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Examination of Prospective Science Teachers' Pedagogical Content Knowledge in Terms of their Approaches to Error: An Example of Content Knowledge about Electric Circuits

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Abstract
The aim of this study was to examine prospective science teachers' pedagogical content knowledge in terms of their approach to error. For this purpose, a data collection tool consisting of 5 questions for conceptual understanding of electrical circuits and steps containing correct and incorrect explanations for each question was prepared and applied to prospective science teachers. This study was carried out using case study method, one of the qualitative research approaches. The participants consisted of 30 prospective science teachers studying in 4th Grade in a state university. The data were analyzed using descriptive analysis method. The findings showed that the rate of prospective teachers who provided correct explanations in the solution of the questions about electrical circuits was high. In addition, the rate of detecting the solution steps given incorrectly was at a moderate level. It was revealed that very few participants who identified the wrong solution steps were able to make correct explanations for the solution of the question. Majority of the participants had some misconceptions such as "Generators are constant current sources", "Local reasoning" and "Regardless of how the generator and light bulbs are connected in the circuit, if the number of generators increases, the brightness of the bulb increases". These misconceptions were evaluated as an indication that prospective teachers' pedagogical content knowledge was not at a level that could be considered sufficient in terms of understanding the student. In this context, error-based activities can be included in teaching in order to prevent the formation of misconceptions, incomplete and/or incorrect information in students or prospective teachers, and to correct existing misconceptions. The effects of error-based activities on individuals' learning can be investigated in future studies.
Keywords: Pedagogical Content Knowledge/PCK, Electrical Circuits, Approach to Error, Student Understanding, Misconceptions, Prospective Science Teacher.

Introduction

With today's modern tools and development, societies have started to develop in the education and teaching process significantly. Teaching is a complex activity. In this sense, Schoenfeld emphasized that it is necessary to investigate the knowledge that teachers have in order to understand the complexity of teaching (Sherin, Sherin. & Madanes, 2000). Depending on the research findings on education, rearrangements are made in different fields and levels of education when needed in Turkey as in other countries. Based on the regulations made by the Ministry of National Education (MoNE) in the Primary Education Science Curriculum in Turkey, it is aimed to educate science-literate individuals (MoNE, 2018). In their study, Aydın and Boz (2012) stated that the most basic component of reaching the desired goals in science, which aims to raise students who acquire the scientific knowledge and skills required by the current century, and who can transfer this knowledge to life, is teachers.

Belge Can (2019), on the other hand, took this one step further and included prospective teachers in this most basic component. In this context, the knowledge of science teachers and prospective teachers is extremely important. Van Driel, Verloop and De Vos (1998) defined teacher knowledge/ content knowledge as an integrated knowledge that represents the accumulated wisdom of teachers about teaching practices and guides their actions in practice, especially covering their knowledge and beliefs about various elements such as pedagogy, students, subject and curriculum. Verloop, Van Driel and Meijer (2001, p. 446) also stated that the researchers in the literature expressed the aspects of teacher knowledge as "personal knowledge, practical wisdom, professional craft knowledge, action-oriented knowledge, knowledge about content and context, knowledge that is largely implicit, and knowledge based on reflection on experiences. Verloop et. al (2001) used teacher knowledge or teacher practice knowledge to indicate all of the knowledge and understandings underlying teachers' actions in teaching practices. Studies on teacher knowledge show that teacher knowledge affects both what the teacher will teach and how he or she will teach it (Uluçınar Sağır, 2018).

Subject matter knowledge (SMK) comes first at the beginning of the knowledge that teachers should have for effective teaching (Alev & Karal, 2013). A teacher should have a sufficient level of pedagogical knowledge (PK) in order to adapt his/her subject matter knowledge to students' psychology and individual learning needs (Shulman, 1986a; Shulman, 1987; cited in Alev & Karal, 2013). The inadequacy of studies that focus on teachers' subject matter knowledge and pedagogical content knowledge in explaining the effects of teacher knowledge on teaching results brought along new discussions (Magnusson, Krajcik & Borko, 1999). Therefore, it is important for the teacher to not only develop the PK or PCK alone but also to integrate these two in learning to teach (Gess-Newsome, 1999). For this reason, teachers should have the characteristics that can contribute to the understanding of the concepts and the subject for the students, as well as having SMK and PK. These features form the basis of the concept of pedagogical content knowledge (PCK), which is the ability of the teacher to organize the subject according to the characteristics of the students and the learning environment (Alev & Karal, 2013).

Various PCK models used in science education related to teacher knowledge have been proposed by many researchers in the literature. Shulman (1986a), who pioneered the creation of PCK models, considered SMK, PC, and curriculum/ curriculum knowledge (CK) as components of teacher knowledge in the first model he proposed. In another study (Shulman, 1986b) these components were named as SMK, CK and PAB (cited in Uluçınar Sağır, 2018). Shulman and Sykes (1986) defined a teacher's PCK as the ability to understand basic topics, skills, and attitudes in a given field, to know students' comprehension difficulties or interests, to choose and develop examples for the best presentation. In the related study, the components of PCK were general education, content knowledge, content-specific pedagogical knowledge, general pedagogical knowledge, and curriculum knowledge. In another study by Shulman (1987), teacher knowledge consisted of the dimensions of content knowledge, general pedagogical knowledge, CK, PCK, knowledge of learners and their characteristics, educational context knowledge and educational goals, values, and knowledge of their philosophical and historical background (cited in Uluçınar Sağır, 2018).

Some researchers use Shulman's (1987) PCK model as assessment knowledge (Tamir, 1988), context knowledge (Grossman, 1990), media knowledge (Marks, 1990), general and specific context knowledge (Carlsen, 1999), science teaching orientation, by adding components such as knowledge of science comprehension and knowledge of instructional strategies in science (Magnusson, Krajik & Barko, 1999) (cited in Uluçınar Sağır, 2018). Cochran, DeRuiter, and King (1993) focused on the difference between knowledge and knowing, and renamed it as "pedagogical content knowledge", based on the structuralist approach to teaching. Gess-Newsome (1999) proposed a PCK model by rearranging the integrative and transformative PCK models. In addition, Morine-Deshimer and Kent proposed a PCK model (1999) rearranging the teacher knowledge components of Shulman (1987) (cited in Uluçınar Sağır, 2018). In his doctoral thesis, Park (2005) first rearranged Grossman's (1990) PCK model, then combined the PCK models suggested by Tamir (1988), Grossman (1990), and Magnusson et. al (1999) for teacher knowledge to form the pentagon model of PCK. He then suggested the hexagon PCK model by adding teacher competence to the model. Six components of PCK in the hexagon model were as follows: I) orientation in science teaching, II) knowledge of student understandings in science, III) knowledge of science curriculum, IV) knowledge of science instructional strategies, V) knowledge of science assessment and VI) teacher competence. Abell (2007), combining the PCK models of Grossman (1990) and Magnusson et al. (1999), developed a model that includes teacher knowledge domains, and took the KCK defined by Shulman into the center of PCK by separating it as syntactic and basic knowledge. Gess-Newsome (2015), on the other hand, defined the teacher professional knowledge and skill model and the PCK model, which includes all the complexity of teaching and learning (cited in Uluçınar Sağır, 2018).

The studies in the literature shows that the general pedagogy and SMK have a great impact on the creation of PCK. The studies of Bennett and Turner-Bisset (1993), Even (1993), Boz (2004), Capraro, Capraro, Parker, Kulm and Raulerson (2005), and Türnüklü (2005) show that there is a close relationship between SMK and PCK. In addition, Bennett and Turner-Bisset (1993) stated that it is impossible to distinguish between SMK and PCK during teaching. Marks (1990), on the other hand, revealed that SMK is an important component of PCK and it is not possible to separate PCK from SMK (cited in Konyalıoğlu, 2013).

In the hexagon model, Park (2005) uses the component of student understandings in science, teachers' misconceptions in students, learning difficulties, motivations, interests, learning needs, abilities, learning styles, and levels of development as a component for understanding information. In this model, firstly, the knowledge of misconceptions in the component of student understandings in science is emphasized. Error in this model is expressed as "misuse and conclusion of information and ideas" by Erbaş, Çetinkaya, and Ersoy (2009, p. 46). In the PCK model adapted by Kartal (2017, p. 27) using the model of Marks (1990), "common mistakes of students" information can be added as information of "student mistakes in science". In this sense, there should be erroneous questions and/or erroneous solutions to questions in both student answers and written sources. For this reason, a science teacher or prospective teacher should be able to correctly question the mistake. A teacher or prospective teacher who can question the mistake correctly means that he/she has learned that concept in a meaningful way and has formed a correct opinion about the cause of the mistake (Konyalıoğlu, Aksu, Şenel & Tortumlu, 2010). Since verbal/non-verbal answers, misconceptions, incomplete or incorrect information of the students will affect the teaching practices, the teacher should be aware of the misconceptions and verbal/non-verbal errors in the students (Uluçınar Sağır, 2018). This awareness is provided with the development of the teacher's pedagogical content knowledge. The teacher who develops PCK can complete the cognitive and affective deficiencies of the student, thus facilitating the teaching.

Konyalıoğlu (2013) states that the structure of the knowledge or concept aimed at teaching and the psychology formed for this knowledge are among the most important factors in the process of determining the pedagogy to be used in teaching. Therefore, in the development of PCK, first of all, the subject to be taught needs to be known in depth. A good SMK increases student success and the quality of teaching (Ball, Thames & Phelps, 2008; Brown & Borko, 1992; Hill, Rowan & Ball, 2005; Ma, 1999, cited in Konyalıoğlu, 2013). It can be said that the teacher's subject knowledge is important in disciplines such as Mathematics and Science (physics, chemistry and biology), which are thought to be difficult for most students and have difficulty in learning. Identifying students' mistakes is related to general content knowledge, having an idea about the cause of the error is related to special content knowledge, and being aware of where students will make mistakes most is related to knowing students (Ball, Thames & Phelps, 2008, cited in Konyalıoğlu, 2013). Konyalıoğlu, Özkaya, and Gedik (2012) emphasized that correct identification of the error and correct solution proposal is one of the components that can be used in determining the adequacy of the subject matter knowledge, and that in-depth content knowledge is required to identify the error correctly and explain the reason. It can be expected that prospective teachers, who can identify incorrect information in Science and Physics as well as in other disciplines and explain the reasons correctly, will be able to make the teaching-learning process more efficient by being aware of the reasons for mistakes when they become teachers.

The studies on electrical circuits revealed that primary, elementary and high school students, even prospective teachers and teachers, have incomplete or incorrect information or misconceptions/ alternative concepts and have difficulty in learning this concept. Shipstone et. al. (1988), emphasized that the differences among the students participating in their study were very slight. In their study, the electrical principles revealing important differences were divided into two main groups: one of which was current, charge flow, and energy, and the other was voltage and its relationship with the current. As a result, they stated that regardless of the country, the students showed the same learning difficulties and the existence of an almost "natural" harmony within the cognitive structure. McDermott and Shaffer (1992), found that students, Physics teachers, and prospective teachers in the USA had difficulties in connecting the ammeter and voltmeter to the circuit and the concepts related to resistance, current, and potential difference. Borges and Gilbert (1999), in the study they conducted with individuals with different characteristics in Brazil, gathered their understanding of concepts such as electricity, current, voltage, energy, and resistance under four various mental electricity models. They also evaluated elementary school students' mental perceptions of the lamp's light under seven different titles. They found some students, teachers, and electrical professionals in the experiment group used energy and current as if they were the same concept. Some of the elementary school students participated in Lee and Law's study (2001) in Hong Kong stated that "generators were a constant current source, light bulbs consumed current, the battery was a current source, the current was consumed by the components in the circuit, the farther the light bulb was from the battery, the dimmer it would be, in a parallel circuit. It was emphasized that they had alternative concepts such as the current was divided into equal parts. Pardhan and Bano (2001) emphasized that science teachers in Pakistan had alternative concepts about electric current and direct current circuits such as "current is not conserved, the current is shared among circuit elements...". Sencar, Yılmaz, and Eryılmaz (2001) investigated the answers given by the high school students in Turkey to the theoretical and practical questions about the subject of simple electrical circuits. They discussed the students' misconceptions based on 11 common misconceptions in the literature (coincident current model, sink model, short circuit bias, weakening current model, shared current model, resistance and equivalent resistance, local reasoning, sequential reasoning, etc.). Çepni and Keleş (2006) examined understanding and misconceptions of primary school, elementary school, and prospective science teachers about simple electrical circuits. In the study, they stated that some of the participants had misconceptions such as "it is sufficient to connect a single cable between the generator and the light bulb for the light bulb to light up, the current is consumed by the circuit elements,...". Küçüközer and Kocakülah (2007) used the conceptual understanding test they developed about electrical circuits, in which lamps and batteries had serial and parallel connections. The elementary students participated in the research in Turkey said that "batteries are constant current sources, the current is consumed by circuit elements, none of the bulbs turn on when the switch is closed. Satır (2007) showed that some high school students, prospective teachers, and in-service teachers in Turkey had misconceptions such as "constant current source, distance to generator affects the lamp brightness, lamps connected in series are brighter, ammeter and voltmeter serve the same function,.....". Karal, Alev, and Yiğit (2009) in their study on "prospective teachers' field knowledge in electricity", found that some prospective Physics teachers in Turkey stated that "the generator is a constant current source, the lamps are brighter in series-connected circuits, the current emitted from the battery is not affected by the changes in the external circuit. They emphasized that they had misconceptions such as changing the size of a series-connected resistor does not affect the brightness of the lamp. In addition, Karal et. al. (2009) reported that some of the students in their study also had incorrect and incomplete information about electrical circuits. Peşman and Eryılmaz (2010) used a three-stage test they developed to detect the misconceptions of high school students participating in the study about simple electrical circuits, and found that some of the students in the study regarded "power supply as a constant current source, colliding current, shared current model, short circuit" parallel circuit misconception, local reasoning, attenuation model...". The researchers also emphasized that the students also lacked knowledge about the subject. Alev and Karal (2013) in their study on Physics teachers' PCKs on Electricity and Magnetism in Turkey, emphasized that some participants had incorrect and incomplete information about the brightness of lamps in series and parallel mixed circuits related to the subject of electric circuits and current sharing in parallel arms. Gaigher (2014) stated that some in South Africa had wrong and incomplete information and misconceptions about electrical circuits. At the same time, he emphasized that these teachers preferred to teach their own truths instead of going against the misconceptions and wrong information in the students. Sinanoğlu (2019) used a three-stage test he developed on electrical circuits as a data collection tool, and investigated the knowledge of 7th-grade students in Turkey on the concept of "brightness of light bulbs connected in series and parallel, short circuit, current sharing in parallel branches..." He stated that they had misconceptions, incomplete and incorrect information. Suryadi, Kusairi, and Husna (2020) conducted a comparison of elementary school students, high school students, and pre-service Physics teachers in Indonesia in terms of incomplete information, misinformation, and misconceptions about simple electrical circuits. They stated that there were incomplete information and misconceptions. It can be easily revealed that the common point of the studies above is that they aimed at determining the missing or incorrect information and misconceptions of the participants.

Electricity is considered as a difficult and important subject in the school Science curriculum by students and teachers (Gunstone, Mulhall, & McKittrick, 2009, cited in Gaigher, 2014). Therefore, it is expected to find a large body of literature on alternative electrical concepts, particularly simple direct current circuits. It has been shown that many misconceptions occur beyond the boundaries of culture and language (Küçükozer & Kocakülah, 2007: Shipstone et al., 1988, cited in Gaigher, 2014) and that misconceptions are present in some children, students, and university lecturers (Stocklmayers & Treagust, 1996, cited in Gaigher, 2014).

Based on this information and the studies in the literature, it can be emphasized that students at different education levels, prospective Physics and Science teachers, and in-service teachers have incomplete or incorrect information about simple electrical circuits, and they have misconceptions / alternative concepts about the subject. The literature review on simple electrical circuits shows that incomplete or incorrect information and misconceptions are common in every society, regardless of the country, and that studies on this subject have been carried out for about 50 years and that the interest of researchers on the subject still continues. When we look at the studies on the subject of electrical circuits in the literature, although there are a large number of studies on the detection of incomplete or incorrect information and misconceptions, there is an absence of studies that includes an approach to error, which indicates the significance of the present study. In this context, it can be emphasized that the PCKs of prospective science teachers, the teachers of the future, should be examined in terms of their approach to error. It can also be stated that the subject is worth doing research, considering that the obtained information will guide science teachers and prospective teachers who teach or will teach on this subject, especially academicians who work or will work in teacher training institutions of universities. For these reasons, in this study, the PCKs of the prospective science teachers were examined by considering their approaches to the questions in which there were errors in their solutions.

The Purpose of the Study

This research was carried out in order to examine the pedagogical content knowledge of prospective science teachers in terms of their approach to error and to determine their student understanding. Within the framework of this main purpose, answers to the following questions were sought:

1. What is the status of prospective science teachers in distinguishing between true or false information about electrical circuits?
2. What is the approach of prospective science teachers to error about electrical circuits?

Method

In this section, the design of the research, the study group, the data collection tool and process, the analysis of the data, and the ethical permissions of the research are described, respectively.

Research Pattern

This study aimed to examine the pedagogical content knowledge of the 4th-grade prospective teachers in the Science Education Program in the spring semester of the 2019-2020 academic year in terms of their approach to error and to determine their student understanding. Therefore, in the study, qualitative research approach was employed. The study was also descriptive as it aimed to reveal a past or present situation.

Study Group

The study group consisted of 30 (F=21, M=9) prospective teachers studying at 4th grade in Science Education Department of the Faculty of Education in a Turkish state university in the spring semester of the 2019-2020 academic year. The principle of volunteering and easy accessibility in terms of research ethics principles were taken into consideration. The sample was selected using the purposeful sample selection. In qualitative research-based studies, the multi-purpose sample selection method is used. The demographic characteristics of the participants are presented in Table 1. The real names of the participants were not used in terms of ethical principles; Instead, their names were coded as PT1, PT2,..., and PT30.

Table 1 Demographic Characteristics of the Study Group

Graduated High School	Female		Male		Total	
	n	%	n	%	n	%
Anatolian High School	14	46,67	6	20,00	20	66,67
Vocational high School	2	6,67	2	6,67	4	13,33
Imam Hatip High School	3	10,00	-	-	3	10,00
Teacher High School	1	3,33	-	-	1	3,33
Basic High School	1	3,33	1	3,33	2	6,67
Total	21	70,00	9	30,00	30	100,00

As seen in Table 1, 70% of the participants were women and 30% were men and 66.67% graduated from Anatolian high schools.

Data Collection Tool and Process

Two-stage data collection tool developed by the researcher was used in the study. It consisted of 5 open-ended questions for conceptual understanding and the steps in which correct and incorrect information were included in the solutions given for these questions. An example of an item in the data collection tool is presented below:

"1. Identical bulbs give light in the electrical circuit in Figure 1. When the rheostat slider is moved from position 1 to position 2, how does the brightness of the X and Y lamps change? Why? (Internal resistance of the generator is negligible.)

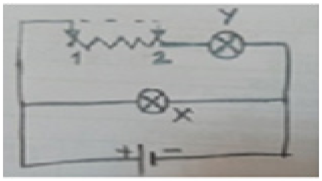

Figure 1

Solution

Step 1: When the rheostat slider is moved from the 1st position to the 2nd position, the electric current passing through the Y bulb increases as the equivalent resistance value in that arm will decrease. Depending on the increase in the electric current, the brightness of the Y bulb will also increase. (….)

Explanation:......

Step 2: When the rheostat slider is moved from the 1st position to the 2nd position, since the equivalent resistance of the circuit does not change, the current flowing over the X bulb and the brightness of the X bulb do not change. (….)

Explanation:.....

They were asked to examine the solutions given to 5 open-ended questions on conceptual understanding prepared in the form of....” step by step, and to write the letter T in parentheses if it is True (…..) in the first step, in terms of the steps given in the solutions themselves, and the letter F if it is incorrect. In the second stage, the research group was also asked to write the correct/required information/solution in the explanation part, stating why it is correct if it is correct, and why it is incorrect for the information or explanation they deem incorrect.

Analysis of Data

In data analysis, first of all, the frequencies and percentages of the participant explanations are presented in tables by examining the correct and incorrect answers given by the participants for the solution steps of each question in the data collection tool. The data were coded in a way that the participants could identify the errors in the incorrect solutions. The solutions were classified under predetermined categories and codes in line with the purpose of the study. Therefore, the data were analysed using descriptive analysis. The analysed data were tabulated and the answers given in each category and codes were supported with direct quotations. The categories and codes used in data analysis are presented in Table 2.

Categories

1. No answer: The participants did not express an opinion on the correctness of the solution.
2. Failure to detect the error: This is the category in which the participants correctly evaluated the solution step given as wrong.
3. Detecting the error: It is the category of detecting that the solution given by the participants was incorrect.

Table 2 Categories and Codes

Categories	Codes
No answer	
Failure to Detect Error	No Explanation
	Incorrect Explanation
	Partially Correct Explanation
	Correct Explanation
Detecting the Error	No Explanation
	Incorrect Explanation
	Partially Correct Explanation
	Correct Explanation

Codes

The explanations of the participants regarding the solutions of the questions were evaluated under four different coding:

1. No explanation: The participants did not give an explanation for the solution step of the question.
2. Incorrect explanation: The participants evaluated the solution as completely wrong.
3. Partially correct explanation: The participants did not evaluate the solution as completely correct. They were considered as incomplete explanations, or some of the explanations were considered correct or incorrect. Some of these answers may contain minor errors, while others may contain very few correct answers. The reason why these explanations were not evaluated under the incorrect explanation code can be shown as the fact that these explanations contained correct explanations according to incorrect answers. The answers that were scientifically correct but not related to the given question were evaluated within this coding.
4. Correct explanation: The participants evaluated the solution as completely correct and in the desired way.

For the validity and reliability of the category and coding processes, expert opinion was obtained from an expert faculty member. The list of the established categories and codes were arranged in line with these views. Reliability was calculated using the formula [Reliability = consensus / (consensus + disagreement) X 100], in which consensus and disagreement were used together, determined by Miles and Huberman (1994), especially for qualitative data in the literature. It is stated in the literature that a desired level of reliability is achieved when the agreement between the opinions of the researchers and/or experts is 90% or more (Saban, 2009). In this study, it was observed that there was a 95.45% agreement between the researcher and the expert in listing the of the participants. Then, the obtained data were digitalized and codes and categories were formed and presented in tables. In the evaluation of the findings, the levels developed by the researcher were used to evaluate the percentages of the participants who could or could not detect the error and at the same time could make a correct explanation by detecting the error. These levels were: very high (80 - 100%), high (60 - 80%), medium (40 - 60%), low (20 - 40%), and very low (0 - 20%).

Ethical Approval for the Study

In this study, all the rules specified to be followed within the scope of the "Higher Education Institutions Scientific Research and Publication Ethics Directive" were complied with. None of the actions specified under the heading "Actions Contrary to Scientific Research and Publication Ethics", which is the second part of the directive, were taken.

Ethics Committee Permission Information

The required ethics committee permission was obtained from Amasya University Social Sciences Ethics Committee (16/03/2020 dated and 30640013-044 numbered)

Findings

In this section, the findings related to research questions are presented in order.

1. *What level are science teachers at distinguishing between correct and/or incorrect information about electrical circuits?*

The participants' correct and incorrect responses are presented in Table 3.

Table 3 Frequency and Percentages of Prospective Teachers Who Determined that the Explanations Given in the Solution Steps Are Correct or Wrong

Frequency and Percentages of Prospective Teachers Identifying the Correct Explanations				Frequency and Percentages of Prospective Teachers Identifying the Incorrect Explanations			
Question	Step	f	%	Question	Step	f	%
1.	1.	27	90.00	1.	2.	12	40,00
2.	1.	24	80,00	2.	3.	13	43,33
	2.	26	86,67	3.	4.	14	46,67
3.	1.	30	100,00		5.	13	43,33
	2.	29	96,67	4.	2.	26	86,67
	3.	28	93,33		4.	21	70,00
4.	1.	28	93,33	5.	1.	11	36,67
	3.	21	70,00		3.	16	53,33
5.	2.	28	93,33				

As shown in Table 3, the participants' responses showed that the frequency and percentage of the participants provided correct explanations was the highest (100%) in the 2nd question. "Ammeter is connected in series to the branch whose current is to be measured, and the voltmeter is connected in parallel to the circuit element between which the potential difference is to be measured." was the given explanation. In contrast, the participants had the lowest frequency and percentage (70%) for correct explanations in the 4th question. The explanation was "The brightness of the bulbs is equal because the potential differences/voltages formed between the ends of the X, Z and T bulbs are of equal magnitude." The frequency and percentage of the participants who found that explanations were incorrect were the highest (86.67%) in the 4th Question and the explanation was "in bulbs connected to identical generators, the brightness of the bulb does not depend on the bulb resistance." The lowest frequency and percentage (36.67%) of the participants who detected erroneous explanations was given in step 5 of the 5th question and the explanation was "The brightness of the bulbs is directly proportional to the number of batteries in the circuit and inversely proportional to the number of bulbs."

2. *What is the approach of prospective science teachers to error about electrical circuits?*

The first question and solution presented for this research question were as follows:

"1. Identical bulbs give light in the electrical circuit in Figure 1. How does the brightness of the X and Y bulbs change when the rheostat slider is moved from the 1st position to the 2nd position? Why? (The internal resistance of the generator is unimportant.)

Solution

Step 2: When the rheostat slider is moved from the 1st position to the 2nd position, since the equivalent resistance of the circuit does not change, the current flowing over the X bulb and the brightness of the X bulb do not change. (….)

Explanation:….

Table 4 shows the answers and explanations given by the participants.

Table 4 Error Detection Status, Explanation Codes and Sample Answers of Participants for Question 1, Step 2

Categories	Codes	Participants	Sample Answers
Failure to Detect Error	No Explanation	PT6, PT15, PT23, PT24, PT30	
	Incorrect Explanation	PT12	*When the rheostat slider is moved from the 1st position to the 2nd position, the brightness of the X bulb does not change because the equivalent resistance of the circuit does not change.*
	Partially Correct Explanation	PT1, PT2, PT9, PT11, PT20, PT21, PT26, PT27	*Since the current will change according to the resistance in the arms, the current will increase if the resistance gets smaller. The brightness of the X bulb increases.*
	Correct Explanation	PT4, PT7, PT17, PT18	*The current through the X bulb does not change. Because the X lamp is connected in parallel to the generator and the potential difference between its points does not change. So the brightness does not change.*
Detecting the Error	Incorrect Explanation	PT5, PT13, PT16, PT25, PT29	*When the rheostat slider is moved from the 1st position to the 2nd position, the brightness of the X bulb increases as the equivalent resistance of the circuit will increase.*
	Partially Correct Explanation	PT8, PT10, PT14, PT19, PT22, PT28	*When the rheostat slider is brought to the 2nd position, the resistance decreases and the current increases. The equivalent resistance changes. The Y bulb is brighter than the X bulb.*
	Correct Explanation	PT3	*When the rheostat slider is moved to the 2nd position, the equivalent resistance of the circuit changes. Since the potential difference is constant, the current through bulb Y increases while the current through bulb X does not change. Since the current does not change, the brightness of the X bulb does not change..*

The number of participants who identified the erroneous explanation was one. In addition, six participants said that the solution was partially correct. The percentage of those provided correct explanations was 23.33%. Furthermore, four participants did not detect the error in this step but provided a correct explanation.

The following question and solution were provided to the participants:

"2. In the electrical circuit in Figure 2, when the switch S is open, the brightness of the X bulb is P. When the switch S is closed, what is the brightness of the bulb? Why? (The generators are identical and their internal resistances are insignificant.)

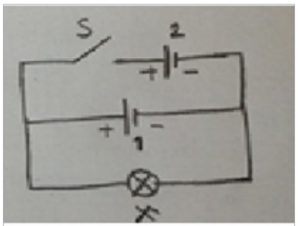

Figure 2

Solution

Step 3: When the switch S is closed, the current through the X bulb doubles as the 2nd generator will give the circuit I current. In this case, the energy consumed by the bulb per unit time

P^1=Energy/ time=V.2I= 2P

Since the brightness of a bulb is proportional to the Power, the brightness of the X bulb is doubled when the switch S is closed. (….). Table 5 shows the results regarding this question.

Table 5 Error Detection Status, Explanation Codes and Sample Answers of Participants for Question 2, Step 3

Categories	Codes	Participants	Sample Answers
No Answer		PT15	
Failure to Detect Error	No Explanation	PT11, PT23, PT24, PT30	
	Incorrect Explanation	PT5, PT7, PT9, PT10, PT12, PT14, PT19, PT20, PT22	*Since the brightness of the bulb in the circuit is proportional to the number of generators in the circuit, the brightness of the X bulb doubles when the S switch is closed.*
	Partially Correct Explanation	PT3, PT8, PT29	*As the current passing through the bulb increases, the brightness of the bulb increases.*
Detecting the Error	No Explanation	PT25	
	Incorrect Explanation	PT13, PT18, PT27	*There is an inverse relationship between current and voltage. If the current doubles, the voltage is halved.*
	Partially Correct Explanation	PT6, PT28	*The bulb brightness remains the same.*
	Correct Explanation	PT1, PT2, PT4, PT16, PT17, PT21, PT26	*When the switch S is closed, the batteries will be connected in parallel and increasing the number of batteries connected in parallel will not affect the potential difference between the ends of the bulb in this circuit, so the brightness of the bulb will not change.*

The number of the participants, who identified the erroneous explanation presented in Step 3 of 2nd Question and provided a correct explanation was 7. In addition, the number of partially correct explanations was 2. The percentage of correct explanations was 30%.

The third question and solution were as follows:

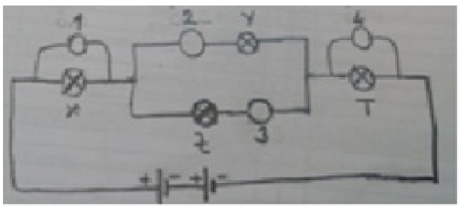
Figure 3

"3. In Figure 3, only X and Y bulbs are asked to give light in the electrical circuit established by using identical bulbs, identical generators and measuring instruments (ammeter and voltmeter). Accordingly, measuring instruments 1, 2, 3 and 4 are required. What should it be chosen as? Why?

Solution

Step 4: 3 which is ammeter for measuring device is connected in series with the Z bulb. (….)

Table 6 shows the results regarding this question.

Table 6 Error Detection Status, Explanation Codes and Sample Responses of Participants for Question 3, Step 4

Categories	Codes	Participants	Sample Answers
Failure to Detect Error	No Explanation	PT2, PT18, PT23, PT24, PT25	
	Incorrect Explanation	PT5, PT9, PT10, PT17, PT19, PT21, PT29	*The meter 3 is an ammeter because it is connected in series with the Z bulb.*
	Partially Correct Explanation	PT7, PT8, PT29	*The ammeter is connected in series with the circuit, has an infinitely small resistance, and measures the current flowing through the circuit element.*
	Correct Explanation	PT28	*Since we only want to receive light from the X and Y bulbs, we must connect a voltmeter in series with the Z bulb. Since the internal resistance of the voltmeter is large, no current flows through the Z bulb.*
Detecting the Error	No Explanation	PT6	
	Incorrect Explanation	PT1, PT12, PT13, PT14, PT16, PT30	*The ammeter is connected in series with the circuit, but since the measuring instrument 3 is connected in parallel to the Y bulb, it is a voltmeter, not an ammeter.*
	Partially Correct Explanation	PT11, PT22, PT26	*3 which meter is a voltmeter.*
	Correct Explanation	PT3, PT4, PT15, PT20	*If the measuring instrument no. 3 is an ammeter, the Z bulb will light. The Z bulb should not light, so the voltmeter must be connected.*

Four participants identified the erroneous explanation presented in Step 4 of the 3rd Question and provided a correct explanation. In addition, three participants provided a partially correct explanation. The percentage of correct explanations was 23.33%. The number of participants who could not detect the error in the step but gave a correct explanation was one.

The third question and Step 5 were as follows

"3. In Figure 3 (P. 11) in an electrical circuit installed using identical bulbs, identical generators, and measuring instruments (ammeters and voltmeters), only X and Y bulbs are required to give light. Accordingly, what should be selected as measuring instruments 1, 2, 3, and 4? Why?"

Solution

5th step: Since the meter 4 is connected in parallel to the T bulb, it is a voltmeter. (….)

Table 7 shows the results regarding this question and step.

Table 7 Error Detection Status, Explanation Codes and Sample Answers of Participants for Question 3, Step 5

Categories	Codes	Participants	Sample Answers
Failure to Detect Error	No Explanation	PT2, PT18, PT23, PT24, PT25	
	Incorrect Explanation	PT5, PT7, PT9, PT10, PT12, PT13, PT21, PT29	*It's a voltmeter. It is connected in parallel to measure voltage.*
	Partially Correct Explanation	PT8, PT17, PT19, PT28	*Voltmeter is connected in parallel to the circuit. When a voltmeter is connected instead of measuring instrument 4, the T bulb continues to light.*
Detecting the Error	No Explanation	PT6	
	Incorrect Explanation	PT14, PT27, PT30	*Since both points of the measuring instrument no. 4 are connected to different places, it may be a voltmeter, but since it is not known whether the T bulb gives light or not, nothing can be said for sure.*
	Partially Correct Explanation	PT11	*The measuring instrument number 4 is ammeter.*
	Correct Explanation	PT1, PT3, PT4, PT15, PT16, PT20, PT22, PT26	*Since the T bulb should not give light, an ammeter is connected to the ends of the bulb and short-circuited. Therefore, measure 4 instrument is ammeter.*

The number of the participants, who identified the erroneous explanation in Step 5 of the 3rd Question and provided the correct explanation, was 8. In addition, one participant provided a partially correct explanation. The percentage of correct explanations was 30%.

The fourth question and the second step of this question were as follows:

"4. What is the relationship between the brightness of the bulbs in electrical circuits established with identical bulbs and generators with insignificant internal resistances (Figure 4)? Why?

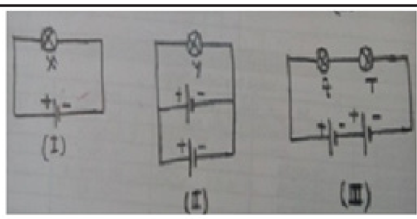

Figure 4

Solution

Step 2: Identical to the generators connected bulbs, the bulb does not depend on the brightness of the bulb resistance. (….)

Table 8 shows the results regarding this question and step.

Table 8 Error Detection Status, Explanation Codes and Sample Answers of Participants for Question 4, Step 2

Categories	Codes	Participants	Sample Answers
Failure to Detect Error	No Explanation	PT11	
	Incorrect Explanation	PT2, PT6, PT17	*Because the resistance of the bulbs is very small, it is ignored/neglected.*

Detecting the Error	No Explanation	PT24	
	Incorrect Explanation	PT13, PT16	*If the resistance of the bulb is high, the brightness is high, if the resistance is low, the brightness is low.*
	Partially Correct Explanation	PT1, PT5, PT7, PT9, PT14, PT15, PT18, PT23, PT28, PT29	*It depends. It gives light because the resistor inside the bulb gets hot. It changes depending on it.*
	Correct Explanation	PT3, PT4, PT8, PT10, PT12, PT19, PT20, PT21,PT22, PT25, PT26, PT27, PT30	*It depends. As the resistance of the bulb decreases, its brightness increases. As the resistance increases, the brightness decreases.*

The number of the participants, who identified the erroneous explanation in step 2 of question 4 and provided the correct explanation, was 13. Also 10 participants provided a partially correct explanation. The percentage of correct explanations was 76.67%.

The fourth question and the fourth step of this question were as follows:

"4. What is the relationship between the brightness of the bulbs in electrical circuits established with identical light bulbs and generators with insignificant internal resistances (Figure 4, p. 13)? Why?

Solution

4th step: II. Since 2 generators are used in the circuit, the brightness of the Y bulb is greater than the others.

P_Y>P_X=P_Z=P_T (….)

Table 9 shows the results regarding this question and step.

Table 9 Error Detection Status, Explanation Codes and Sample Answers of Participants for Question 4, Step 4

Categories	Codes	Participants	Sample Answers
Failure to Detect Error	No Explanation	PT5, PT11, PT18, PT30	
	Incorrect Explanation	PT10, PT13, PT19, PT20, PT22,	*Since there are 2 generators in the circuit II, more current flows through the bulb.* $P_Y > P_X = P_Z = P_T$
Detecting the Error	No Explanation	PT3	
	Incorrect Explanation	PT1, PT6, PT7, PT8, PT9, PT24, PT27, PT28, PT29	*The higher the number of batteries, the higher the brightness. As the number of bulbs increases, the brightness of the bulb decreases.* $P_Y > P_X = P_Z = P_T$
	Partially Correct Explanation	PT2, PT16	*Since the generators are connected in parallel in the circuit where the Y bulb is connected, it does not increase the brightness, it only prolongs the duration of the light. Since the generators are connected in series in the circuit where the Z and T bulbs are connected, their brightness is higher than other bulbs.* $P_X = P_Y < P_Z = P_T$

	Correct Explanation	PT4, PT12 , PT14, PT15, PT17, PT21, PT23, PT25, PT26	*If the generators are connected in parallel, a single generator value is taken. Since the potential difference between the points of the identical bulbs given here is equal, the currents passing through the bulbs are equal. Therefore, the bulb brightness is equal.* $P_X = P_Y = P_Z = P_T$

The number of the participants, who identified the erroneous explanation in Step 4 of question 4 and provided a correct explanation, was 9. In addition, two participants provided a partially correct explanation. The percentage of correct explanations was 36.67%.

The fifth question and the first step of this question were as follows:

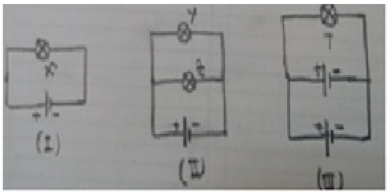

Figure 5

"5. What is the relationship between the brightness of X, Y, Z and T bulbs in electrical circuits built with identical generators/batteries and identical bulbs with 5th insignificant internal resistances (Figure 5)? Why?

Solution

Step 1: In the electrical circuits in the figure, the brightness of the bulbs is directly proportional to the number of batteries in the circuit and inversely proportional to the number of bulbs. (….)

Table 10 shows the results regarding this question and step.

Table 10 Error Detection Status, Explanation Codes and Sample Answers of Participants for Question 5, Step 1

Categories	Codes	Participants	Sample Answers
Failure to Detect Error	No Explanation	PT11, PT15, PT23, PT24, PT28, PT30	
	Incorrect Explanation	PT3, PT7, PT9, PT10, PT12 ,PT13, PT14 PT19, PT20, PT22, PT27, PT29	*As the number of bulbs increases, the brightness decreases because the resistance increases. The higher the number of batteries, the higher the brightness.*
	Partially Correct Explanation	PT1	*In series connected bulbs, as the number of bulbs increases, the current decreases, and accordingly, the brightness of the bulb decreases. In parallel, the brightness is the same as the current passing through the bulbs will be the same.*
Detecting the Error	No Explanation	PT5, PT25	
	Incorrect Explanation	PT8	*The brightness is twice the current.* $P = i^2.R$
	Partially Correct Explanation	PT6, PT17, PT18, PT21,	*When the generators are connected in parallel, the bulb gives a longer light but burns with the same brightness.*
	Correct Explanation	PT2, PT4, PT16, PT26	*The brightness of light bulbs in electrical circuits depends on the battery and the way the light bulbs are connected.*

Four participants identified the erroneous explanation in step 1 of the 5th question and provided a correct explanation was 4. In addition, four participants provided a partially correct explanation. The percentage of correct explanations was 26.67%.

The fifth question and the third step of this question were as follows:

"5. What is the relationship between the brightness of X, Y, Z and T light bulbs in electric circuits built with identical generators/batteries and identical light bulbs with unimportant internal resistances (Figure 5, p. 15)? Why?

Solution

3rd step: Since the brightness of the bulbs in the electric circuits in the figure is directly proportional to the number of batteries in the circuit and inversely proportional to the number of bulbs, the relationship between the brightness of the bulbs is $P_T > P_X > P_Y = P_Z$

Table 11 shows the results regarding this question and step.

Table 11 Error Detection Status, Explanation Codes and Sample Answers of Participants for Question 5, Step 3

Categories	Codes	Participants	Sample Answers
Failure to Detect Error	No Explanation	PT24, PT25, PT30	
	Incorrect Explanation	PT3, PT5, PT8, PT9, PT10, PT12 ,PT13, PT19, PT20, PT22, PT27	*If a current of I passes through the bulb X, a current of 2I passes through the bulb of T, I/2 of the bulbs Y and Z. The brightness is directly proportional to the current. P= V. I*
Detecting the Error	No Explanation	PT28	
	Incorrect Explanation	PT1, PT2, PT4, PT6, PT7, PT11, PT15, PT18, PT29	*The relationship between bulb brightness is $P_x > P_t > P_y = P_z$. Because the generators in Pt give less energy as they are connected in parallel.*
	Partially Correct Explanation	PT14, PT16, PT17	*Since the batteries in the T lamp are connected in parallel, it can be considered as a single battery. Therefore, X and T's brightness is the same. The relationship between the brightness of the bulbs is $P_T = P_X > P_Y = P_Z$*
	Correct Explanation	PT21, PT23, PT26	*Since the potential difference between the ends of all lamps is equal, the currents passing through them are equal. Therefore, their brightness is also the same. $P_T = P_X = P_Y = P_Z$*

The number of participants, who identified the erroneous explanation in Step 3 of Question 5 question and provided a correct explanation, was 3. Also three participants provided a partially correct explanation. The percentage of correct explanations was 20%.

Discussion and Conclusion

Boz (2004) emphasized that subject knowledge is a crucial factor in understanding and analyzing students' mistakes. Konyalıoğlu et. al (2010) revealed that not only the correct solution was sufficient for teaching, but also that students should be aware of the mistakes they can make, arguing that this was one of the components of the dimension of understanding the student. Based on this information, the answers provided by the participants were examined separately for the categories and coding given in Table 2 (p. 7). Emphasis was on whether PCK's were sufficient in terms of understanding the student errors.

The answers provided to Step 2 of Question 1 step in the solution of the 1st question (Table 4,) suggested that the useful feature of the rheostat was not fully understood since the equivalent resistance of the circuit does not change when the rheostat slider is moved from the 1st position to the 2nd position in the electrical circuit. This idea can also be considered as a symptom of a misconception that the equivalent resistance of the circuit would not change since the rheostat was not completely removed from the circuit. At the same time, these thoughts of the participants can also be evaluated as a "local reasoning" misconception reported in the literature (Peşman & Eryılmaz, 2010; Satır, 2007; Sencar, Yılmaz & Eryılmaz, 2001; Suryadi, Kusairi & Husna, 2020). The answers of the participants who could not detect the error in the second step of this question and provided a partially correct explanation, revealed that the participants thought that the brightness of the X bulb would increase, in parallel connected electrical circuits, although the potential difference in the arms did not change. This can be seen as misconceptions given as "current is divided into equal parts in parallel circuit" and "parallel circuit fallacy" (Lee & Law, 2001; Peşman & Eryılmaz 2010, Satır, 2007; Sinanoğlu, 2019; Suryadi, Kusairi & Husna, 2020). In the second step, the participants who provided incorrect explanations thought that "… and the brightness of the X bulb does not change." It may suggest that they focused only on the information at the end of the sentence and that they had a lack of reading comprehension or attention.

The answers of the participants who provided incorrect explanations to 2nd step in the solution of the 1st question indicated that there were misunderstandings regarding the use of rheostat. At the same time, it is stated in the literature that "brightness increases if the resistance or equivalent resistance increases." (Karal, Alev & Yiğit, 2009). It may also show that they had misconceptions. The answers of the participants who detected the error in the explanation but provided partially correct explanations in step 2 in the solution of this question showed that the participants had a lack of knowledge about electrical circuits or parallel circuit misconceptions. In the solution of the first question, it can be stated that the conceptual understanding of the participants, who both detected the erroneous explanation and provided correct explanation in step 2 was at a good level and their learning was at a metacognitive level. Although the percentage of the participants (90%) who found the correct explanations in the 1st step of the 1st question was at a very high level, the percentage of the participants (40%) who detected the incorrect explanation in the 2nd step of the same problem was at a medium level. The fact that only one participants was able to correct the mistake showed that the PCKs of the majority of the participants were not sufficient. Accordingly, it can be emphasized that the participants should review their subject knowledge about electrical circuits and develop their PCKs when they become teachers in order not to lead to incorrect learning in students. The answers of the participants, who could not detect the incorrect explanation about the brightness of the bulb given in the 3rd step of the 2nd question showed that they argued that the brightness of the light bulb was directly proportional to the number of generators in the circuit. It may show a misconception which is supported by the literature (Karal, Alev & Yiğit, 2009; Lee & Law, 2001; Satır, 2007). Although they could not detect the error in step 3 in the 2nd question, it can be argued that there was a lack of information because they stated that the brightness of the bulb would increase as the current flowing through the bulb increases, but they did not specify how this increase would happen. At the same time, the reason for not being able to correctly identify the erroneous explanation was due to a misconception of "power supply as a constant current source" or "generators are a constant current source" (Karal, Alev & Yiğit, 2009; Küçüközer & Demirci, 2008; Küçüközer & Kocakülah, 2007; Lee & Law, 2001; McDermott & Shaffer, 1992; Peşman & Eryılmaz, 2010; Satır, 2007; Suryadi, Kusairi & Husna, 2020). The answers of the participants, who provided incorrect explanation despite detecting the error in step 3 showed that the participants argued that "There is an inverse relationship between current and voltage...". Thus, it can be suggested that they used the concepts of "current, voltage and resistance" interchangeably. Accordingly, it can be put forward that the participants did not fully comprehend the concepts about electricity and there was a misconception of using another concept instead of one. It can also be emphasized from the explanations that the participants were not sufficient in knowing, comprehending and interpreting Ohm's law. The participant who were able to provide a partially correct explanation by detecting the error said that "The brightness of the bulb remains the same." Such statements can be considered as a sign of a lack of knowledge. The participants, who were able to both identify the erroneous explanation and provide a correct explanation in the solution phase of the problem, stated that the brightness of the bulb depended on the potential difference between the ends of the bulb and that the potential difference between the ends of the bulb did not change when the generators were connected in parallel in this circuit. These participants had metacognitive effects on the parallel connection of the generators. It can be given as an indication of meaningful conceptual learning. Although the percentages of participants who identified the correct explanations in the 1st and 2nd steps of the 2nd question were at a very high level (80% - 86.67%, respectively), the percentage of the participants (43,33%) who detected the incorrect explanation in the 3rd step of the same question was low. This finding indicated that the PCKs of most of participants were not sufficient. Accordingly, it can be stated that the participants should improve their subject knowledge about parallel connection of generators and develop their own PCK in order not to cause incorrect learning in students when they become teachers. In line with this view, it can be stated that the prospective science teachers who participated in the research and were in this category should review their subject knowledge about parallel connection of generators and develop their own PCK in order not to cause wrong learning in students when they become teachers. The answers of participants who could not identify the erroneous explanation in the 4th step of the 3rd question showed that there was a misconception that "every measuring instrument connected in series to the bulb is an ammeter" and/or "misuse of ammeter and voltmeter" or "ammeter and voltmeter". Such a misconception is reported in the literature (Küçüközer & Demirci, 2008; Satır, 2007). It can be emphasized that they had a misunderstanding that voltmeter can be used interchangeably.

The answers of the participants who could not identify the erroneous explanation in the 4th step of the 3rd question and made an incorrect explanation revealed a misconception that "every measuring instrument connected in series to the bulb is an ammeter" and/or "misuse of ammeter and voltmeter" or "ammeter and voltmeter", which can also be observed in the literature (Küçüközer & Demirci, 2008; Satır, 2007). It can be emphasized that they had a misunderstanding that voltmeter can be used interchangeably. It may also indicate that these participants did not fully know the characteristics of the ammeter and voltmeter or they had application deficiencies in how the brightness of the bulb is affected when the ammeter or voltmeter is connected in series and/or parallel to the bulb/circuit element. The answers of participants, who could not detect the error in step 4 of this question but provided partially correct explanations, showed that the participants did not care whether the bulb lights up or not and that they had the misconception presented as "local reasoning" in the literature (Peşman & Eryılmaz, 2010; Satır, 2007; Sencar, Yılmaz & Eryılmaz, 2001; Suryadi, Kusairi & Husna, 2020). Although their explanation was scientifically correct, the participants only look at the specified point and did not think about how other parts of the circuit would be affected by their choices, which indicates a lack of strategy. The answer of the participants, who provided a correct explanation but could not detect the error in the 4th step of the same question, revealed that the participants did not pay attention to the information given in the question. It can be thought that they could not detect the error as they thought that the explanation "was compatible". Likewise, it can be emphasized that such participants lacked attention and shared their thoughts without fully understanding the question and answers asked to them. The answers of the participants whose explanations were wrong in the 4th step of the same question indicated that there was a lack of application at the point of connecting the voltmeter in series and parallel. Depending on this, it can be put forward that the participants did not fully understand the parallel connection. The answers of those provided a partially correct explanation showed that they have insufficient in-depth content knowledge because they did not or could not express their reasons. In the solution of this question, it can be emphasized that the participants who both detected the error in step 4 and revealed the causes of the error, had a complete conceptual understanding of the voltmeter's features and use, indicating that they had in-depth field knowledge. Accordingly, it can be said that they will not have a problem in the teaching-learning process when they become teachers and they will carry out this process efficiently. The answers of the participants who could not identify the erroneous explanation in the 5th step of the 3rd question showed a misconception regarding "every measuring instrument connected in parallel to the bulb is a voltmeter" regardless of whether the bulb lights up or not, and/or "ammeter and voltmeter can be used interchangeably" (Küçüközer & Demirci, 2008; Satır, 2007). In addition, this finding may also indicate that they did not fully know the characteristics of the ammeter and voltmeter and they had application deficiencies regarding how the brightness of the bulb was affected when the ammeter or voltmeter was connected in series or parallel to the bulb/circuit element. The answers of the candidates who could not detect the error in step 5 in the solution of this question but provided partially correct explanations showed that the participants did not look at whether the bulb lights up or not and that they had the misconception reported as "local reasoning" in the literature (Peşman & Eryılmaz, 2010; Satır, 2007; Sencar, Yılmaz & Eryılmaz, 2001; Suryadi, Kusairi & Husna, 2020). Although the explanation was correct, it can also be expressed as a shortcoming that the participants only focused on the specified point and did not think about how the other parts of the circuit would be affected by their choices. The answers of the participants whose explanations were wrong in the 5th step of the same question revealed a lack of application and attention to what was given in the question. The answers of the participants, who were able to make a partially correct explanation showed that the participants had sufficient general content knowledge but insufficient in-depth content knowledge, since their answers were scientifically correct but they could not express their reasons. In the solution of this question, it can be emphasized that the participants who both detect the error given in step 5 and reveal the causes of the error correctly had a complete conceptual understanding of the features and use of the ammeter, and that the candidates had in-depth field knowledge. Although the percentages of the participants, who identified the correct explanations in the 1st, 2nd and 3rd steps in the solution of the 3rd question were at a very high level (100%, 96.67% and 93.33%, respectively), the percentages of candidates who detected the erroneous explanation in the 4th and 5th steps (46.67% and 43.33%, respectively) were at a moderate level. It was revealed in the study that PCK of the participants were not sufficient in terms of understanding the student. Accordingly, the participants should improve their knowledge on the subject of "the use of ammeter and voltmeter in electrical circuits, the characteristics of the specified measuring instruments and how these measuring instruments are connected in series and parallel to the circuit elements in the circuit".

In the 2nd step of the 4th problem, the participants who could not detect the erroneous explanation argued that "because the resistance of the bulbs is very small, they are ignored/neglected." It can be said that they were not aware of the basic concepts affecting the brightness of the bulb and their field knowledge on this subject was insufficient. In addition, it can be emphasized here that they could not internalize Ohm's law, and therefore, they adopted the idea that the brightness of the bulb did not depend on the resistance of the bulb. When the answers of the participants who provided incorrect explanations in step of this question showed that the participants had a misunderstanding as they thought that "If the resistance of the bulb is high, the brightness is high, if the resistance is low, the brightness is low." Accordingly, it can be concluded that they did not know the concept of resistance or they misinterpreted it. The answers of the participants who provided a partially correct explanation indicated a lack of knowledge. Although their explanations were scientifically correct, they did not have in-depth field knowledge because they did not explain the reasons for the information they expressed Examination the answers of the participants who could not identify the erroneous explanation in the 4th step of the 4th question showed a misconception due to the fact that the participants had the idea that "There are 2 generators in the circuit no. II, more current flows through the light bulb. PY>PX=PZ=PT" (Karal, Alev & Yiğit, 2009; Küçüközer & Demirci, 2008; Küçüközer & Kocakülah, 2007; Lee & Law, 2001; McDermott & Shaffer, 1992; Peşman & Eryılmaz, 2010; Satır, 2007; Suryadi, Kusairi & Husna, 2020).

It can be stated that they had misconceptions such as "depends on the number of generators regardless of the number of generators". At the same time, it may show that the participants have the misconception of "the brightness of the bulb is directly proportional to the number of generators in the circuit and inversely proportional to the number of bulbs, regardless of the connection type of the generators in the circuit" reported in the literature. The answers of the participants, who made incorrect explanation despite detecting the error in step 4 of the 4th question showed that the participants thought that "the higher the number of batteries, the brightness increases. The higher the number of bulbs, the lower the brightness of the bulb. PY>PX=PZ=PT". Thus, it can be stated that they had the misconception given that "regardless of the connection type of the generators in the circuit, the brightness of the bulb is directly proportional to the number of generators in the circuit and inversely proportional to the number of bulbs". Such a misconception is mentioned in the literature as well (Karal, Alev & Yiğit, 2009; Küçüközer & Demirci, 2008; Küçüközer & Kocakülah, 2007, Lee & Law, 2001; Satır, 2007; McDermott & Shaffer,1992; Peşman & Eryılmaz, 2010; Suryadi, Kusairi & Husna, 2020). The answers of the participants who provided a partially correct explanation revealed that the participants learned that the increase in the number of generators did not change the brightness of the bulb in the circuits where the generators were connected in parallel. It can be said that there was a misconception that an increase in the number of generators in a series circuit (see Figure 4, see III, p. 13) increases the brightness of the bulb regardless of the number of bulbs in the circuit. current sources" (Karal, Alev & Yiğit, 2009; Küçüközer & Demirci, 2008; Küçüközer & Kocakülah, 2007; Lee & Law, 2001; McDermott & Shaffer,1992; Satır, 2007; Peşman & Eryılmaz, 2010; Suryadi, Kusairi & Husna, 2020). The participants who both identified the incorrect explanation and provided a scientifically correct explanation stated that the brightness of the bulb depended on the potential difference between the ends of the bulb and the current flowing over the bulb, and by connecting the generators in parallel in the circuit (see Figure 4, p. 13) between the ends of the bulb. Since the potential difference did not change, it can be said that the participants did not have the misconception of "considering generators as a constant current source" and had metacognitive learning regarding the serial and parallel connection of generators. In the 4th question solution, the percentage of the participants who identified the correct explanation was at a very high level.

In the 1st step of the 5th problem, it was stated that "The brightness of the bulbs in the electrical circuits is directly proportional to the number of batteries in the circuit and inversely proportional to the number of bulbs." The answers of the participants who could not detect the erroneous explanation revealed that they thought that "As the number of bulbs increases, the brightness decreases because the resistance will increase. The brightness increases as the number of batteries increases." It can be said that they were not aware of the basic concepts affecting the brightness of the bulb and their content knowledge on this subject was insufficient. In this sense, it can be said they adopt the idea that "generators are constant current sources" and/or "Irrespective of the way the bulbs are connected, the brightness of the bulb decreases as the resistance increases with the increase in the number of bulbs" (Karal, Alev & Yiğit, 2009; Küçüközer & Demirci, 2008; Küçüközer & Kocakülah, 2007; Lee & Law, 2001; McDermott & Shaffer, 1992; Peşman & Eryılmaz, 2010; Satır, 2007; Suryadi, Kusairi & Husna, 2020). It can also be put forward that they did not master the concept of equivalent resistance for connecting resistors. The answer of the participant who provided partially correct explanations in step 1 of the same problem showed that he said that "In series-connected bulbs, as the number of bulbs increases, the current decreases accordingly, the brightness of the bulb decreases. In parallel, the brightness is the same as the current flowing through the bulbs will be the same." In this sense, it can be said that the participant knew the concepts but his knowledge was incomplete. Therefore, it can be argued that there was a misunderstanding/learning that cannot be found in the literature for the brightness of the bulb given that he explained as follows: "Brightness is twice the current. $P= i^2.R$". It is clear that this participant had an operational misconception. The participants who were able to make a partially correct explanation argued that: “When the generators are connected in parallel, the bulb gives a longer light, but it burns with the same brightness.” Their answers showed that they had a lack of knowledge and that although their explanations were scientifically correct, they did not or cannot write the reasons for the information they expressed, indicating that they did not have in-depth content knowledge. It can be said that the participants who provided a correct explanation had in-depth content knowledge about the brightness of the bulbs. The answers of the participants who could not identify the erroneous explanation in the 3rd step the 5th question shoed that the participants said that “If I current flows through the X bulb, 2I current flows through the T bulb, I/2 current through the Y and Z bulbs. The brightness is directly proportional to the current. The fact that they have P= V. Accordingly, it seems that the participants had common misconceptions such as “generators are constant current sources” and/or “brightness is directly proportional to current”, reported in the literature (Karal, Alev & Yiğit, 2009; Küçüközer & Demirci, 2008; Küçüközer & Kocakülah, 2007; Lee & Law, 2001; McDermott & Shaffer, 1992; Peşman & Eryılmaz, 2010); Satır, 2007; Suryadi, Kusairi & Husna, 2020). In addition, the answers of the participants showed that they had another misconception that “regardless of connection type of circuit generator, as the number of generators in the circuit increases lamp brightness increases” which was reported by some studies (Karal, Alev & Yigit, 2009; Lee & Law, 2001; Row, 2007). Although the participants were aware of the concept of power correctly in the mathematical model, the fact that they explained the brightness with direct proportion to the current can be regarded as an indication that they did not consider the relationship of the potential in the model with the current. In the solution of the 5th question, the participants who detected the error in the 3rd step but provided wrong explanations said that “The relationship between the bulb brightness is $P_X > P_T > P_Y = P_Z$. Considering that they made a statement such as “The generators in P_T are connected in parallel, they give less energy”, it can be said that they had the misconception of “the use of current and energy concepts interchangeably”, mentioned in the literature (Borges & Gilbert, 1999; Satır, 2007). In addition, it may also suggest that they had a lack of knowledge about Ohm’s law. The participants who made a partially correct explanation said that “Because the batteries in the T lamp are connected in parallel, they can be considered as a single battery. Therefore, the brightness of the X and T are the same. The relationship between the brightness of the bulbs is $P_T = P_X > P_Y = P_Z$.” Accordingly, it can be stated that the participants had correct knowledge about the effect of parallel connection of the generators on the brightness of the bulb. However, while determining the brightness of the bulb in the I. and II. circuit they disassociated the comparison between the brightness of the bulbs in the circuit. This was due to misconception of “generators are constant current sources” (Karal, Alev & Yiğit, 2009; Küçüközer & Demirci, 2008; Küçüközer & Kocakülah, 2007; Lee & Law, 2001; McDermott & Shaffer,1992; Peşman & Eryılmaz, 2010; Satır, 2007; Suryadi, Kusairi & Husna, 2020). In addition, they did not have an adequate kmowledge of the factors affecting the brightness of the bulb, the equivalent resistance-current relationship, and Ohm’s law or they had misaligned these issues.” The percentage of participants who provided the correct explanation in the 2nd step of the question was at a very high level (93,33%). However, the percentage of the participants who detected the incorrect explanation in the 1st step was at a low level (36.67%), Accordingly, prospective science teachers who participated in the study should improve their knowledge of the subject matter related to the parallel connection of generators and light bulbs and they needed to use their PCK in order not to cause incorrect learning in students when they become teachers.

It was seen that 89.26% of the participants found the correct explanations given to them in the question solution whereas 52.50% identified the incorrect explanations of the question solution. Accordingly, it can be said that the participants’ detection of correct information was much better than their detection of incorrect information. It was found that the majority of the participants identified the correct explanations in the question solution steps. Although it depended on the question, it can be stated that the number of those who identified the erroneous explanations in the solutions was about half of the participants. In this context, it can be stated that the participants found the error at the "knowing/detecting the existence of the error" step, which is the lowest level of the error analysis steps (Detection, Interpretation, Evaluation, and Correction) of Peng and Luo (2009). The findings also showed that the number of the participants who both identify the erroneous explanations and provided scientifically acceptable answers was few. Hence, it can be argued that the general content knowledge of the participants about electrical circuits was at a sufficient level, but their in-depth field knowledge and PCKs were not sufficient in terms of understanding and measuring-evaluating the students. Baki (2006) emphasized that in order for conceptual understanding to be fully realized, the individual should not only define the concept but also reveal the relations and differences between concepts and reach a solution (cited in Demirci, Özkaya & Konyalıoğlu, 2017). The approaches of the participants who identified the incorrect explanations indicated that that the majority of the participants could not provide correct explanations. An indication of having learned something is not only to tell the truth or to determine the correct information about that thing, but also to identify the erroneous information given about that thing and to explain the erroneous solutions with their reasons. In this context, it can be said that the participants had a very poor level of learning in terms of detecting incorrect information in the solution steps of the questions and correcting the errors, and their proficiency was at a low level. This result is consistent with the results reported by Ball (1990b), Even and Markovitz (1995), and Even and Tirosh (1995) (cited in Konyalıoğlu, Aksu, Şenel & Tortumlu, 2010). Being able to identify the errors as well as finding the correct solution is crucial in terms of measurement and evaluation, especially in the evaluation of student answers. A teacher, who cannot detect the incorrect information in the students' answers, cannot evaluate the teaching-learning results correctly. This is also an indication that the teacher's content knowledge is not sufficient. If the teacher cannot detect errors both in the teaching-learning process and in the assessment-evaluation phase, he/she may not consider the need to make a change in the teaching process. It is an important part of the teaching-learning process to identify the mistakes in their questions or solutions and explain why they are wrong. In this context, the participants who did not detect errors or provided incorrect or incomplete explanations should improve their knowledge by being aware of the reasons for these errors

The findings of this study were in line with those in Suryadi, Kusairi and Husna (2020), Sinanoğlu (2019), Peşman and Eryılmaz (2010), Karal, Alev and Yiğit (2009), Küçüközer and Demirci (2008), Küçüközer and Kocakulah (2007), Lee and Law (2001), Sencar, Yılmaz and Eryılmaz (2001), Borges and Gilbert (1999) and McDermott and Shaffer (1992). It is possible for prospective teachers to take into account the mistakes they make due to their lack of knowledge and wrong learning, and they can turn their own learning mistakes into an advantage for their students in the process of teaching concepts and information when they become teachers. Most of the in-service Science and Physics teachers have similar misconceptions as students (Cohen, Eylon & Ganiel, 1983, cited in Karal, Alev & Yiğit, 2009; Pardhan & Bano, 2001; Satır, 2007; Suryadi, Kusairi & Husna, 2020; Yağbasan & Gülçiçek, 2003). Therefore, using assessment activities related to student errors in or possible mistakes that students may make in teacher education may be beneficial for prospective teachers to understand the sources of error, to organize the lessons by taking these into account, and to construct their knowledge correctly (Konyalıoğlu and others, 2010). A student who can correctly solve a problem related to physics subjects, even if the result is correct in the same type of question, should be able to both identify where the mistake is and correctly explain the cause of the mistake. If the student can do this, it means that he or she has learned the relevant concept or knowledge in a meaningful way. When prospective teachers become teachers, they should be aware of students' misunderstandings and mistakes and take the necessary precautions to prevent students from falling into these and similar situations. Detecting errors and being able to reveal their causes is related to learning. If there is learned knowledge, the individual should be able to identify existing errors with this knowledge since it is important to determine the correctness of something, as well as to determine the cause of the error (Konyalıoğlu et al., 2010).

It can be said that identifying student mistakes is effective in developing content knowledge specific to a subject (Carpenter, Franke & Levi, 2003; Ma, 2010; Tsamir, 2007). In addition to giving correct and detailed information and concepts to students who encounter information and concepts related to a subject for the first time, theoretically and practically, it is extremely important for students to learn information and concepts related to the subject at a metacognitive level. This depends on the adequacy of the teacher's SMK, which is intertwined and in a close relationship with the teacher's PCK. With the constructivist approach, negative information that supports metacognitive development as well as positive information that repeats the truth began to be effective in education (Melis, Sander & Tsowvaltzi, 2010). Negative information, which makes a significant contribution to the elimination of errors (Heinze, 2005), provides the student with the opportunity to reflect on their experiences (Akpınar & Akdoğan, 2010) and supports the student to be aware of situations that should be avoided (Gartmeier, Bauer, Gruber & Heid, 2008). In addition to being important in terms of heuristics (Gartmier et al., 2008), it also helps the person to understand what one knows and what not to do with positive information (Parviainen & Eriksson, 2006, cited in Demirci, Özkaya & Konyalıoğlu, 2017).

In this context, considering the difficulties in learning abstract knowledge and concepts related to electrical circuits at all levels of education, error-based activities can be included to prevent the formation of incomplete and/or incorrect information, misconceptions or correct existing misconceptions, and to enable learning to take place at the metacognitive level. The effects of error-based activities on students' learning can be investigated. A study can be carried out on the changes in the knowledge levels of students and prospective teachers by using real circuit elements on electrical circuits. Similar studies can also be carried out on the subject knowledge of students in physics, where there are too many misconceptions, incomplete and wrong learning, and students have learning difficulties. Prospective and in-service science teachers' subject knowledge in terms of their approaches to error can be examined and studies can be conducted to identify misconceptions, deficiencies, interests, difficulties, motivations, and strategy information in the student comprehension component of the hexagon model of PCK proposed by Park (2005). In the education and teaching process, by doing error-based activities related to physics subjects, the effect of the activities on the development of PCKs of prospective teachers can be investigated. The reasons why the prospective science teachers could not detect the mistake can be investigated through semi-structured interviews.

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