Journal of Turkish Science Education, 2021, 18(4), 691-706.
DOI no: 10.36681/tused.2021.98

Journal of Turkish Science Education
http://www.tused.org
© ISSN: 1304-6020

What Does Black-body Radiation Mean for Pre-Service Physics Teachers?

Sevim Bezen[1], Işıl Aykutlu[2], Celal Bayrak[3]

[1]*Dr., Hacettepe University, Faculty of Education, Department of Mathematics and Science Education, Ankara, Turkey, ORCID ID: 0000-0002-0304-5314.*
[2]*Assoc. Prof. Dr., Hacettepe University, Faculty of Education, Department of Mathematics and Science Education, Ankara, Turkey, ORCID ID: 0000-0003-4068-0453.*
[3]*Prof. Dr., Hacettepe University, Faculty of Education, Department of Mathematics and Science Education, Ankara, Turkey, ORCID ID: 0000-0002-9269-2029.*

ABSTRACT
This study aims to determine pre-service teachers' conceptual understanding of black-body radiation. Designed as a qualitative study, it employed a case study design, which is one of the descriptive research methods. The study group consists of 18 pre-service physics teachers enrolled as seniors. An opinion form and a concept map were used as data collection tools. In other words, results were intended to be comparatively examined by using two different qualitative data collection methods. Pre-service teachers' answers were analysed with the help of answer sculptures. At the end of the study, it was determined that while pre-service teachers generally have the correct conceptual structure, they still have some specific gaps in knowledge. It was seen that pre-service teachers have problems with understanding, especially the Wien law and electromagnetic radiation taking place in black-body radiation.

ARTICLE INFORMATION
Received:
27.12.2020
Accepted:
10.06.2021

KEYWORDS: Black-body radiation, conceptual understanding, pre-service teachers, quantum physics.

Introduction

Modern physics is a field that examines the world of sub-atomic particles, and it denotes the fundamental theories that differentiate quantum physics from classical physics. It is also a science branch that tries to explain electrons and photons in quantum physics (Mashhadi & Woolnough, 1999). Quantum physics, along with modern technology, underpins various concepts (Henriksen et al., 2014). Modern physics, dealing with abstract concepts, is complicated for many people due to its mathematical and conceptual structure. With the advancing technology, understanding the nature of quantum physics has become a requirement, and quantum physics now has a critical role (Johansson & Milstead, 2008). Therefore, teaching of modern physics plays a vital role in the field. When the learning of contemporary physics is examined, students consider those classes challenging to learn, and educators think of them as challenging to teach because the concepts are abstract and complex (Ayene et al., 2011; Ke et al., 2005; Sadaghiani, 2005). It is thought that modern physics is not linked to daily life while teaching it and teaching it as such makes conceptual understanding more difficult. Even when modern physics is related to everyday life, it is seen that teachers usually resort to simplifications from classical physics teachings, such as using pictures, graphics, or analogies; and this often creates misconceptions. It can be argued that using explanations that are appropriate for classical physics while teaching quantum physics often causes misunderstandings in students (Singh, 2006). Moreover, this complex and challenging nature of modern physics results in a decrease in modern physics studies. When studies on physics in literature published in the last 20 years are examined, it can be seen that only 1% of these studies is on concepts of modern physics (Passante et al., 2015). When literature is examined, it is also determined that those studies are mainly on the teaching of quantum physics, reading students' conceptual understanding, attitude towards the topic, material design, or selecting methodology (DeVore & Singh, 2015; Marshman & Singh, 2016; McKagan et al., 2010; Ogborn & Taylor, 2004; Passante et al., 2015; Shi, 2013). Studies show that since secondary school pre-service teachers have tried to learn concepts only by relating them with formulae, they have problems in their conceptual understanding. It is specifically evident that students cannot mentally structure the abstract concepts of modern physics, and they cannot relate concepts with one another (Galvez, 2008; Hinojosa, 2008). At this point, it is necessary to recall that determining pre-service teachers' conceptual difficulties concerning the topics of modern physics is a necessity and an essential factor to ensure meaningful learning because pre-service teachers are usually expected to have a good grasp of the fundamental aspects of topics and to be able to relay them to their students (Ohle et al., 2015; Shulman, 1986). In other words, it is thought that teachers should teach by knowing basic concepts, by making applications of the theoretical, and that they should teach confidently. Otherwise, they would create misconceptions in their students and not be able to answer their students' questions (Balta, 2018; Kınık Topalsan & Bayram, 2019). Thus, it is important that pre-service teachers thoroughly learn the topic because a teacher who has internalized it would realize teaching by using proper teaching strategies and adapting to the changing and evolving learning process. Moreover, when pre-service teachers have enough comprehension of basic concepts and keep getting more competent, this would positively impact the learning process (Melo et al., 2020). To this end, this study aims to determine pre-service teachers' conceptual understanding of black-body radiation, which is one of the concepts of modern physics. As such, it is thought that this study contributes to previous studies on black-body radiation and provides helpful information for the teaching of the topic. Unlike literature, this study comparatively examines pre-service teachers' conceptual understanding by using two different data collection tools; and this is believed to bring a fresh angle to the field.

In the study, while pre-service teachers' conceptual understanding of black-body radiation was examined, they were expected to internalize the fact that black-body radiation is born out of the energy of the light disseminated by objects at a specific temperature on absolute zero (Ranganath, 2008) because an ideal black-body is defined in literature as an object that could absorb all light that comes it's the way. On the other hand, a ray is described to be composed of energy packages called photons (Serway, 1996). As is known, Max Planck is a scientist who caused the birth of quantum physics by rearranging the classical thermal radiation, which did not accord with the experimental results. In this respect, it can be said that in theoretically expressing thermal radiation of black bodies, Wien's formula was employed in high frequencies, and Rayleigh-Jeans formula was used in low frequencies; the conclusion is reached by putting these two formulae together and by also taking into account Boltzmann's entropy (Gearhart, 2009). In short, black-body radiation is an important concept that bridges the gap between classical and quantum approaches. Considering all these, it can be argued that seeing teachers have limited or incorrect knowledge of black-body radiation, which has an important place in the transition from classical to modern physics, is the reason why this study was realized (Balta, 2018). Therefore, one aim was to contribute to the literature and the educators in the field; hence, it was decided that the study should investigate pre-service teachers' conceptual understandings. Different from literature, concept maps were used along with opinion forms in this study to examine pre-service teachers' conceptual understanding because it is thought that concept maps are graphical tools that lay bare pre-service teachers' conceptual understanding as well as their knowledge concerning the relationship between concepts (Novak, 1990). Concept maps enable learning to be stored concretely and visually in the mind, and they help schematize the relationship between ideas. It is also believed that concept maps would be used as a measuring tool to reveal pre-service teachers' alternative concepts. In short, concept maps are supposed to ensure examining pre-service teachers' cognitive structures (Novak et al., 1983; Ruiz-Primo & Shavelson, 1996).

Theoretical Framework

When recent studies in the literature were examined, it was seen that Ribeiro (2014) designed an activity for students to understand the black-body better. In his research, the aim was to create a simple material, concerning Boltzmann and Wien laws. He argued that the designed simulation program made concrete teaching black-body radiation at the end of the study. Lancor and Lancor (2018) wanted students to realize that the designed solar oven mechanism locks energy by absorbing it, and they wanted to show how black-body radiation takes place. In the study, project-based learning was adopted, and students were asked to design a solar oven. Simultaneously, it was indicated that students were encouraged to learn so that meaningful learning was realized. Balta (2018) aimed to determine high school teachers' conceptual understanding of black-body radiation, and he argued that teachers have incomplete or even wrong information about black-body radiation. At the end of the study, it was determined that pre-service teachers could not fully explain what black-body radiation is and that they defined black-body as a spherical object. Similarly, Görecek Baybars and Küçüközer (2014) tried to determine the effect of pre-service science teachers' ideas about quantum physics and the impact of its teaching on their conceptual understanding. Their study showed that before learning, these pre-service teachers had numerous alternative concepts. At the same time, after education, they obtained a scientific conceptual structure to reach a conceptual understanding. Likewise, Ünlü Yavaş and Kızılcık (2018) explored the reasons why high school students, as well as pre-service science teachers, have difficulty in the topics in the introduction to quantum physics. Their study concluded that students' conceptual understanding was negatively impacted by the lack of relating these topics to daily life situations. Emigh et al. (2013) aimed to determine pre-service physics teachers' comprehension of black-body radiation. Their study argued that traditional teaching is not helpful for students to learn the conceptual and mathematical dimension of black-body radiation. In the study, the aim was to take students outside of traditional teaching boundaries, and hence online homework was designed. However, at the end of the study, it was indicated that using merely this material is not enough for learning black-body radiation and that more effective teaching materials should be designed. Sadoğlu and Akdeniz (2015) aimed to determine high school students' perception of black-body radiation. In their study, data were collected through open-ended questions; it was seen that students defined black-body radiation as "a body that cools down the light falling upon it". Similarly, Kural (2015) aimed to determine high school students' conceptual understanding of black-body radiation. At the end of the study, it was determined that students have several misconceptions. These misconceptions were laid bare by the students' non-scientific expressions such as "Black-body radiation is explained by the wave characteristic of light," "Black-body radiation proves that light is a wave," "If the temperature of black-body increases, so does its wavelength," "There is no relationship between the temperature of black-body and the radiant intensity," and "If the temperature of black-body increases, its energy increases, the intensity remains the same, and thus radiance takes place." It was determined that students could not make sense that there could be radiance at temperatures higher than absolute zero. Students were also seen to voice scientifically wrong ideas by likening Wien's Law to photon energy. In his study, Ejigu (2014) likewise found out that students had difficulty drawing the intensity-wavelength graphics of black-body and misconceptions in this association. Vokos et al. (2000), on the other hand, contended that the misconstruction of wavelength as a concept is the underlying reason for this misconception. Finally, Pinochet (2019) brought together all misconceptions in the literature and emphasised that students' basic misconception about black-body is expressing black-body as something that absorbs everything, as something big and black with high density.

Consequently, literature shows that black-body radiation has been examined both internationally and nationally. However, the number of studies focusing on the level of comprehension of quantum physics topics, which are deemed hard to understand, is still low (Tiruneh et al., 2017). In this respect, this study aims to contribute to the literature by being a source for studies to be conducted with pre-service physics teachers.

Purpose of The Research

In this study, pre-service teachers' conceptual understanding of black-body radiation was examined via an opinion form and concept map; and the results of these two were aimed to be examined comparatively. The problem sentence of the study was determined as "How is pre-service physics teachers' conceptual understanding of black-body radiation?"

Method

Model of The Study

Designed as a qualitative study and to determine pre-service teachers' conceptual understanding of black-body radiation, this study was realized by employing a case study, one of the descriptive research methods (Creswell, 2007). The case study enables a thorough examination of an event or a phenomenon (Merriam & Tisdale, 2016). Also, the researchers wanted to get detailed information about the situation and get this in a short amount of time through the context (Yin, 2003). The case was handled holistically while seeking answers to scientific questions, and one objective was to lay bare how the said situation is influenced. Moreover, one case was examined through multiple data collection tools, thereby creating methodological diversity (Creswell, 2007; Patton, 2014). It is believed that the situation obtained in the survey would reveal what prospective studies should pay specific attention to. Thus, events were examined within their natural habitat without any control. Finally, because one group was worked in the case study, a holistic single case pattern was employed (Yin, 2003).

Study Group

The study group consists of 18 pre-service physics teachers (age range 21-24; 8 male, 10 female) enrolled as seniors at a state university in the spring semester of the 2018-2019 academic year. Criterion sampling was used to determine the study group because it is known that when the researchers in quantitative studies determine the criterion, the aim of the study can be more easily classified, and richer information concerning the phenomenon can be presented (Marshall & Rossman, 2014). In this respect, the criterion was for pre-service teachers to have taken quantum physics and modern physics lab classes. By determining pre-service teachers, findings' validity and reliability were expected to be increased (Strauss & Corbin, 2014).

Data Collection Tools

In the study, an opinion form and concept map designed by pre-service teachers were used as data collection tools. Since the aim was to examine pre-service teachers' conceptual understanding thoroughly, two different sets of data collection tools were used. In the opinion form, six open-ended questions would lay bare students' conceptual understanding of black-body radiation; in the concept map, students were presented with the concepts "black-body" and "photon." These concepts were selected because they are fundamental concepts that explain black-body radiation. When data collection tools were designed, a detailed literature review was conducted, ideas that students mentally have were considered, and two experts who hold PhDs in physics education were consulted. In this respect, while there were two central concepts in the concept map, the following questions were given in the opinion form:

(1) Visualize the black-body in your mind and explain what you have visualized.
(2) Are there any concepts you associate with black-body? If yes, what are they? Please explain.
(3) What do you think was the contribution of the discovery of black-body radiation to science in general? Please explain.

(4) What do you think is the reason for us to see objects black? Can the things that we see black be given as examples to black-body? Please explain.
(5) Would there be electromagnetic radiation in black bodies? Please explain.
(6) Can you elaborate on the relation between the Planck hypothesis and Wien law and black-body radiation?

Procedure

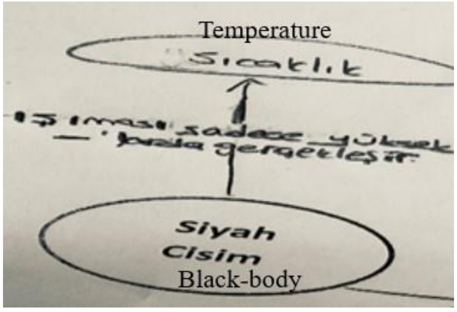
In the study, the teaching of quantum physics and modern physics laboratory was carried out by the teaching program's present content; there was no difference of application in these classes. In this respect, the opinion form and concept map were applied at a different date to the pre-service teachers. After class hours, each application was done at suitable times for both the student and the researchers in two weeks. Participation was voluntary, and each application took 20-30 minutes. First asked to complete the opinion form, pre-service teachers were then asked to form a concept map at the end of one month. Pre-service teachers were briefed about creating a concept map, and they were asked to develop the map by meaningfully associating concepts related to one another. Moreover, pre-service teachers were expected to display their conceptual structures with concept maps and express their hidden knowledge on the issue. However, no activity that would help pre-service teachers was done before the research. In short, in this study, pre-service teachers were given written documents to freely express their opinions, enabling them to reflect on the questions directed at them (Fraenkel et al., 2012).

Data Analysis

The answers pre-service teachers have given to open-ended questions and the concept map were analysed with the help of answer sculptures. Answer sculptures is an explanatory model which enables presenting pre-service teachers' answers with a new map. In this study, data obtained via two different data collection tools were analysed with the same method so that findings could be presented to the reader in a more meaningful way. In other words, the central concept, which is the black-body, was located at the centre, and the connections of this concept and its relation to various sub-concepts were described via answer sculptures (Fraenkel et al., 2012). In the formation of the answer sculptures, pre-service teachers' answers were considered; similar results concerning black-body radiation were put together. Then, categories were formed; these categories were gathered under common themes and were presented to the reader under a general frame (Cohen et al., 2007). According to the "correct, partially correct, incorrect, and irrelevant" evaluation steps, open-ended questions were analysed. Then, answers were categorised according to their similarities, and frequency values of each category were expressed within geometrical shapes. In the concept map analysis, statements indicating the relationship between concepts were examined under the "correct, partially correct, incorrect, and irrelevant" categories. For instance, a pre-service teacher made an incorrect association between black-body and temperature in the concept map. This association was expressed in the circle with the statement, "Radiation in black bodies takes place only in high temperatures" (Fig. 1.)

Figure 1

Sample Concept Map Section of a Pre-Service Teacher

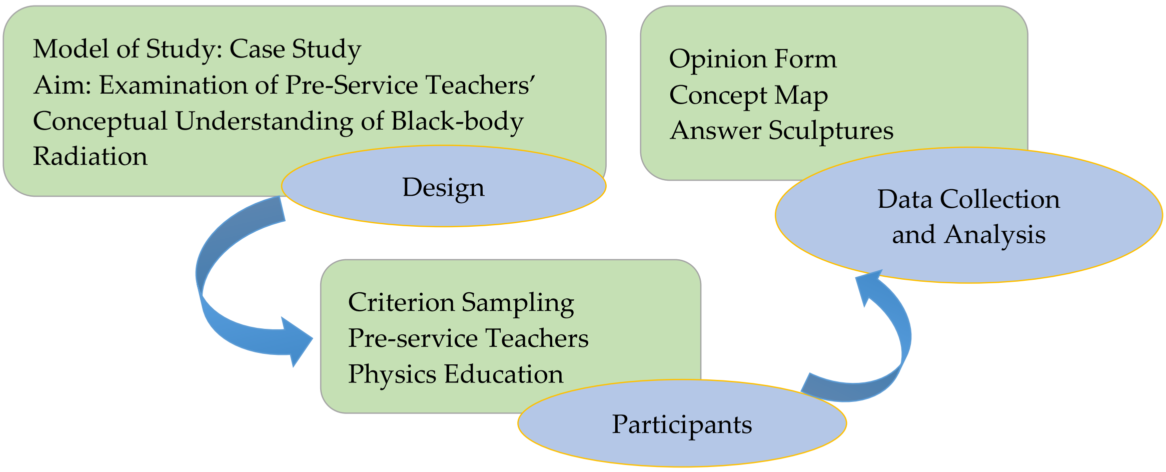


In other words, pre-service teachers' conceptual structures were presented to the reader with the help of geometrical shapes, just as it was done with the analysis steps of the open-ended questions. In the study, the rectangle represents the correct answer, the pentagon the partially correct answer, the circle the incorrect answer, and the trapezoid represents the irrelevant answer; as such, concept maps were formed to avoid conceptual confusion. In short, pre-service teachers' responses were expressed with symbols so that the reader could reflect on them. The frequency of pre-service teachers' conceptual understanding was also indicated so that their conceptual understanding of black-body was put forth (Weber, 1990). Consequently, pre-service teachers' detailed answers were made clear and comprehensible by presenting them with answer sculptures in this study (Saljö, 1994).

In the study conducted by Balta (2018), data obtained from a single data collection tool (online questionnaire) was analysed through answer sculptures and presented. In that study, it was indicated that the use of answer sculptures is an effective way for classifying participants' answers and laying bare their conceptual understanding. Furthermore, it was argued that answer sculptures could see alternative concepts held by participants. In this respect, this study had intended to analyse data through answer sculptures. However, different from Balta's study (2018), this study gathered pre-service teachers' conceptual understanding of black-body radiation through two different data collection tools and explanatory model analysed data. Analysis conducted by answer sculptures enabled the researcher to compare data. Two answer sculptures were designed with the opinion form and the concept map, and these two were comparatively examined. Thus, special attention was paid to categories and connections while creating the answer sculptures. Considering all these, the research process was summarized in Fig. 2 in terms of design, participants, data collection, and data analysis.

Figure 2

Process of The Research



Validity and Reliability

In the study, such strategies as believability (internal validity), transmissibility (external validity), consistency (internal reliability), and confirmability (external reliability) were employed for validity and reliability. To this end, analysis of the study was done by different researchers, who have PhDs in the physics education field, at other times; they were compared, and another two independent experts' observer examined the harmony between analyses, thereby ensuring the reliability of the study. Experts evaluated the expressions they considered correct by giving it 1 point, and they offered 0 points to those they deemed to be incorrect. In the study, categories, relationships between types, and the appropriateness of answers to the geometric shapes were examined; consistency between experts was examined by Miles and Huberman's (1994) formula [Reliability=Number of agreements/ (Number of the accords + Disagreements)] and was determined to be 0.80. Since any harmony above 0.75 is considered a perfect balance in literature, the study was reliable. Expert observers reached a consensus for the different codifications, and codifications took their final shape. Also, direct quotations from pre-service teachers were given in the study, and the process was presented in detail. The study's internal validity was ensured with participant control; the reasonableness of the results obtained in this context was checked along with the data sources, and data diversity was achieved (Cohen et al., 2007). The study was checked by the experts so that internal validity was increased. Obtained data were presented to the reader in detail to ensure external validity. Complex answers were given clearly and understandably in this process, so special attention was paid to categories and themes.

Ethical Procedures

Ethical principles and rules were followed during the planning of the research, data collection, analysis, and reporting. This research was found ethically appropriate with the decision numbered 35853172-600 at the meeting held by our University Senate Ethics Commission on 23 July 2019.

Findings

In this part of the study, pre-service teachers' conceptual understanding of black-body radiation was examined using an opinion form and concept map. Answers obtained from the opinion form and concept map were tackled under separate headings, and they were presented to the reader below within answer sculptures.

Findings Obtained from the Opinion Form

Pre-service teachers answered six open-ended questions in the opinion form, and answer sculptures were designed accordingly. These answer sculptures reveal that pre-service teachers' answers vary (Fig. 3). Containing different categories, answer sculptures show that pre-service teachers gave 18 correct and 5 incorrect answers in total. The number of pre-service teachers giving correct and incorrect answers indicated in brackets inside the geometrical shapes. These values put forth that pre-service teachers' usually use the correct expressions for black-body radiation. Moreover, because there appears to be a connection between geometrical shapes, it is thought that pre-service teachers could relate the main concepts with sub-concepts. In this respect, it can be argued that pre-service teachers explained black-body radiation most frequently by calling it "a body that absorbs all light" and the pioneer of quantum physics. In addition to these, pre-service teachers used the following correct expressions to explain black-body radiation: Wien law cannot adequately explain black-body radiation, Planck put forth black-body radiation, a sphere with a small hole which locks the electromagnetic wave inside, electromagnetic radiation can take place over 0°K, examples to black-body radiation are the Sun and the stars, the radiator, the human body, and the universe, and finally not every object that looks black is a black-body. In the study, similar expressions of pre-service teachers were grouped to create categories, and therefore answers were presented in clear and comprehensible terms. Pre-service teachers' scientifically incorrect answers were determined to be the following: Wien law completes the gaps in Planck, black-body is an object that has flames around it, but it does not burn itself, black-body is a black curtain, black bodies can give electromagnetic radiation at all temperatures, and radiation takes place only in high temperatures (Fig. 3).

Findings Obtained from the Concept Map

Pre-service teachers' conceptual structures of black-body radiation were examined with the concept map and were presented with the help of answer sculptures. Pre-service teachers' statements that give the relationship between concepts were put together according to their similarities to form categories. These categories were indicated in the answer sculptures in geometrical shapes, including the number of pre-service students. When pre-service teachers' statements were examined, it was determined that pre-service teachers have different conceptual structures, and those conceptual structures usually included correct words. Answer sculptures put forth that pre-service teachers' have 16 valid, 2 partially correct, and 3 incorrect conceptual knowledge (Fig. 4). It was noteworthy that pre-service teachers could make associations between concepts, and they defined black-body with the statement "an object that absorbs all light that falls on itself." Similarly, they correctly expressed that Rayleigh-Jeans law tried to explain black-body radiation, Planck put forth black-body radiation, not every object that we see as black could be an example to black-body, and good examples to black-body could be the Sun and the stars, the radiator, and the black hole, and that black-body has high energy. In associating the black-body with the photon, they made the following correct statements: the photon is reflected within the black-body, the photon does not have mass, the photon carries energy and momentum, and scientists work on the photon. Those pre-service teachers' answers who thought that photon displays the only wave and particle characteristic were considered partially correct answers. Finally, pre-service teachers' scientifically incorrect answers were the following: Wien law pioneered black-body radiation. Black-body can give electromagnetic radiation at all temperatures or only in high temperatures (Fig. 4).

Figure 3

Answer Sculptures Concerning the Opinion Form (Correct Conceptual Expression (Rectangle) and Incorrect Conceptual Expression (Circle))

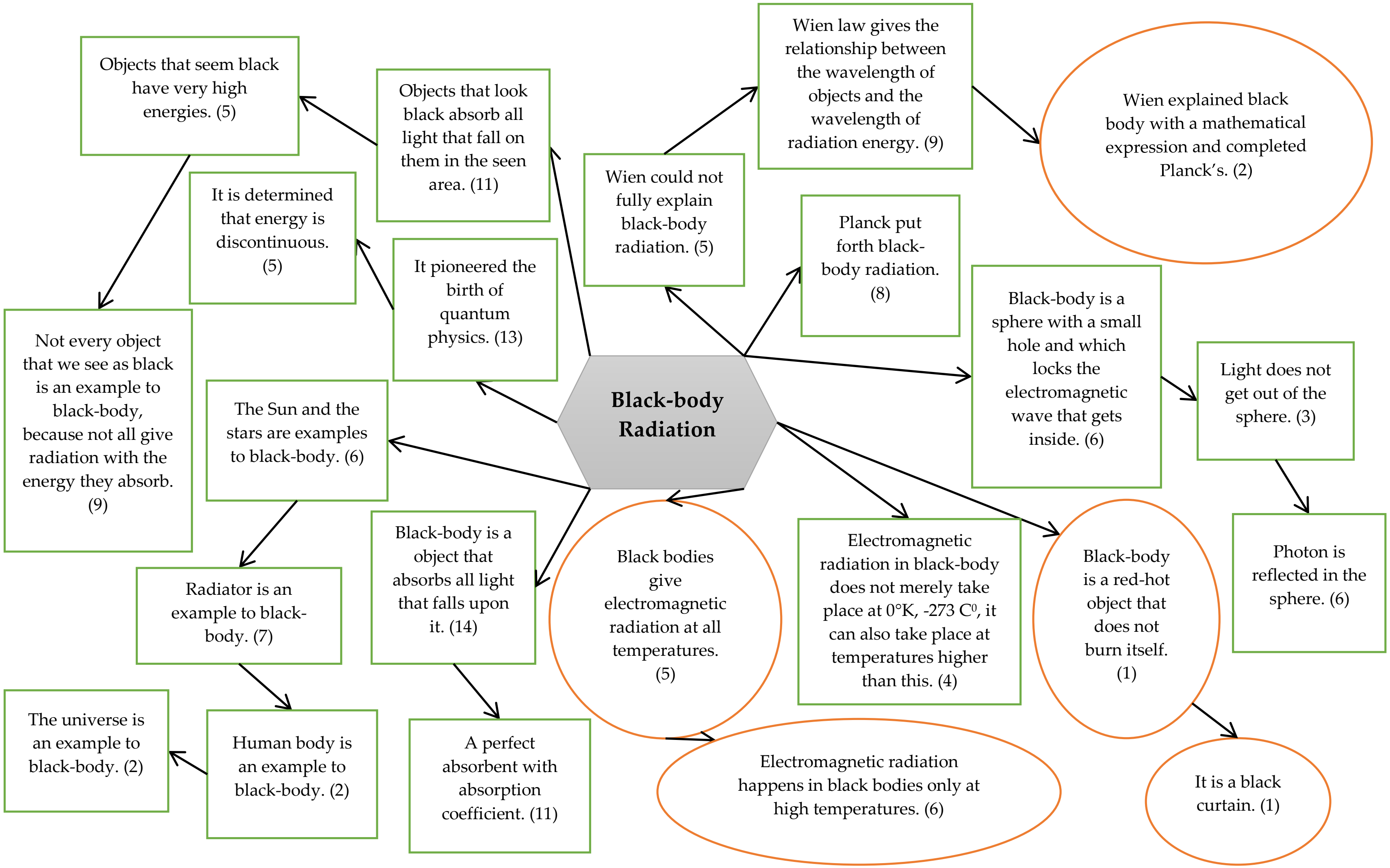
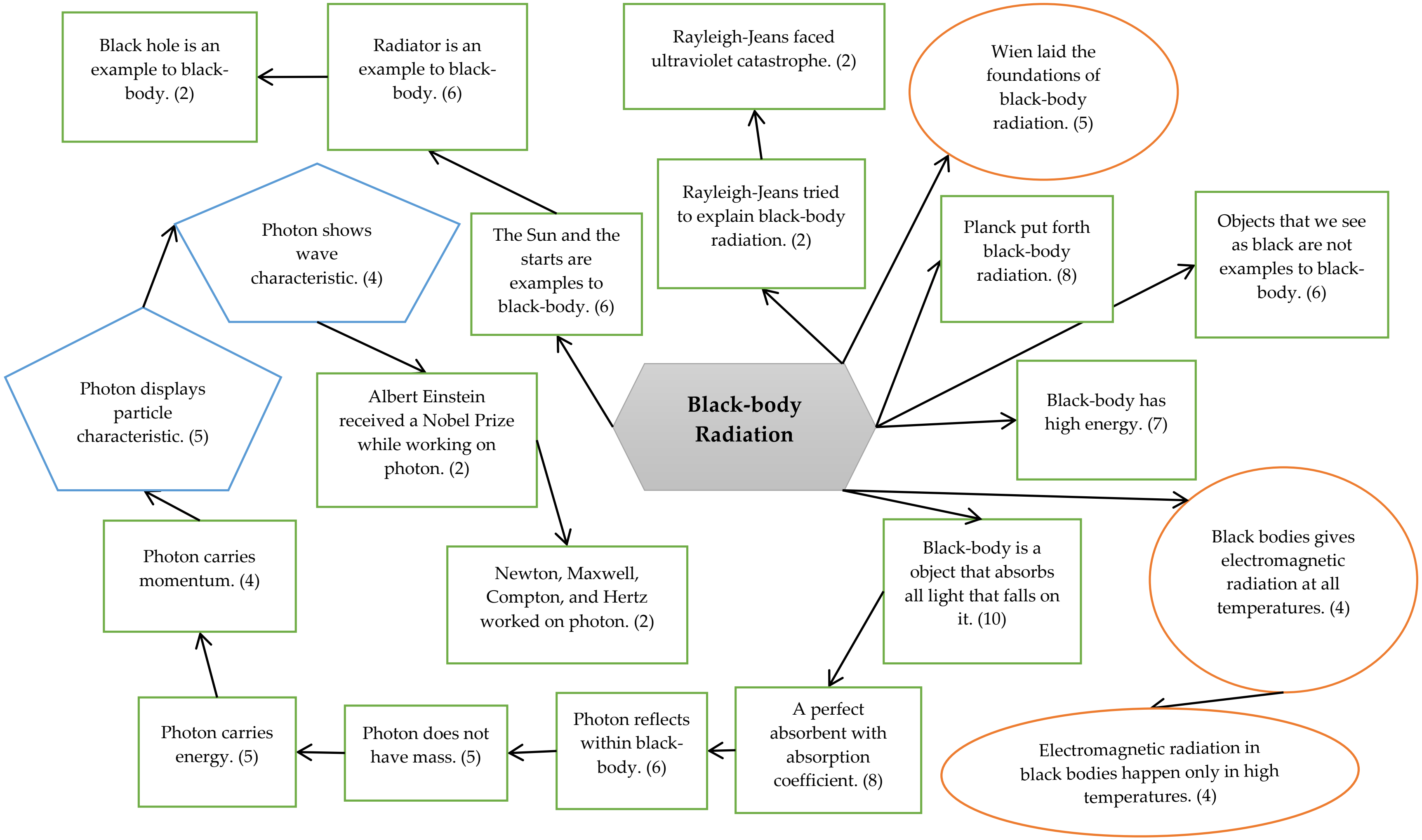


Figure 4

Answer Sculptures Concerning Concept Map (Correct Conceptual Expression (Rectangle), Partially Correct Conceptual Expression (Pentagon), Incorrect Conceptual Expression (Circle))



Discussion

Opinion Form

In the study, pre-service teachers' conceptual understanding of black-body radiation was put forth using an opinion form and answer sculptures. The opinion form analysis with answer sculptures showed that pre-service teachers have correct and incorrect knowledge of black-body radiation. While pre-service teachers' views were usually scientifically accurate, it was also seen that some of them gave scientifically wrong answers for the discoveries of Wien and Planck. The study determined that pre-service teachers had difficulty scientifically explaining the birth of quantum physics and Planck's importance on the development of modern physics. In literature, the same problem was also voiced in Kural's study (2015) on high school students. In that study, it was seen that students had difficulties, especially with Wien's law, and expressed scientifically false ideas by likening Wien's law to photon energy. In addition to these, it was determined that pre-service teachers associated black-body with a black curtain or an object that shoots fire around, although it does not burn itself. Pinochet (2019) argued that the most critical misconception about the black-body is thinking of it as a black object. Similarly, in this study, it was seen that pre-service teachers had this misconception. It is believed that this is the result of students answering the questions digressing from an ideal black-body. Özdemir (2017) also determined that pre-service teachers have opinions and argued that the black-body is an abstract concept. Another result obtained in the study is that pre-service teachers could define the black-body as an object that absorbs any light that befalls on it; however, they give contradictory descriptions by not mentioning electromagnetic radiation at this point. It was determined that pre-service teachers have difficulty explaining electromagnetic radiation realised by black bodies, and they cannot correctly interpret laws concerning black-body radiation. In other words, pre-service teachers were determined to comment on the external look of the black-body rather than the thermal movement of the loads within it. In this respect, it can be argued that pre-service teachers are not proficient in the characteristics of an ideal black-body (Sadoğlu & Akdeniz, 2015). Also, since it is known that black-body radiation is the pioneer of quantum physics, it is inevitable for pre-service teachers who cannot properly make sense of Rayleigh-Jeans law to be confused (Persson, 2018). In short, data obtained from the opinion form indicate that pre-service teachers have mental difficulties concerning black-body radiation. This is because black-body is an abstract concept, and pre-service teachers have not wholly comprehended that objects can give radiation only at specific temperatures.

Concept Map

In the study, pre-service teachers' conceptual understanding of black-body radiation was put forth using a concept map and answer sculptures. The analysis of the concept map with answer sculptures, just like the opinion form analysis, showed that pre-service teachers have correct, partially correct, and incorrect knowledge of black-body radiation. It was determined that pre-service teachers could associate the photon and black-body and talk about the photon's characteristics. A study conducted by Sadoğlu and Akdeniz (2015) determined that high school students have a similar conceptual understanding. However, different from the literature in this study, it was determined that pre-service teachers could talk about scientists while expressing photons. This reveals pre-service teachers' interest in the history of science (MacLeod, 2014). Moreover, it was determined that pre-service teachers who have incomplete knowledge concerning only the photon showing a particle and wave characteristic have incomplete or incorrect views. Supporting this finding, Krijtenburg-Lewerissa et al. (2017) determined that students had the most difficulty with the concept of the photon, and they argued that teaching strategies should be developed on this topic. In addition to these, just as in the opinion form, it was determined that pre-service teachers' concept maps have scientifically wrong ideas about Wien's law. Interestingly, however, it was determined that they have correct postulations on Rayleigh-Jeans. In other words, it was determined that pre-service teachers have incomplete knowledge about the discovery of black-body radiation and Planck. In literature, it is opined that this problem may be resulting from proactive inhibition, from still thinking through fundamental concepts of classical physics (Ladj et al., 2010).

Moreover, pre-service teachers' scientifically incorrect views (such as black-body radiation being realised in every temperature or high temperatures in blackbodies) were also revealed in concept maps. Vadnere and Joshi (2009) argue that multimedia learning software and simulations should be utilised to alleviate these misconceptions. The study also determined that pre-service teachers think of the black-body as an object that absorbs light. On the other hand, it was determined that pre-service teachers have conflicting views (such as black-body spreads energy or radiates). This makes one believe that pre-service teachers cannot fully make sense of black-body radiation (Didiş, 2012). Pre-service teachers were able to give appropriate examples for black-body, which implies that pre-service teachers memorise rather than make sense of concepts while learning them since it is known that individuals tend to memorise concepts that they cannot relate to daily life (Sadoğlu & Akdeniz, 2015). It is believed that prejudice against concepts that are abstract and believed to be hard to learn detracts people from conceptual learning (Johnston et al., 1998).

Conclusion and Suggestions

The study shows that pre-service teachers can primarily define an ideal black-body, give examples, and associate black-body with the photon. While having the correct conceptual structure, pre-service teachers also had difficulties at specific points (Singh, 2001). It can be said that pre-service teachers have a problem in their analogies of black-body, do not have a full grasp of the historical developments at the emergence of quantum physics, do not know the characteristics of electromagnetic radiation, and cannot express together the wave-particle characteristic of the photon (Emigh et al., 2013; Olsen, 2002). In the two data collection tools, it was revealed that there were issues with the Wien law and the electromagnetic radiation that occurs in black-body radiation. It is thought that pre-service teachers have misconceptions about these, and they are resistant to change. In this respect, it can be said that pre-service teachers acquired these misconceptions in their previous learning (Park, 2006). It is believed that concept maps should also determine pre-service teachers' prior knowledge to prevent such misunderstandings because concept maps are among the alternative measuring tools used to reveal students' ideas about concepts (Kara & Kefeli, 2018). Moreover, it is known that black-body radiation is a topic that necessitates more contemplation by following a different route of teaching compared to other issues (Lautesse et al., 2015). In other words, it can be argued that by determining pre-service teachers' incomplete or incorrect knowledge, one can amend these during the act of teaching. Consequently, these issues would cause pre-service teachers (and their prospective students) problems when the time comes for them to teach black-body radiation. In that case, pre-service teachers should not be left alone but supported by various projects and simulation-supported laboratory applications because only then can resistant-to-change misconceptions be overcome (Kohnle et al., 2014; McKagan et al., 2010; Yener et al., 2020). Moreover, it is thought that model, simulation, and augmented reality applications should be part of teaching to distance students from learning by rote (Emigh et al., 2013; Ventura et al., 2017). The study conducted by Yalçın and Emrahoğlu (2017) also put forth that using different methods and techniques in teaching the relevant course enabled high school students to transfer their knowledge of black-body radiation to daily life quickly.

In addition to all of these, it is thought that data obtained from different data collection tools support one another, and they are also helpful in putting forth different opinions. In other words, because both the opinion form and the concept map are powerful data collection tools in themselves, a comparative examination of the data has created a solid foundation for putting forth the conceptual structure. Simultaneously, the opinion form and the concept map complement each other since they help determine the cognitive structure differences. As in this study, further studies should also use different methods to enhance the research's conclusion (Kwon & Cifuentes, 2009).

Finally, answer sculptures, which is an innovative strategy, were used to make sense of findings more efficiently in their entirety. Data obtained from different data collection tools were analysed by the same method thanks to the answer sculptures, and the study was made more understandable for the reader. It can be argued that presenting the findings through an innovative strategy adds a new viewpoint to literature. In this respect, the use of answer sculptures can be recommended for future studies since it enables presenting findings on a single figure by categorising multiple answers, and it is a strategy open for improvement (Balta, 2018).

References

Ayene, M., Kriek, J., & Damtie, B. (2011). Wave-particle duality and uncertainty principle: phenomenographic categories of description of tertiary physics students' depictions. *Physical Review Special Topics-Physics Education Research, 7*(2), 1–13. 10.1103/PhysRevSTPER.7.020113

Balta, N. (2018). High school teachers' understanding of blackbody radiation. *International Journal of Science and Mathematics Education, 16*, 23-43. 10.1007/s10763-016-9769-z

Cohen, L., Manion, L., & Morrison, K. (2007). Observation. In *Research Methods in Education*, 396-412. 10.4324/9780203029053

Creswell, J. W. (2007). *Qualitative inquiry & research design: Choosing among five approaches.* Sage.

DeVore, S., & Singh, C. (2015). *Development of an interactive tutorial on quantum key distribution.* Physics Education Research Conference Proceedings, 59–62.10.1119/perc.2014. pr.011

Didiş, N. (2012). *Investigation of undergraduate students' mental models about the quantization of physical observables* [Unpublished doctoral thesis]. Middle East Technical University, Ankara.

Ejigu, M. A. (2014). *Conceptual understanding of quantum mechanics: an investigation into physics students' depictions of the basic concepts of quantum mechanics* [Unpublished doctoral thesis]. University of South Africa, Pretoria.

Emigh, P. J., Passante, G., & Shaffer, P. S. (2013). *Student understanding of blackbody radiation and its application to everyday objects.* 2013 Physics Education Research Conference, Portland.

Fraenkel, J. R., Wallen, N. E., & Hyun, H. H. (2012). *How to design and evaluate research in education (8th ed.).* McGraw-Hill.

Galvez, E. J. (2008). *Photon quantum mechanical labs.* The annual meeting of American Association of Physics Teachers (AAPT), Edmonton.

Gearhart., C. (2009). Black-body radiation, In Greenberger, D., Hentschel, K., & Weinert, F. (Eds.), *Compendium of quantum physics: concepts, experiments, history and philosophy* (pp. 39–42). Springer Science & Business Media.

Görecek Baybars, M., & Küçüközer, H. (2014). The pre-service science teachers' conceptual understanding of quantum physics. *MSKU Journal of Education, 1*(1). 10.21666/mskuefd.36735

Henriksen, E. K., Bungum, B., Angell, C., Tellefsen, C. W., Fraget, T., & Vetleseter Boe, M. (2014). Relativity, quantum physics and philosophy in the upper secondary curriculum: challenges, opportunities and proposed approaches. *Physics Education, 49*(6), 678–684. 10.1088/0031-9120/49/6/678

Hinojosa, C. M. (2008). *Learning the uncertainty principle: A study of its difficulties.* The annual meeting of American Association of Physics Teachers (AAPT), Edmonton.

Johansson, K. E., & Milstead, D. (2008). Uncertainty in the classroom-teaching quantum physics. *Physics Education, 43*(2), 173–179. 10.1088/0031-9120/43/2/006

Johnston, I. D., Crawford, K., & Fletcher, P. R. (1998). Student difficulties in learning quantum mechanics. *International Journal of Science Education*, *20*(4), 427–446. 10.1080/0950069980200404

Kara, F., & Kefeli, N. (2018). The effect of using concept maps on student's success, logical thinking and attitudes towards science. *Necatibey Faculty of Education Electronic Journal of Science and Mathematics Education, 12*(2), 594-619. 10.17522/balikesirnef.506475

Ke, J., Monk, M., & Duschl, R. (2005). Learning Introductory Quantum Physics: Sensori-motor experiences and mental models. *International Journal of Science Education*, *27*(13), 1571–1594. 10.1080/09500690500186485

Kınık Topalsan, A., & Bayram, H. (2019). Identifying prospective primary school teachers' ontologically categorized misconceptions on the topic of "force and motion". *Journal of Turkish Science Education, 16*(1), 85-109. 10.12973/tused.10268a

Kohnle, A., Bozhinova, I., Browne, D., Everitt, M., Fomins, A., Kok, P., Kulaitis, G., Prokopas, M., Raine, D., & Swinbank, E. (2014). A new introductory quantum mechanics curriculum. *European Journal of Physics*, *35*(1), 015001. 10.1088/0143-0807/35/1/015001

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

Kural, M. (2015). *Teaching for hot conceptual change: an example of grade 11 modern physics* [Unpublished doctoral thesis]. Balikesir University Institute of Science, Balikesir.

Kwon, S. Y., & Cifuentes, L. (2009). The comparative effect of individually-constructed vs collaboratively-constructed computer-based concept maps. *Computers & Education, 52*(2), 365-375. 10.1016/j.compedu.2008.09.012

Ladj, R., Oldache, M., Khiari, C. E., & Belarbi, T. (2010). On students' misunderstanding of the basic concepts of quantum mechanics: the case of Algerian Universities. *Latin-American Journal of Physics Education, 4*(2), 286-293.

Lancor, R., & Lancor, B. (2018). Solar cookers in the physics classroom. *The Physics Teacher*, *56*(9), 607–610. 10.1119/1.5080574

Lautesse, P., Vila Valls, A., Ferlin, F., Héraud, J. L., & Chabot, H. (2015). Teaching Quantum Physics in Upper Secondary School in France: 'Quanton' Versus 'Wave–Particle' Duality, Two Approaches of the Problem of Reference. *Science and Education*, *24*(7–8), 937–955. 10.1007/s11191-015-9755-9

Macleod, K. (2014). Pre-service teachers' perceptions of teaching STSE-Based high school physics: Implications for post-secondary studies. *European Journal of Physics Education, 5*(1), 1-15. 10.20308/ejpe.v5i1.59

Mashhadi, A., & Woolnough, B. (1999). Insights into students' understanding of quantum physics: Visualizing quantum entities. *European Journal of Physics*, *20*(6), 511–516. 10.1088/0143-0807/20/6/317

Marshman, E., & Singh, C. (2016). Interactive tutorial to improve student understanding of single photon experiments involving a Mach–Zehnder interferometer. *European Journal of Physics, 37*(2), 024001. 10.1088/0143-0807/37/2/024001

Marshall, C., & Rossman, G. B. (2014). *Designing qualitative research.* Sage.

McKagan, S. B., Perkins, K. K., & Wieman, C. E. (2010). Design and validation of the quantum mechanics conceptual survey. *Physical Review Special Topics-Physics Education Research, 6*(2), 1–17. 10.1103 /PhysRevSTPER.6.020121

Melo, L., Cañada-Cañada, F., González-Gómez, D., & Jeong, J. S. (2020). Exploring Pedagogical Content Knowledge (PCK) of Physics Teachers in a Colombian Secondary School. *Education Sciences*, *10*(12), 362. 10.3390/educsci10120362

Merriam, S. B., & Tisdale, E. J. (2016). Qualitative research: A guide to design and implementation. Josey-Bass.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook.* Sage.

Novak, J. D. (1990). Concept maps and Vee diagrams: two metacognitive tools to facilitate meaningful learning. *Instructional Science*, *19*(1), 29–52. 10.1007/BF00377984

Novak, J. D., Bob Gowin, D., & Johansen, G. T. (1983). The use of concept mapping and knowledge vee mapping with junior high school science students. *Science Education*, *67*(5), 625–645. 10.1002/sce.3730670511

Ogborn, J., & Taylor., E. F. (2004). Quantum physics explains Newton's laws of motion. *Physics Education, 40*(1), 26–34. 10.1088/0031-9120/40/1/001

Ohle, A., Boone, W. J., & Fischer, H. E. (2015). Investigating the impact of teachers' physics CK on students' outcomes. *International Journal of Science and Mathematics Education, 13*(6), 1211–1233. 10.1007 /s10763-014-9547-8

Olsen, R. V. (2002). Introducing quantum mechanics in the upper secondary school: A study in Norway. *International Journal of Science Education*, *24*(6), 565–574. 10.1080/09500690110073982

Özdemir, E. (2017). Comics in modern physics: Learning blackbody radiation through quasi-history of physics. *Studies in Educational Research and Development, 1*(1), 41-59.

Park, E. J. (2006). *Student perception and conceptual development as represented by student mental models of atomic structure* [Unpublished doctoral thesis]. The Ohio State University, Ohio.

Passante, G., Emigh. P. J., & Shaffer, P. S. (2015). Examining student ideas about energy measurements on quantum states across undergraduate and graduate levels. *Physical Review Special Topics-Physics Education Research, 11*(2), 1–10. 10.1103/PhysRevSTPER.11.020111

Patton, M. Q. (2014). *Qualitative research & Evaluation methods.* Sage.

Persson, J. R. (2018). Evolution of quasi-history of the Planck blackbody radiation equation in a physics textbook. *American Journal of Physics*, *86*(12), 887–892. 10.1119/1.5054005

Pinochet, J. (2019). Five misconceptions about black holes. *Physics Education*, *54*(5), 055003. 10.1088/1361-6552/ab26c3

Ranganath, G. S. (2008). Black-body radiation. *Resonance*, *13*(2), 115–133. 10.1007/s12045-008-0028-7

Ribeiro, C. I. (2014). Blackbody Radiation from an Incandescent Lamp. *The Physics Teacher*, *52*(6), 371–372. 10.1119/1.4893096

Ruiz-Primo, M. A., & Shavelson, R. J. (1996). problems and issues in the use of concept maps in science assessment. *Journal of Research in Science Teaching*, *33*(6), 569–600. 10.1002/(SICI)1098-2736(199608)33:6<569::AID-TEA1>3.0.CO;2-M

Sadaghiani, H. R. (2005). *Conceptual and mathematical barriers to students learning quantum mechanics* [Unpublished doctoral thesis]. Ohio State University, Ohio.

Sadoğlu, G. P., & Akdeniz, A. R. (2015). Turkish student's perception about the black body radiation, photoelectric effect and Compton scattering phenomena. *Journal of Studies in Education, 5*(3), 309-326. 10.5296/jse.v5i3.8109

Saljö, R. (1994). Minding action: Conceiving of the world versus participating in cultural practices. *Nordisk Pedagogik, 14*(2), 71-80.

Serway, R. A. (1996). *Physics for scientists and engineers, with modern physics (4th ed.)*. Saunders College.

Singh, C. (2001). Student understanding of quantum mechanics. *American Journal of Physics*, *69*(8), 885–895. 10.1119/1.1365404

Singh, C. (2006). *Student difficulties with quantum mechanics formalism.* Physics Education Research Conference, New York, 26-27 July, pp. 883.

Shi., W. Z. (2013). The effect of peer interactions on quantum physics: A study from China. *Journal of Baltic Science Education, 12*(2), 152–158.

Shulman, L. S. (1986). Those who understand: knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14. 10.3102/0013189X015002004

Strauss, A., & Corbin, J. (2014). *Basics of qualitative research techniques.* Sage.

Tiruneh, D. T., De Cock, M., Weldeslassie, A. G., Elen, J., & Janssen, R. (2017). Measuring critical thinking in physics: development and validation of a critical thinking test in electricity and magnetism. *International Journal of Science and Mathematics Education*, *15*(4), 663–682. 10.1007/s10763-016-9723-0

Ünlü Yavaş, P., & Kızılcık, H. Ş. (2018). Investigating the causes of students' having difficulties in the introductory quantum physics topics. *Gazi University Journal of Gazi Educational Faculty, 38*(1), 25-73.

Vadnere, R., & Joshi, P. (2009). On analysis of the perceptions of standard 12 students regarding a physics concept using techniques of quantum mechanics. *Physics Education*, *26*, 279-290.

Ventura, R. D., Carvalho, S. P., & Dias, A. M. (2017). Standing waves in an elastic spring: A systematic study by video analysis. *The Physics Teacher, 55,* 232-234. 10.1119/1.4978723

Vokos, S., Shaffer, P. S., Ambrose, B. S., & McDermott, L. C. (2000). Student understanding of the wave nature of matter: diffraction and interference of particles. *American Journal of Physics*, *68*(S1), S42–S51. 10.1119/1.19519

Weber, R. P. (1990). *Basic content analysis.* Beverly Hills, CA: Sage.

Yalçın, O., & Emrahoğlu, N. (2017). Examining the high school students' transfer levels of modern physics topics to daily life. *Pegem Journal of Education and Instruction, 7*(1), 115-158. 10.14527/pegegog.2017.005

Yener, D., Köklü, N., Yamaç, R. Z., & Yalçın, S. (2020). Analysis of the studies done on laboratories in Turkey. *Journal of Turkish Science Education, 17*(2), 162-179. 10.36681/tused.2020.19

Yin, R. K. (2003). *Case study research design and methods, applied social research methods.* Sage.