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Development of Three-Tier Scale: Insufficiencies of Classic Physics Conceptual Comprehension Scale

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ABSTRACT
The aim of this study is to develop a conceptual understanding scale on Insufficiencies of Classical Physics concerning Quantum Physics Courses. In the first stage, 36 items were developed, depending on the target behaviours and the scale was transformed into 33 items with the opinion of two expert academicians. The draft scale was then applied to 139 (40 male 99 female) pre-service teachers from the departments of Science Education and Physics Education at a state university. Following the item analysis efforts, final version of the scale with a total number of 20 items, has been obtained. The Cronbach Alpha reliability coefficient of the final scale was found to be 0,78.
Keywords: Physics Education, conceptual understanding scale, three-tier scale, insufficiency of classical physics

Üç Aşamalı Ölçek Geliştirme: Klasik Fiziğin Yetersizlikleri Kavramsal Anlama Ölçeği

ÖZET
Bu çalışmanın amacı, Kuantum Fiziği dersi içerisinde yer alan Klasik Fiziğin Yetersizlikleri konusu üzerine öğrencilerin kavramsal anlama düzeylerini belirlemeye yönelik üç aşamalı Kavramsal Anlama Testi geliştirmektir. Başlangıç aşamasında ilgili literatür taraması ve kaynak kitap araştırması doğrultusunda 36 taslak madde hazırlanmıştır. Uzman görüşleri doğrultusunda test 33 maddeye indirgenmiştir ve taslak test oluşturulmuştur. Taslak test, Türkiye'de bir devlet üniversitesinin Fen Bilgisi Öğretmenliği ve Fizik Öğretmenliği bölümlerinde öğrenim gören 139 öğretmen adayına uygulanmıştır. Madde ayırt edicilik analizi sonucunda Siyah Cisim Işıması, Fotoelektrik Olay ve Compton Saçılması konularını kapsayan toplam 20 maddeden oluşan sonuç test elde edilmiştir. Testin güvenirlik katsayısını belirlemek için yapılan analiz sonucunda testin Cronbach Alfa güvenirlik katsayısı 0,78 olarak bulunmuştur.

Anahtar Kelimeler: Kavramsal anlama, kavramsal anlama testi, üç aşamalı kavram testi, klasik fiziğin yetersizlikleri

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INTRODUCTION

Physics investigates almost anything at any level, including energy or matter within the reference frames of time and space, therefore naturally includes complicated concepts and heavy mathematical equations that give the relationships between those concepts (Serway and Jewett, 2018). The concepts are in fact the mental structures of something with certain and well-defined properties and the name given to the concept represents it (Galili and Lehavi, 2006). Physics as a complicated area of sciences, includes many concepts, some being really difficult to internalize, hence conceptual understanding has traditionally been a hot topic of physics education research (Kryjevskaia, 2019; Koponen and Nousiainen, 2019; Laws, Sokoloff and Thornton, 1999; McDermott and Redish, 1999). In addition to those concepts, physics expresses the relations between those concepts by mathematical equations. However, the leading role is not due to the equations but the concepts by which the complicated events and processes are explained.

At this point, it is clearly seen that the concepts are very crucial for physics education and the importance of the conceptual understanding can easily be recognized (Wieman and Perkins, 2005). When an event occurs or an observation emerges, initially the scientific problem ought to be determined and then a hypothesis can be created about the scientific problem. In accordance with the scientific method, the hypothesis is tested by controlled experiments and according to the results of the experiments, the hypothesis may be valid or invalid. The validated hypothesis is then subjected to various applications, by determining relating variables, a mathematical equation can be developed as a scientific knowledge (Yerushalmi, Singh and Eylon, 2007). As we can see from these processes, it is not possible to reach the mathematical equations without the actual concepts. Knowing the mathematical equations, does not mean that the relating physics is known. In addition to the equations, the students should be able to understand the concepts, their content sufficiently and to be able to use them in their daily life (Jax, Ahn and Lin –Siegler, 2019; McDermott, 2001). However, sufficient transfer of the conceptual knowledge to the students within the Physics courses can be unsuccessful depending on many reasons (Fishbane, Gasiorowicz and Thornton, 2005; Zacharia and Anderson, 2003). Physics is a natural science and the basic aim in physics education is to educate individuals who can produce solutions to the problems they may face in daily life.

Quantum physics is one of the hardest areas of physics therefore teaching quantum physics has some extra difficulties. Quantum physics is comprised of such concepts that one has to give up the traditional and customary thinking procedures to understand the nature (Bridgman, 1927). Quantum physics emerged as a result of some experimental findings that could not possibly be explained by the classical physical laws in the early 1900s (Beiser,2003). Quantum physics is generally seen as an area that needs to be considered more intentionally because of many abstract concepts and heavy mathematical content. Today, almost all of the technological innovations that can be described as a measure of development level are based on quantum physics. Therefore, quantum physics education is very important. Teaching the concepts of quantum physics and understanding its structure is one of the fundamental issues of physics education research (Hadzidaki, Kalkanis and Stavrou, 2000; Gil and Solbes 1993). The research shows that, most physics teachers do not have sufficient conceptual understanding of quantum physics and this is most likely due to be education in schools with insufficient content and laboratory facilities (Abdurrahman, Saregar and Umam, 2018; Meltzer and Thornton, 2012). Therefore, more emphasis should be engaged on quantum physics education given to prospective physics teachers at university level.

Misconception is defined as the mental structure of a learner significantly differs from the scientific reality of that concept (Riche, 2000; Stepans, 1996; Marioni, 1989; Terry, 1985). The process of learning any concept starts from very early ages, down to pre-school education and also based on the environmental effects (Marsick and Watkins, 2001). If the student has misunderstood a certain concept based on any effect, this confusion eventually leads to solid misconceptions (Alwan, 2011). The misconceptions relating to any subject lead to an inability to establish a link between the correct scientific knowledge and the knowledge of the student (Makiyah, Utari and Samsudin, 2019; Asgari, Ahmadi and Ahmadi, 2018). Therefore, when evaluating learning situations, appropriate measurement tools should be used to measure conceptual comprehension levels and if any misconceptions should be determined and eliminated. Effective methods used to determine students' conceptual understanding levels are 'student interviews',' concept maps', 'surveys',' multiple choice tests', etc. (Peşman and Eryılmaz, 2010; Wuttiprom et al., 2009; Fishbane, Gasiorowicz, and Thornton, 2005; Engelhardt and Beichner, 2004; Tan et al., 2002; Beichner, 1994; Hestenes, Wells, and Swackhamer, 1992 McDermott and Shaffer, 1992). It is not possible to accurately identify misconceptions with multiple-choice tests. Because a student who has misconceptions can give a random correct answer, or a student who has no misconceptions can give a wrong answer in absentia (Peşman and Eryılmaz, 2010). This makes it difficult to correctly identify students who are learning and not learning the subject. And also, it cannot be determined that whether the students who gave the wrong answer because they had no knowledge about the subject or because they had a misconception about the subject. Multiple choice tests fail to make this distinction.

This inadequacy in determining misconceptions of multiple choice tests was overcome by the development of two-tier tests (Treagust, 1988). The first stage of two-tier tests is the classical multiple-choice test stage. In the second stage, a theoretical explanation is given as to why the answer was given in the first stage (Şahin and Çepni, 2011; Peşman and Eryılmaz, 2010).While the two-tier tests are very effective, there are also shortcomings. Students are able to give correct answers to the second stage of the test with reasoning (Arslan, Cigdemoglu and Moseley, 2012). In the following years, the confidence stage was added to the two-tier test and the test was made in three stages (Hasan, Bagayoko and Kelley, 1999).

In the first stage of the three-tier scales, there is a multiple-choice question on the subject; in the second stage, the classical explanation of the answer to the question in the first stage is asked, and in the third stage, it is asked how confident the student is (Caleon and Subramaniam, 2010). With the help of the three-tier scale, the relationship between the knowledge of students on a subject, the ability to explain that knowledge and the self-confidence level can be seen. Thus, students' conceptual understanding levels can be determined in detail (Kaltakçi and Didiş, 2007). While testing students' conceptual comprehension levels, three-tier conceptual scales, which can clearly determine whether the student have the correct knowledge or coincidently answers the questions correctly, are very effective (Taslidere, 2016). If the student selected wrong option with misconception in the first tier, explains their answer with reasons as if it is correct and states that he or she is sure about the answers in the last tier, that student might have a misconception (Arslan, Cigdemoglu and Moseley, 2012; Cetin Dindar and Geban, 2011; Peşman and Eryılmaz, 2010). Table 1 shows how to interpret possible student responses.

Table 1. *Interpretation of the most likely responses to three-tier scales*

Multiple choice	Theoretical explanation	Confidence	Learning status
Correct	Totally correct	Totally / Partly	Fully realized
Correct	Partially correct	Totally / Partly / Confident	Partially realized

Correct	Wrong	Totally / Partly	May have misconceptions
Wrong	Totally/ Partially correct	Totally / Partly	May have misconceptions
Wrong	Wrong	Totally / Partly	May have misconceptions
Wrong	Wrong	Not / Not at all	Not realized

When literature review is made, it is seen that scale development study is almost never done to determine misconceptions about modern physics. Only Taşlıdere (2016) conducted a three-stage scale development study on the photoelectric event. This scale alone is insufficient in terms of providing a basis for conceptual studies on modern physics. The aim of this study was to develop the Insufficiencies of Classic Physics Conceptual Comprehension Scale (ICPCCS), which has a high reliability coefficient, including Black Body Radiation, Photoelectric Effect and Compton Scattering.

METHODOLOGY

Sample

Since the scale had to be applied to students who previously took modern physics courses, the sampling of the study was chosen by using the homogeneus sampling method. The study is carried out in a specific sub-group who have similar characteristics in the homogeneous group. This is one of the purposeful sampling methods in which the research group is selected from a specific section in line with a target. The aim is to examine the people in the group in depth (Patton, 1990; Neuman, 2014). The sampling consists of 139 students (40 male, 99 female). 115 (25 male, 90 female) of these students are from the Department of Science Teaching and 24 (15 male 9 female) from the Physics Teaching Department. The participants were 21 to 24 years old. The study group was selected among the students who had previously taken modern physics courses.

Development of Scale

At the beginning of the scale development process, Black Body Radiation, Photoelectric Effect and Compton Scattering subjects were analysed through various sources (Eisberg and Resnick, 1974; Beichner, Jewett and Serway, 2000). And the propositional knowledge statements in these subjects were determined. Then, questions were started to be written. In this process, find the items to measure the learning statement determined for all subjects was the main objective. In line with this goal, the first form of scale was developed.

In the scale development process, only the multiple-choice test phase of the three-stage scale was applied to the students. When the three-stage scale development studies are examined, it is seen that in some studies, the second stage is offered to students as an elective. In these studies, it was seen that reliability analyzes were performed on the scores obtained from each stage and total scores separately (Daşdemir and Abay, 2018; Özden and Yenice, 2017; Taslidere, 2016; Milenkovic et. al., 2016; Cetin Dindar and Geban, 2011). The second stage is given to students in multiple-choice state in some cases may increase the probability of accidental error and affect the accuracy of the measurement. For example, a student who does not have any knowledge about the subject, can answer both stages correctly by chance. Or the student who doesn't know the subject can answer to the first stage true and wrong to the second stage. And it can lead to the thought that he/she is in a misconception. However, in the second stage, if the students are asked to explain their answers in their own sentences, a student who randomly answers to the first stage will not be able to give an answer in the second stage and any wrong determination about the situation of the student will be prevented. For this reason, in the second stage of the scale developed in this study, the students were asked to explain the theoretical information underlying the answers in their own sentences.

Analyses were made on the points they received at first stage. The reason for this is to prevent possible misleading points from the classical explanation and confidence levels. The three-stage version of the scale can be used to measure the level of conceptual understanding or misconceptions of a group of students after the scale has been developed. However, in the scale development phase, only the first phase, multiple choice test phase, was applied to the students. Because in the second stage, the students are asked to explain their answers in their own sentences and this stage does not need to be included in the scale development process. Similarly, incorporating the third stage into the statistical study in the scale development process may have misleading effects on the reliability of the scale.

First form of scale was 36 questions containing the items in the conceptual comprehension level. In order to determine the validity of the scale, expert instructors' opinions are taken (Kaltakci-Gurel, Eryilmaz and McDermott, 2017). Within the scope of the validity analysis of 36 questions prepared in the conceptual comprehension level, 2 faculty members from the Department of Physics Teaching were examined. 3 items which were considered unsuitable for conceptual comprehension scale were removed from the scale. As a result of corrections and subtractions, the scale became 33 questions. A scale consisting of 33 items was applied to 139 students. As a result of the analysis of collected data, 13 items with item discrimination index less than 0.19 were excluded from the scale. The Cronbach Alpha reliability coefficient of the 20-item scale was found to be 0.78. In this form of scale; 8 questions related to Black Body Radiation, 6 questions related to Photoelectric Event and 6 questions are related to Compton Scattering.

After the development process, in order to determine the students' conceptual understanding levels in more detail scale was transformed into a three-tier form. The first stage of the three-tier scale is the stage of multiple-choice response, the second stage of the classical explanation phase to be written about the answer marked in the first stage, and in the final stage, the student's confidence in the answer is measured. It would not be wrong to say that the most important stage of the three-stage tests is the second stage. At this stage it is clear whether the student has acquired the necessary learning. Therefore, there should be no chance of a random answer at this stage. For this purpose, at this stage, the student should be asked to explain his / her answer with his / her own sentences. If the possible answers are determined in advance and the student is asked to choose one of them, the student can give the correct answer randomly. It is not expected for a student to answer the classical explanation part correctly without any knowledge about any substance. This is very useful in distinguishing the students who know and do not know. In this way, it is possible to prevent the students to make a random mistake without any conceptual understanding. Figure 1 presents an exemplary scale item.

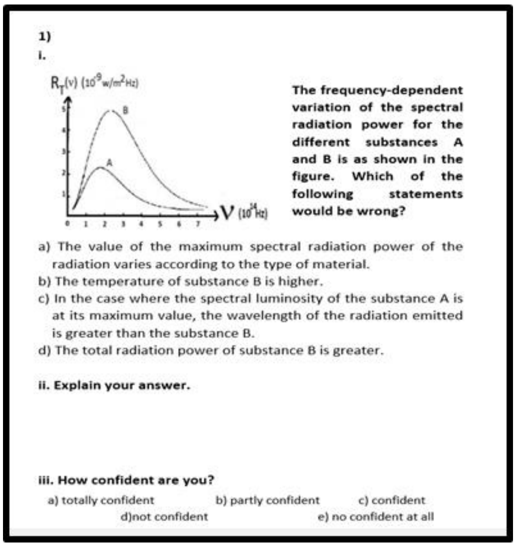

Figure 1. *Sample ICPCCS three-tier scale item*

The first stage is a multiple-choice test phase and when this stage is scored, the correct score is scored as 1, the wrong 0. The second stage is the classical explanation stage and scoring at this stage is definitely done so that the correct answer is 2, partly the correct answer 1, the wrong answer is 0. Concerning the third stage 5, 4, 3, 2 and 1 points are given to 'totally confident', 'partly confident', 'confident', 'not confident' and 'no confident at all', respectively. Table 2 shows the criteria that are taken into consideration when scoring in the second stage, the classical explanation stage.

Table 2. *Scoring method of classical explanation stage*

Classification	Answer	Point
Totally correct	Physical principles, equations, results and explanations are accurate.	2
Partially correct	At least one of the physical principles, equations and interim processes, results and explanations is incorrect.	1
Wrong	None of the physical principles, equations and intermediate processes, conclusions and explanations are correct.	0

Data Analysis

The scale was applied to the study group in the fall semester of 2017-2018 academic year. The analysis of the data was also performed in the same period. It took approximately 1 hour for a student to answer the 33-item scale. The data obtained must be analyzed in order to determine whether the developed scale is available or not. In scale development applications, only the multiple-choice test phase of the scale was used. So, the scoring was done so that the correct answer is 1, the wrong score is 0. Statistical analyses were performed using the SPSS program. The reliability, item discrimination index and item difficulty index analysis of the test were performed.

RESULTS

Findings on the Discrimination Index

The item discrimination index shows the actual measure of knowing the answer or not and employed to distinguish the students who know and who do not. If an item is correctly answered by the students with an overall low score, but has been answered incorrectly by the students with overall high score, then the distinction index of that item is said to be low. When calculating the item discrimination index, the study group is ranked from highest point to lowest point. The highest 27% is selected, called as upper group and lowest 27% named as lower group, are determined. For each item, the difference between the number of students in the upper group (nug) and the number of students who correctly answer the lower group is calculated (nsg). This difference is divided by the total number of students in a single group (n) and the item discrimination index (idci) is calculated by,

$$idci = \frac{nug - nsg}{n} \qquad (1)$$

Discrimination index values less than 0.19, are considered to be inadequate and must be removed from the scale (Neuman, 2014). When the statistical analysis was performed, the discriminability indexes of the 4th, 5th, 6th, 7tht, 10th, 14th, 15th, 16th, 17th, 20th, 28th, 29th and 33th items were found to be inadequate. Therefore, these 13 items were deleted from the scale. The statistical studies after this stage continue through these 20 items. The discrimination indexes of the test items are shown in Table 3.

Table 3. *Item discrimination indexes of test items*

item	idci	item	idci	item	idci	item	idci	item	idci
1	0,21	5	0,59	9	0,28	13	0,51	17	0,37
2	0,55	6	0,29	10	0,35	14	0,34	18	0,32
3	0,64	7	0,42	11	0,29	15	0,51	19	0,48
4	0,81	8	0,87	12	0,60	16	0,23	20	0,31

The learning attainment and question numbers that the questions in the final scale are related to by subject type are presented in Table 5.

Table 5. *Concepts measured by ICPCCS questions, relevant achievements and question numbers*

Subject	Related learning attainment	Question
Black Body Radiation	Recall the spectral radiation-frequency graph, write the relationship between the temperature of the black body, the value at which the radiation power is greatest and the radiation frequency, define the wien law, define the ultraviolet disaster, tell the difference between the classical view and the planck hypothesis, shows wien's law in graph, compares rayleigh-jeans law with experimental data, compares planck hypothesis with experimental data.	1, 2
	Defines thermal radiation, tells which substances make thermal radiation, tells why every radiation is not seen.	3, 8
	Defines the total radiation power.	4
	Remember the spectral radiation-frequency curve, tell the difference between classical view and planck hypothesis, define the concept of quantum (photon), identifies the ultraviolet disaster and shows on the graph, summarize the reason why black body radiation cannot be explained by classical physics, distinguish the difference between classical physics and quantum physics, compare rayleigh-jeans law with experimental data, compare the experimental data with the planck hypothesis.	5, 6, 7

	Know and write correctly connected circuit, know and write reverse connected circuit, write the relationship between the stopping potential and current, write the relationship between applied voltage and current passing through the circuit.	9
Photoelectric Effect	Define the circuit where the photoelectric event is observed, define kinetic energy equation of photoelectrons, summarize the photoelectric event, write the relationship between the intensity of the incoming light and the current flowing through the circuit, write the relationship between the frequency of the incident light and the kinetic energy of the photoelectrons, write the relationship between the work function of metal and kinetic energy of photoelectrons, write the relationship between the stopping potential and current, write the relationship between applied voltage and current flowing through the circuit, write the photoelectric event equation, distinguish the effect of light intensity and frequency on photoelectrons.	10, 11
	Define the reverse connected circuit, define stopping potential, write the relationship between the stopping potential and current, write the relationship between applied voltage and current flowing through the circuit, write the relationship between the frequency of light and stopping potential, explain the current passing through the circuit.	12
	Write the photoelectric event equation, shows the relationship between kinetic energy and frequency through graph, Finds the planck constant through the graph, solve problems on kinetic energy-frequency graph.	13, 14
	Define the momentum of photon, define energy conservation in compton scattering, define the compton equation, writes the relationship between the scattering angle of the scattered photon and the wavelength of the incoming wave and the wavelength of the scattered wave, summarize the compton scattering.	15, 16, 17
Compton Scattering	Says there is no change in the speed of light in Compton scattering.	18
	Writes the Compton scattering equation, defines momentum conservation in compton scattering, defines energy conservation in compton scattering, define the phenomenon of compton scattering, write the relationship between the scattering angle of the scattered photon and the wavelength of the scattered wave.	19, 20

Findings Related to the Reliability of the Scale

The reliability analyses were performed on the remaining 20 items after subtracting 13 items with a discrimination index less than 0.19. The reliability coefficient of the scale is an indicator of the stability of the data obtained from the scale under the same conditions. The reliability of the scale in statistical studies can be done by Cronbach Alpha reliability analysis. In Cronbach's alpha analysis, reliability is correlated with a coefficient which is a statistical value and can take values between 0 and 1. As this value approaches 1, it can be said that the reliability of the scale increases (Reynolds et. al., 2010; Bland and Altman, 1997). The scales are considered to be reliable if the Cronbach alpha coefficient is above 0.7. The reliability analyses were performed on the remaining 20 items after subtracting 13 items with a discrimination index less than 0.19. When the reliability analysis is done to the scale, the Cronbach Alpha reliability coefficient was calculated to be 0.78. Since this value is above 0.7, it can be said that the scale is reliable (Pallant, 2013; Tavakol and Dennick, 2011).

Findings on the Item Difficulty Indexes

Item difficulty index is a measure of the degree of difficulty of the element. This index can take values from 0 to 1. As it gets closer to 1, the matter becomes easier and the matter becomes harder as it approaches 0. The ideal value of the item difficulty index for an element is 0.5. If the item difficulty index is; between 0.00 and 0.29, the matter is considered difficult, between 0.30 and 0.69 the matter is accepted average and between 0.70 and 1.00 the matter is assumed to be easy. When calculating the item difficulty index, the lower group and the upper group are determined as in the calculation of the item discrimination index described at the beginning of section 3. Then, the number of people who correctly answer the item in the upper group (nug) and in the lower group (nsg) are determined. Th sum of (nug) and (nag) is divided by the total number of students (N) in two groups and the item difficulty index (idfi) is calculated by,

$$idfi = \frac{nsg+nug}{N} \qquad (2)$$

The data obtained as a result of the statistical analyses done in the overall 20-item test is given in Table 4.

Table 4. *Item difficulty indices of test items*

item	idfi	item	idfi	item	idfi	item	idfi
1	0,504	6	0,607	11	0,395	16	0,373
2	0,245	7	0,434	12	0,299	17	0,202
3	0,331	8	0,248	13	0,419	18	0,268
4	0,215	9	0,488	14	0,316	19	0,291
5	0,391	10	0,217	15	0,211	20	0,433

0.00<idfi<0.29 matter is difficult, 0.30<idfi<0.69 matter is moderately difficult, 0.70<idfi<1.00 matter is easy.

When Table 4 is examined, it can be said that, the 1st, 6th, 9th, 10th, 11th, 14th, 16th, 17th, 18th and 20th items are difficult; 2nd, 5th, 7th, 12th, 13th, 15th, and 19th items are average; the 3rd, 4th, and 8th items appear to be easy.

DISCUSSION and CONCLUSION

The subject of quantum physics is the basis of many extraordinary discoveries in today's technology age. And there is no doubt that it will form the basis of new technological tools that will emerge in the future. At this point, the importance of educating individuals who have learned quantum physics is quite clear. It has very heavy mathematics in quantum physics subjects. In order to understand these mathematical equations, it is not enough to have high level mathematics knowledge alone. In addition to high-level mathematical knowledge, one should have sufficient conceptual understanding of the relevant quantum physics. For this reason, students should be raised to a certain conceptual level before touching on the mathematical structure in quantum physics. At this point, it is necessary to focus on the conceptual teaching of quantum physics subjects and to make studies on this subject. But there are very few studies focusing on the conceptual comprehension level of quantum physics subjects which are pretty difficult to understand conceptually (Tiruneh et al., 2017; Petri and Niedderer, 1998; Fischler and Lichtfeldt, 1992). One of the leading reasons of this is that the quantum physical concepts cannot be observed with the naked eyes in daily life and the miscellaneous and abstract content of the concepts of quantum physics. Obviously, abstract quantum physical concepts can be taught to the students by various teaching methods and studies on this subject is very significant since the importance of quantum physics in technological progress is inevitably essential (such as nanotechnology, superconductivity) (Krijtenburg-Lewerissa et al., 2019; Wittmann, Steinberg and Redish, 2002; Ireson, 2000). One of the other reasons for the stumpy number of studies in the literature is the lack of a measurement tools that can be used to determine the conceptual understanding levels. At this point, the scale developed in this study, come one step forward as a measurement tool in other to examine the effects of any method on conceptual understanding levels of students in the related subjects.

The subjects of Black Body Radiation, Photoelectric Effect and Compton Scattering in quantum physics are taught to the students at both university and high school levels. Therefore, the three-tier ICPCCS with Cronbach's alpha coefficient of 0.78, can easily be applied to determine the conceptual understanding levels of students and their misconceptions, if any, in the courses of modern physics or quantum physics courses. Therefore, this study is significant because there is no conceptual comprehension scale developed previously in the literature that allows researchers to determine students' conceptual understanding levels.

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