the district in Garut Regency. From this population, the sample of this research is a Physics teacher in grade twelfth who teaches Quantum Physics Concepts. In taking the sample, the researcher used a purposive sampling technique, in which this technique selected the research sample based on the suitability of the researcher's objectives (Gordy et al. 2021). From the predetermined sample, there were three interview participants, namely two twelfth grade physics teachers from private high schools and one twelfth grade physics teacher from public high schools. And there were five questionnaire participants, namely three private high school teachers and two public high school physics teachers. The age range of the participants is between 45-55 years while the teacher's teaching experience ranges from 10 to 30 years.

3.3 Instruments

The research instrument representing the difficulties of high school physics teachers in teaching quantum physics concepts consists of a questionnaire and an interview guide sheet. The questionnaire instrument consisted of 21 closed statements and 16 semi-structured interview questions. There are aspects of understanding concepts, aspects of pedagogical approach, aspects of laboratory activities, and aspects of evaluation.

Before the researcher conducted the research, the researcher conducted an expert test of the questionnaire instrument and interviews in advance to determine the validity of its feasibility. Experts test This instrument was carried out by 2 experts, namely in the fields of physics and physics education. The results of the instrument validation test by the validator on the questionnaire and interviews showed that the instrument was suitable for use with revisions. According to the results of the expert validation test, the researcher improved the questionnaire and interview instruments according to the comments and suggestions from the validator so that the questionnaire and interview instruments became feasible to use in this study.

3.4 Data analysis

The analysis used is descriptive statistical analysis. Descriptive statistics is a method used to simplify data to make it easier to understand in reading research data. The calculation of the questionnaire data is calculated using the following procedure: a) counting the number of respondents (N); b) counting the number of questionnaire items (n); c) Determine the maximum score (S_{max}) with the formula $n \times N \times 5$; d) determine the minimum score (S_{min}) with the formula $n \times N \times 1$; e) determine the range using the $S_{max} - S_{min}$ formula; f) Determine the length of the class (p) with the formula $(S_{max} - S_{min})/\text{number of categories}$; g) determine the scale by referring to Table 1) calculate the percentage with the formula $P = (F/N)100\text{percent}$ where F is the frequency of answers.

Table 1. Scale of interpretation

Total scores (TS)	Interpretation
$S_{min} < TS < S_{min} + p$	very easy
$S_{min} + p < TS < S_{min} + 2p$	easy
$S_{min} + 3p < TS < S_{min} + 4p$	hard
$S_{min} + 4p < TS < S_{max}$	very hard

The analysis that will be used to find interview data in this study uses thematic analysis. Thematic analysis is a flexible method to identify systematically by focusing on the code and meaning (theme) of the data results (27). Here is a 3-phase approach to thematic analysis. Phase I understands the interview data, in this phase the researcher must read the interview transcript data that has been conducted to the respondent and listen to the audio recording repeatedly, then the researcher determines which part will be the open code of the results of the interview transcript. Phase II creates and determines the code category; this phase begins to systematically analyze the data from the open code results that have been made in phase I. This code category can be made from the results of the open code summary according to the interview transcript results and becomes a partial summary of the interview transcript. Phase III of determining the theme, the coding results will begin to form from open code, code categories become themes. Furthermore, the raw data from this research will become a complete data result.

4. Result of the research

4.1 Difficulties in the aspect of understanding of physics concepts

In revealing the physics teacher's perception of the concept of Quantum Physics, 5 questionnaire statements were used which were filled out by 5 Physics Teacher participants. The results of the questionnaire analysis revealed that 60 percent of teachers found it difficult to see the concept of Quantum Physics, 20 percent of teachers found it not difficult, and 20 percent of teachers viewed the concept of Quantum Physics as not difficult. The percentage obtained in the aspect of understanding the concept of physics refers to 5 statements in the questionnaire consisting of 3 substances, namely translating understanding concepts, giving examples, and understanding abstract concepts so that they are easier to understand, and determining the consequences and implications.

More deeply, the teacher sees that the concept of Quantum Physics is an abstract physics concept. With its abstract nature, teachers find it difficult to teach Quantum Physics. This difficulty is due to several reasons. First, the teacher considers the concept of Quantum Physics to study small particles. This can be seen in the following interview excerpts:

"...Things that are difficult for students are related to materials that are difficult to explain, such as what form of energy is it? Is it the same as work i.e., force times displacement, is it as simple as that with such a shape. It turns out that this energy is related to exceedingly small particles, and we present it in a simple formula. The difficult material in my opinion is the production of X-rays and hydrogen atoms. The material is difficult to explain and give examples too, it cannot be seen in real terms, it's all kinds of things that can be touched. If the tool is clear. If there are conventional tools (P-3).

Besides the teacher assumes the concept of Quantum Physics to study exceedingly small particles, the second reason is that the teacher considers the concept of Quantum Physics to be abstract. This can be seen from the following interview results:

"Understanding abstract concepts is exceedingly difficult to convey to students, secondly there are no tools in the lab that can prove quantum theory, one of which is the photoelectric effect. Maybe

a great school has the tools and media, in this school there are no tools. With the virtual lab with Phet, I have not opened up whether Phet has quantum physics in terms of dynamics, kinematics is often the case. It might be an alternative, but children will understand it better with real objects because they feel it directly (P-2).

Although the teachers consider the concept of Quantum Physics to be abstract and they have difficulty in teaching it, they view the material of Quantum Physics as an incredibly challenging material. This can be seen from the following interview results:

"... Physics is a very challenging material because all technology must be discussed with physics, what technology can't be discussed with physics... The most difficult thing is probably De Broglie, whose light has a dualism of one as a wave and another as a particle, and the last one is why De Broglie said that if there is a fast moving particle it will behave like a wave, because it behaves as a wave it will have a wavelength (P-1).

4.2 Difficulties in aspects of the pedagogical approach

The results of the analysis from the aspect of the pedagogical approach consisting of 5 questionnaire statements and filled by 5 teacher participants revealed that 60 percent of teachers did not experience difficulties in carrying out the pedagogical approach, 20 percent found it difficult, and 20 percent found it exceedingly difficult. The percentage obtained in the aspect of the pedagogical approach refers to 5 statements in the questionnaire consisting of 3 substances, namely identifying students' difficulties in learning quantum physics, applying learning theories and learning principles that are suitable for students in learning quantum physics and choosing models, media that used during learning and in accordance with the characteristics of the physical material.

A deeper analysis using interview data obtained several themes in the aspect of the pedagogical approach, namely the teacher prepared before the learning process, the limited media to support the learning of Quantum Physics, the teacher still uses conventional methods in teaching the concept of Quantum Physics, and the teacher has difficulty in determining the characteristics student.

In the first theme, the teacher prepared before carrying out the learning process. The teacher's preparation is to avoid several things, such as not holding a book when learning in class and the teacher is ready to optimize the existing learning media. This can be seen from the following interview excerpts:

"...must understand the material, that's the teacher's first capital, if the teacher does not understand the material, it will be stressful up front. Do not let the teacher hold the book in front of the class, when explaining, you must master the material first...do not let the students explain when they are not ready to learn and even play around...the facilities and infrastructure to support the learning process such as projectors, laptops (P -1)"

The second theme is that there are limited media to support learning in the classroom so that teachers are only glued to using LKPD and Package Books. The understanding of students and teachers is only limited to worksheets and books. There is no deeper knowledge of the concepts of Quantum Physics. Despite the limitations of the media in supporting learning, teachers try to independently find and explore what is happening related to the current development of quantum physics theory, as shown in the following interview results:

many teachers also refer only to books and worksheets. This means that we are colonized by books and worksheets. When we teach only limited to worksheets, our understanding only to that point will not develop. So the teacher must study first, find out what is related to quantum physics, the theory in the past, the current theory and the theory in the future...(P-2)"

The third theme relates to the method that the teacher uses still uses conventional methods. In this context, the teacher teaches the concept of Quantum Physics is dominant using the lecture method which is still. The use of this method in teaching the concepts of Quantum Physics is less than optimal because students are not faced with several simulations or visual representations related to the concepts of Quantum Physics. This can be seen in the following interview results:

"...the government has determined that this must be that, but it is still conventional. Still following the old habits, the method is lectures, methods, media like that provide examples, describe practice questions. Giving students curiosity, giving examples of what it is like first, ideally the teacher conveys that students do not know whether they understand or not...(P-3)"

The fourth theme is the teacher's difficulty in determining the characteristics of students. Middle and lower students show a silent gesture when they understand or do not understand the concept of Quantum Physics. This makes it difficult to explore the character of students during the learning process in class. In addition, each student has a different IQ. Thus, the teacher's treatment of students in the classroom must be different to match the student's capacity. This situation can be seen in the following interview results:

"...want to know that students understand and don't understand it's difficult. It is related to students' understanding, you can't understand the child's character, you can't keep quiet. Maybe on the D-day he understands but when he comes home or the next day, he will forget...(P-1)"

"...children are heterogeneous, not all children have the same IQ, we treat children with appropriate capacities. So here there is a different treatment for children...(P-2)"

4.3 Difficulties in the aspects of laboratory activities

The results of the analysis of aspects of laboratory activities consisting of 6 questionnaire statements filled with 5 teacher participants revealed that 60 percent of teachers did not experience difficulties in aspects of laboratory activities, 20 percent found it difficult, and 20 percent found it exceedingly difficult. The percentage obtained in the laboratory activity aspect refers to the 6 statements in the questionnaire consisting of 4 substances, namely managing students in laboratory activities, what things must be prepared during the practicum, facilities and infrastructure in the learning process and what obstacles hinder the practicum activity process.

Furthermore, the results of interviews with participants reveal an important theme that laboratory activities that are still rarely carried out by teachers are related to teaching Quantum Physics concepts. Although laboratory activities are still rarely carried out due to inadequate facilities and infrastructure in conducting Quantum Physics practicums, teachers can still demonstrate with their own tools to demonstrate the phenomena of Quantum Physics concepts. As the results of the following interview excerpts:

"Because in quantum physics there is no practicum but only demonstration. Because you want to learn or practice, it must be done in class, especially when the tools are few. Even for grade 12 I made my own tools, from the first electric circuit to electromagnetic induction, adjusted if I could make it, I would make the tool to show it to students (P-1)"

"Because I have never done practicum, if there is a lab, there are no tools for practicum. I have never done practicum at all (P-3)"

In the concept of the photoelectric effect, there are no tools to prove the concept. This is one of the difficulties for teachers in carrying out laboratory activities or demonstrations because there are no tools to support laboratory activities. As stated in the following interview excerpt:

"Because this school has never done any practicum at all...there are no tools in the lab that can prove quantum theory, one of which is the photoelectric effect (P-2)"

4.4 Difficulties in the aspects of evaluation

The results of the analysis from the aspect of the evaluation system consisting of 5 questionnaire statements and filled out by 5 participants revealed that 60 percent of teachers did not experience difficulties in the process of evaluating Quantum Physics concepts, 20 percent found it difficult, and 20 percent found it extremely easy. The percentages obtained in the evaluation system aspect refer to 5 statements in the questionnaire consisting of 3 substances, namely compiling cognitive, affective, and psychomotor evaluation assessment instruments, difficulties in compiling and developing evaluation instruments, and feedback carried out during the learning process and results.

Meanwhile, a deeper analysis of the interview data revealed two important themes, namely teacher difficulties and determining affective, psychomotor assessment indicators, teacher limitations in giving assignments, and teacher efforts in providing motivation through feedback. In the first theme, teachers have difficulty in determining what indicators should be used in the affective assessment process. This can be seen from the following excerpt from the interview process:

"It is exceedingly difficult to be affective, what are the indicators. In general, if cognitive is seen from practice. Yes, like that, it's still a mediocre standard and if it's psychomotor the most from group work maybe (P-3)"

For the second theme, the teacher's difficulty in assessing psychomotor assessment indicates that the psychomotor aspect is difficult to measure because of laboratory activities that never exist or are rarely carried out. This is very rational because laboratory facilities to experiment on the concepts of Quantum Physics are exceedingly difficult. This can be seen in the following interview results:

"In skills because I have never practiced until now with limited tools and others (P-2)"

The third theme of this evaluation system aspect is the teacher's limitations in providing assignments for students. At the end of the lesson, the teacher tries to make students understand the concept of Quantum Physics better by giving independent or group assignments. Even so, teachers still experience limitations in providing assignments for students. The teacher only gives assignments in the form of concept maps, making summaries, and papers. This is as from the following interview excerpts:

"...the task of making a concept map, making a summary if the test must be corrected...if the form of the question is an essay of five questions, if it was online, two questions were enough (P-1)"

"...assignments are in the form of papers but not all children write papers because what is it because Google is the reference...(P-2)"

Furthermore, the last theme is the ability of teachers to increase students' enthusiasm in the learning process in the classroom. The teacher's efforts to increase student enthusiasm in the learning process in the classroom are by providing feedback. The form of feedback here is a point where students will be given points when they are active and can work on questions in front of the class. In addition, students also get appreciation with applause. In addition to the teacher providing feedback, the teacher reflects at the end of the lesson by straightening out what the students have said and done. This can be seen in the following interview excerpts:

"Feedback from you with points on how active you are in class and in the future (P-1)"

"Giving applause or being given praise so that the child is happy (P-3)"

"By providing reflection of understandings to children at the end of learning (P-2)"

5. Discussion

The results of the study revealed that the teacher's difficulty in teaching Physics could be caused by the weak understanding of the teacher's physics concept to the concept of Quantum Physics. Even though understanding the concept is especially important for teachers to be able to convey material to students accurately and clearly. This result is in line with previous research that teachers have difficulty in conveying understanding of Quantum Physics concepts because teachers cannot discuss mathematical formalisms in quantum physics (18). They sometimes must struggle first to create and understand Quantum Physics content by actively involving students (Bungum *et al.* 2015).

The results showed that one of the teacher's difficulties in teaching Quantum Physics is the abstract concept of Quantum Physics, such as the proof of the concept of the photoelectric effect. The results of the interview also revealed that the limitations of tools and media that support in schools are a difficult factor so that students can see the visualization of Quantum Physics concepts. This is in line with previous researchers that topics in quantum physics such as the photoelectric effect and the Wien shift are abstract and difficult to visualize in the laboratory (16). In these concepts, students experience conceptual difficulties because they are required to map abstract mathematical models to experiences in the physical world, accept counterintuitive phenomena and concepts, make the transition from a deterministic world view to a probabilistic view, and understand language to express phenomena. and the concept of Quantum Physics (Bouchée *et al.* 2021).

In the context of the pedagogical aspect, understanding the abstract and virtual material of Quantum Physics makes it difficult for some teachers to give examples in everyday life. Although it was difficult, the teacher revealed that the material for quantum physics was interesting and incredibly challenging for the teacher to choose and develop a particular pedagogical approach. This is in line with previous researchers who revealed that some high school students were more enthusiastic about learning Quantum Physics than other Physics topics when the learning process used a philosophical approach (Bungum *et al.* 2015). However, high school students still feel that this Quantum Physics material is abstract material and does not even make sense (Bøe, Henriksen, and Angell 2018) so that an interesting pedagogical approach is needed and makes it easier for students to understand Quantum Physics concepts.

In the context of laboratory activities, physics teachers rarely facilitate students with laboratory activities related to Quantum Physics learning. To encourage laboratory activities in the teaching process of quantum physics, adequate media and tools are needed. This encourages students to understand better if they are involved in laboratory activities because they can observe Quantum Physics phenomena. When practicum tools are not available, teachers must be creative by showing videos that make it easier for teachers and students to understand the concept of Quantum Physics. For example, when the teacher has difficulty in conveying examples from Quantum Physics, the teacher can use a cellphone to look for examples of phenomena that often occur in Quantum Physics. This is in line with the thoughts of other researchers who argue that to improve teaching and learning Quantum Physics can be done by using digital materials that are available for free such as on You tube (Henriksen *et al.* 2018). When involving digital material related to Quantum Physics, the teacher will find it easy to carry out the learning process and students will be easy to understand the concept of Physics because they are involved in the exploration and visualization of phenomena.

Finally, the evaluation aspect is an aspect for teachers to see the success of the learning process including learning Quantum Physics. In this study it was revealed that the teacher did not know what indicators were contained in the affective assessment. This means that it is difficult for teachers to carry out evaluations of classroom learning in the Quantum Physics learning process. For example, students show a silent gesture when they understand or do not understand the concept of Quantum Physics. This makes it difficult for teachers to explore the character of students during the learning process in class. This is in line with the results of other studies that the affective and psychomotor assessment processes are carried out by teachers (Loughran 2019). So, teachers must be able to

prepare, manage and implement evaluation systems in affective and psychomotor aspects well by knowing the characteristics of their students.

6. Conclusions

Teachers have difficulty understanding abstract Quantum Physics Concepts. Weak understanding of Physics teachers in Quantum Physics material is a trigger factor for students' difficulty in understanding the concept. The limitations of media and tools are also one of the factors that support the difficulty of teachers in teaching Quantum Physics in the classroom. For example, silent gestures whether students understand or not understand the concepts of Quantum Physics being taught and laboratory activities that are rarely carried out make teachers experience problems because they do not know what indicators are in affective and psychomotor assessment.

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