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Development of a Three-Tier Test to Assess Misconceptions About Simple Electric Circuits

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ABSTRACT. The authors aimed to propose a valid and reliable diagnostic instrument by developing a three-tier test on simple electric circuits. Based on findings from the interviews, open-ended questions, and the related literature, the test was developed and administered to 124 high school students. In addition to some qualitative techniques for establishing the validity, some quantitative techniques were also used. Consequently, Cronbach's alpha reliability coefficient was estimated for the test as .69, and results revealed that the test scores could be a valid and reliable measure of students' qualitative understanding of simple electric circuits.

Keywords: physics education, misconceptions, three-tier tests, simple electric circuits

Researchers in science education are in agreement that students come to classes with conceptions, most of which are different from scientists' conceptions (Hammer, 1996). Terms such as *naive beliefs*, *erroneous ideas*, *preconceptions*, *multiple private versions in science*, *underlying sources of error*, *personal models of reality*, *spontaneous reasoningy*, or *persistent pitfalls* were used to refer to these conceptions in the related literature (Wandersee, Mintzes, & Novak, 1994). However, the most commonly used term is *misconception*, which we use throughout the article. Moreover, Gowin (1983, as cited in Wandersee et al.) used *mistake* (error) instead of *misconception*; however, this term has quite a negative connotation with respect to misconception.

Hammer (1996) reported that misconceptions are stable cognitive structures to change, affect students' understanding of scientific concepts, and must be overcome so that students learn scientific concepts effectively. Thus, assessment of misconceptions is very important for effective science instruction. Therefore, in the purpose of assessing ninth-grade Turkish students' misconceptions on simple electric circuits, we developed a three-tier test, the Simple Electric Circuits Diagnostic Test (SECDT). In this manner, the purpose of the present study was to propose a novel diagnostic instrument to assess student misconceptions in addition to reporting Turkish students' misconceptions about simple electric circuits.

Research Questions

In line with the purposes of the present study, the research questions were as follows:

Research Question 1: Is there a misconception which has not been reported in the literature but Turkish students hold?
Research Question 2: Are the SECDT results a valid and reliable measure of students' qualitative understanding of simple electric circuits?
Research Question 3: How prevalent are the misconceptions Turkish students hold about simple electric circuits?

Rationale

For assessing student misconceptions in physics, interviews (Fredette & Clement, 1981; Fredette & Lochhead, 1980; McDermott & Shaffer, 1992; Osborne & Gilbert, 1980) and multiple-choice tests (Beichner, 1994; Engelhardt & Beichner, 2004; Odom & Barrow, 1995; Tan, Goh, Chia, & Treagust, 2002) have been used commonly. Conducting interviews enables researchers to probe student responses and make sense of their understanding (Osborne & Gilbert). However, findings from interviews have problems with generalizability due to small samples. On the other hand, multiple-choice tests can be administered to large samples, easily analyzed, and allow greater generalizability of findings, except for probing student responses (Beichner). Beichner stated that combining interviews and multiple choice tests seems to be the best way for making sense of students' understanding when taking the pros and cons of them into account. Also, Redish and Steinberg (1999) emphasized the significance of interviews in eliciting students'

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difficulties with understanding of physics concepts and suggested designing multiple-choice tests with distracters selected from students' common wrong answers in interviews.

Furthermore, R. Cohen, Eylon, and Ganiel (1983) observed in their study that some students with a misconception may have given correct responses to multiple-choice questions assessing that misconception. They interpreted this observation as an indicator of student responses' inconsistency in different situations. In other words, all correct responses to multiple-choice questions may not reflect a clear understanding. Hestenes and Halloun (1995) named such correct responses with wrong conceptions as *false positives*. In the same way, students with correct conceptions may give wrong responses. Such ones were named *false negatives* by Hestenes and Halloun. Hestenes and Halloun used these terms in order to reply to some concerns about the validity of the Force Concept Inventory (FCI), designed by Hestenes, Wells, and Swackhamer (1992). It was suggested that the lower the probability of false negatives and false positives, the greater the validity of a multiple-choice test (Hestenes & Halloun). They claimed the probability of false negatives to be associated with construction of test items and it was reported to be less than 10%. That is, the Newtonian responses on the FCI items are so obvious and unproblematic that students did not have difficulty in properly understanding them. But, minimizing the probability of false positives is more difficult because of the chance factor students have got when they take a multiple-choice test (Hestenes & Halloun). Nevertheless, they reported two ways as an attempt to reduce the probability of false positives. First, they assessed each dimension of the force concept with several questions. Thus, the researchers were able to compensate a probable false positive on one item by a non-Newtonian response on another item. Second, non-Newtonian alternatives were culled from extensive student interviews so as to provide non-Newtonian thinkers with reasonable distracters.

Consequently, although wrong answers given to conventional multiple-choice tests for assessing student misconceptions are accepted to be misconceptions, all wrong answers on multiple-choice tests are not necessarily misconceptions, even though distracters are based on common misconceptions culled from the related literature or interviews. As previously mentioned, a wrong answer can be given on a multiple-choice test by a student who has the correct conception (false negative) or a correct answer can be given by a student who has a wrong conception (false positive). In other words, conventional multiple-choice tests overestimate students' scores based on correct responses and misconceptions. Such deficiencies of conventional multiple-choice tests finally resulted in the development of two-tier tests by Treagust (as cited in Tan et al., 2002). The first tier of a two-tier test is a typical multiple-choice question, whereas the second tier forces students to select a reason for the first-tier response (Chen, Lin, & Lin, 2002; Griffard & Wandersee, 2001; Odom & Barrow, 1995; Tan et al.). Therefore, two-tier tests provide researchers with the opportunity to make sense of whether a wrong answer to the first tier of an item is due to a misconception and if a correct answer to the first tier is because students actually understand the scientific concept. However, a diagnostic instrument should also be able to detect a lack of knowledge. By definition, misconceptions are strongly held cognitive structures that are not consistent with scientific concepts (Hammer, 1996). This definition can be restated as accepting a conception held by a student to be a misconception requires not only being inconsistent with scientific concepts but also being strongly advocated by the student. Paying attention to this aspect of the definition of a misconception, Hasan, Bagayoko, and Kelley (1999) developed a simple and effective way for distinguishing a lack of knowledge or concept from a misconception. Distinguishing a lack of knowledge from a misconception is crucial because remediation of a lack of knowledge or a misconception may entail different instructional methods. Besides, remediation of a misconception is more difficult than remediation of a lack of knowledge (Hasan et al.). They used the Certainty of Response Index (CRI) accompanying items of a diagnostic instrument. The CRI is usually based on a scale, such as a Likert-type scale, and provides a measure of the degree of certainty with which a student answers each question. The researchers treated an answer with a low CRI value as a lack of knowledge, irrespective of if the answer was correct or wrong. They stated a correct answer with high CRI value indicates a thorough understanding of the related concept. Likewise, they accepted a wrong answer with a high CRI value to indicate the existence of a misconception.

As a result, a three-tier test is simply a two-tier test except for an additional tier asking students if they are sure about their responses to the first two tiers. The present study was based on combining two-tier tests with the CRI. Three-tier tests provide researchers with an understanding of students' reasoning beyond their responses, thus providing estimated percentages of false negatives and false positives without conducting follow-up interviews. Moreover, by means of third tiers, a misconception and a lack of knowledge can be distinguished. Three-tier tests are also novel diagnostic instruments because only two three-tier tests could be encountered in the scope of this study's literature review (Cataloglu, 2002; Eryılmaz & Sürmeli, 2002).

Misconceptions About Simple Electric Circuits

Although instructors succeed in helping students acquire the ability to solve complicated quantitative problems, they still have difficulty in analyzing qualitative problems on simple electric circuits (R. Cohen et al., 1983). Therefore, there is an extensive literature on students' conceptual understanding of simple electric circuits. Without giving the details of individual studies, the common misconceptions in the related literature are the following: (a) the sink model, in which only a single wire connection between an electrical device and a power supply is believed to run the device (Chambers & Andre, 1997; Fredette & Lochhead, 1980;

Sencar & Eryılmaz, 2004); (b) the attenuation model, in which an electric current traveling around an electrical circuit in one direction is thought to decrease gradually due to consumption of it by devices within the circuit (McDermott & Shaffer, 1992; Sencar & Eryılmaz; Shipstone, 1988); (c) the shared current model, in which an electrical current is thought to be shared equally by electrical devices (Sencar & Eryılmaz; Shipstone); (d) the sequential model, in which it is assumed that a change at a point in an electrical circuit affects the circuit forward in the direction of the current, not backward (Dupin & Johsua, 1987; McDermott & Shaffer; Sencar & Eryılmaz; Shipstone; Shipstone et al., 1988); (e) the clashing current model, in which positive and negative electricity from the power supply meet at an electrical device and their clashing there causes it to run (Chambers & Andre; Sencar & Eryılmaz, 2004); (f) the empirical rule model, in which the further away a bulb is from the battery, the dimmer the bulb is (Heller & Finley, 1992; Sencar & Eryılmaz); (g) the short circuit misconception, in which wires with no electrical devices are ignored when analyzing an electrical circuit (Chambers & Andre; Fredette & Clement; Sencar & Eryılmaz); (h) the power supply as constant current source, in which any power supply is thought to provide an electrical circuit with a constant electrical current rather than electrical energy (R. Cohen et al.; Dupin & Johsua; McDermott & Shaffer; Sencar & Eryılmaz; Shipstone; Shipstone et al.); (i) the parallel circuit misconception, in which resistors are thought of as an obstacle to current flow, assuming any increase in number of resistors in parallel to increase the total resistance (Chambers & Andre; R. Cohen et al.; McDermott & Shaffer; Sencar & Eryılmaz); and (h) local reasoning, in which in case of a change in a part of an electrical circuit, the local part is focused on instead of global analysis (R. Cohen et al.; Sencar & Eryılmaz; Shipstone et al.).

Method

Procedure

In the light of the related literature, the development of the SECDT consists of three main phases: (a) conducting interviews, (b) constructing and administering open-ended questions, and (c) developing and administering the SECDT.

Interviews were conducted in the purpose of being aware of any possible unknown misconceptions as well as the reported ones in the literature. Clinical interview (Piaget, 1929, as cited in Fredette & Lochhead, 1980) and interview-about-instances (Osborne & Gilbert, 1980) techniques were used in the interviews. In the clinical interview, as Fredette and Lochhead did, students were given several conducting wires, a battery, and a light bulb, with the goal to light up the bulb, so the types of connections students tried were observed. In the interviews about instances, a card depicting some diagrams was shown to the interviewees, and then the related questions in the interview guide were distributed. All of the diagrams on the card were selected or adapted from the literature about student difficulties in electricity (R. Cohen et al., 1983; Heller & Finley, 1992; Shipstone, 1988; Shipstone et al., 1988). Furthermore, the interviews were semistructured. That is, some additional probing questions were constructed during the interviews, except for the questions in the interview guide. Conducting interviews showed that misconceptions reported in the literature are held by Turkish students, too. In addition to the reported ones, an unreported misconception was detected in the interviews. The diagram in Figure 1 was one of the diagrams used in the interview card. When the interviewees were asked to rank the currents at Points 1, 2, and 3, a few students said the current at Point 1 was the biggest, the current at Point 2 was slightly smaller, and the current at Point 3 was the smallest. They explained their reasoning that most of the current at Point 1 goes straight into the path at which Point 2 is. It is more difficult to pass through the path at which Point 3 is because it is perpendicular to the previous current flow. They said that current flow within a wire was like water flow in a pipe. This misconception has been named *current flow as water flow* by the researchers. Although this misconception has not been reported in the literature, Stocklmayer and Treagust (1994) reported some criticism about water–circuit analogy. They cited that some misconceptions held by students may be associated with use of such analogies.

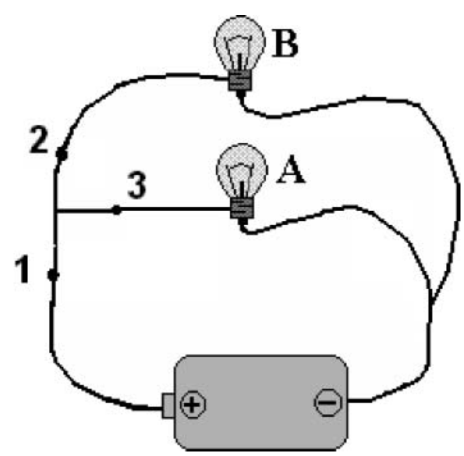


FIGURE 1. The diagram used for eliciting current flow as water flow misconception.

The findings from the interviews and the related literature helped us develop open-ended questions. Most of the questions were adapted from the questions in the interview guide—thus, from the related literature. In addition to the questions existing in the literature, one additional question was written by the researchers in order to assess the current flow as water flow misconception. Also, some textbooks and test banks were reviewed for finding some more qualitative questions assessing students' conceptual understanding and for assessing each misconception with more than one item. However, almost all of the questions in the textbooks and test banks were quantitative, and, with highly careful considerations, one question was found to be worthy adding to the questionnaire based on the interviews. Also, three questions were added from the related literature (Engelhardt & Beichner, 2004; Fredette & Lochhead, 1980). Afterwards, in order to establish the content validity, the questions and table of specification were delivered to two physics teachers and an instructor who was at the Department of Physics Education at the Middle East Technical University in Turkey and had expertise in assessment of student misconceptions. The experts investigated the questions in terms of whether they were appropriate for the grade level and misconceptions intended to be assessed, and whether they were unproblematic. After administering the open-ended questions to 99 high school students, student responses to the questions were categorized in order to write the distracters of the SECDT. Briefly, similar student responses for each question were joined together to form a category, and thus each question had several categories: one involved correct answers and the others involved misconceptions. The number of student responses in each category was labeled as the frequency of each category. As a result, the categories with high frequencies were used as the distracters of the SECDT in order to present common misconceptions. So, items in the SECDT were based on all the open-ended questions but Item 2. Because none of the few responses to Item 2 could not be any distracters could not be written for Item 2 and it was not used for the SECDT. For establishing the content validity of the SECDT, the test was given to the instructor again in order to check if reasons presented in the second tier were consistent with the first tier, in addition to if items had been written properly. After some suggested improvements, the last version of the SECDT (see Appendix) was administered to 124 students. The original version of the SECDT is Turkish. However, it was translated into English in the purpose of adding it to this article.

Population and Sample

All ninth-grade high school students in Polatlı, which is the biggest outlying district of the Turkish capital, Ankara, formed the accessible population of the study. General high school, Anatolian teacher training high school, and foreign-language-based high school were determined as the school types in which to carry out the study. These schools were selected because they had been expected to differ in achievement. Anatolian teacher training high schools accept students who are able to be successful on the Secondary Schools Student Selection Examination, which is a national exam to select students from elementary schools for secondary schools in Turkey. Students who are not able to succeed in the exam but have high cumulative grade point averages enroll at the foreign-language-based high schools. Students who are not able to enroll at the Anatolian teacher training or foreign-language-based high schools enroll at the general high schools. Afterwards, among the schools, convenient intact classes were selected in which to administer the SECDT. Briefly, schools were selected purposively while the intact classes were selected conveniently. Finally, 124 students took the SECDT and the students were between 14 and 16 years old. Also, female students constituted 61.3% of the sample, and all the students had taken instruction on simple electric circuits before administering the SECDT.

Instruments

In the present study, we used two instruments: the Interest–Experience Questionnaire About Electricity (IEQ) and the SECDT.

The IEQ, which was developed by Sencar and Eryılmaz (2004), was used for determining the interviewees. Except for questions on students' school type, name, gender, physics grades, and grade levels, there are 15 items in the questionnaire. Five items of the questionnaire, rated on a 4-point Likert-type scale ranging from 1 (*very interested*) to 4 (*very uninterested*), addressed students' interest in electricity. Remaining 10 items were rated on a 3-point Likert-type scale ranging from 1 (*never*) to 3 (*frequently*) and asked for students' experiences in electricity. Sencar and Eryılmaz established the face and content validity of the IEQ by asking some experts for comprehensiveness of items, representativeness of content by the selected items, and appropriateness of the format. They administered the questionnaire to 166 ninth-grade students from different high schools for a pilot study. The Cronbach's alpha reliability coefficient was estimated as .89.

The SECDT is a 12-item, three-tier test consisting of three tier items for assessing students' understanding of simple electric circuits. The first tier of an item is a conventional multiple-choice question with mostly two or three choices. The second tier presents some reasons for the given answer for the first tier. The third tier of questions examine if students are confident about their answers for the first two tiers.

Variables

After administering the SECDT to 124 ninth-grade high school students, data were typed into Microsoft Excel as raw data (items in columns and students in rows). Scoring of items was done by means of the answer key of the SECDT (see Appendix). In addition to students' scores based on the answer key, students were given misconception scores as well using alternative sets indicating each misconception (Table 1). In Table 1, the number of items assessing each misconception can be seen in addition to the alternative sets indicating each misconception.

Eight variables were produced using the answer key and the alternative sets indicating each misconception. These are Score 1, Score 2, Score 3, confidence levels, scores based on only second tier, Misconception 1, Misconception 2, and Misconception 3. While the first five were produced using the answer key, the remaining variables were

TABLE 1. Alternative Sets Indicating a Misconception According to All Three Tiers

Misconception	Choice selections indicating a misconception according to all three tiers	*n*
1. Sink model	1.1 a, 1.2 a, 1.3 a; 10.1 a, 10.2 b, 10.3 a; 10.1 b, 10.2 b, 10.3 a	2
2. Attenuation model	4.1 c, 4.2 c, 4.3 a; 4.1 b, 4.2 c, 4.3 a	1
3. Shared current model	3.1 b, 3.2 c, 3.3.a; 3.1 a, 3.2 c, 3.3.a; 4.1 d, 4.2 c, 4.3 a; 5.1 b, 5.2 c, 5.3 a; 5.1 a, 5.2 c, 5.3 a	3
4. Clashing current model	1.1 b, 1.2 b, 1.3 a; 10.1 a, 10.2 a, 10.3 a	2
5. Empirical rule model	4.1 b, 4.2 a, 4.3 a; 7.1 b, 7.2 b, 7.3 a; 12.1.a, 12.2.b, 12.3 a	3
6. Short circuit misconception	8.1 b, 8.2 b, 8.3 a; 8.1 c, 8.2 c, 8.3 a; 10.1 a, 10.2 c, 10.3 a; 12.1 b, 12.2 d, 12.3 a	3
7. Power supply as a constant current source model	3.1 c, 3.2 a, 3.3 a; 3.1a, 3.2.a, 3.3 a; 5.1 c, 5.2 e, 5.3 a; 9.1 d, 9.1 d, 9.3 a	3
8. Parallel circuit misconception	5.1 a, 5.2 a, 5.3 a	1
9. Sequential reasoning	9.1 a, 9.2 a, 9.3 a; 9.1 c, 9.2 b, 9.3 a	1
10. Local reasoning	2.1 a, 2.2 a, 2.3 a; 5.1 a, 5.2 b, 5.3 a; 12.1 a, 12.2 c, 12.3 a	3
11. Current flow as water flow	6.1 a, 6.2 a, 6.3 a; 7.1 c, 7.2 a, 7.3 a; 11.1 a, 11.2 b, 11.3 a	3

produced according to the alternative sets indicating each misconception. They can be respectively explained in the subsequent sections.

Score 1. Score 1 was produced by taking student responses for only the first tier of items into account. Correct answers were coded as 1 and others were coded as 0. Summing rows gave students' scores based on only the first tier and summing columns gave the sum of correct responses to only the first tier. Dividing the latter by the total number of students gave the fraction of correct responses for each item (difficulty levels of first tier).

Score 2. Score 2 was produced by taking the first two tiers of items into account. When a student's responses to the first and second tiers were correct, it was coded as 1, otherwise it was coded as 0. Summing rows gave students' scores based on correctness of responses to the first two tiers and summing columns gave sum of correct responses to the first two tiers. Dividing the latter by the total number of students gave the fraction of correct responses for each item (difficulty level of the two-tier test).

Score 3. Score 3 was based on student responses to all three tiers of items. If a student's response to the third tier of a question was "Yes, I am," and both responses to the first two tiers were correct, then, it was coded as 1. Otherwise, it was coded as 0. In the same manner, summing the rows gave students' scores based on all three tiers. Summing the columns gave the total number of correct responses according to all three tiers. Again, the fraction of the correct responses was obtained by dividing the latter by the total number of students (difficulty level of three-tier test).

Confidence levels. Confidence levels were created according to student responses to only the third tier, which questioned if respondents were confident about their responses to first two tiers. It was coded as 1 for confident students and as 0 for unconfident students. Summing rows gave students' confidence level scores.

Scores based on only the second tier. This variable was shaped according to only the second tier. It was coded as 1 for a correct response and as 0 for an incorrect response. This variable was used for estimating the percentages of false negatives and false positives.

Misconception 1. This variable was produced by taking only first tiers in Table 1 and student responses to only the first tiers into account. In order to illustrate the production of Misconception 1, Figure 2 was prepared by showing only the first and the last three students in rows among 124 students and a few misconceptions in columns. For example, the sink model (M1) was assessed by two items (Items 1 and 10) as seen from Table 1. If a student's response to the first tier of Item 1 was A, then it indicated M1 and was coded as 1, otherwise it was coded as 0 (see the first column under M1 in Figure 2). If a student's response to the first tier of Item 10 was A or B according to Table 1, then it was coded as 1, otherwise it was coded as 0 (see the second column under M1 in Figure 2). In all, 23% of 124 students (29 students) had M1 according to Item 1 and 99% (123 students) had M1 according to Item 10. On average, students holding M1 comprised 61% of the total.

Misconception 2. The process of producing Misconception 2 was the same as the production of Misconception 1.

Student	M1		M2	M3				M10			M11			Sum
1	0	1	0	1	1	1		1	1	1	0	0	0	15
2	0	1	0	0	1	1		0	1	0	0	0	0	10
3	0	1	0	0	0	1		0	0	0	0	1	0	8
122	1	1	0	0	0	1		0	1	0	0	1	0	11
123	1	1	0	1	1	1		0	0	0	1	0	0	12
124	1	1	1	0	0	1		1	1	0	0	1	0	11
Sum	29	123	50	82	21	79		66	51	23	36	18	48	
Percent	23	99	40	66	17	64		53	41	19	29	15	39	
Average	61		40	49				38			28			

Note. M1: Sink Model, M2: Attenuation Model, M3: Shared Current Model

FIGURE 2. Example showing how Misconception 1 scores were produced on Microsoft Excel.

However, in this case, the first two tiers of items in Table 1 were taken into account.

Misconception 3. The production of this variable was also the same as the production of Misconceptions 1 and 2. However, all three tiers of items in Table 1 were taken into account in this case.

Results

In this section, we explore a possible relationship between Score 2 and confidence levels for checking the validity of the SECDT. For the same purpose, we calculated the percentages of false negatives and false positives. Then, we present overall descriptive statistics of the SECDT. Finally, we present the percentage of students' correct responses and misconceptions, estimated as a result of the use of the SECDT.

The correlation between Score 2 and confidence levels was investigated because students with high scores were expected to be more confident than were students with low scores (Cataloglu, 2002). This expectation might have been observed if items of the test worked properly, and it is related to the construct validity of the SECDT. So, Pearson's product–moment correlation coefficient was estimated. As a result, there was a strong, positive correlation between Score 2 and confidence levels ($r = .51$, $p < .01$). Because the sample size was large (more than 100), irrespective of whether the value of Pearson correlation coefficient was small or large, a statistically significant correlation had been expected (Pallant, 2001). However, values of Pearson product–moment correlation coefficients greater than .50 are suggested as strong relationships by J. Cohen (as cited in Pallant, 2001, p.120). Therefore, it can be concluded that items of the SECDT work properly. Furthermore, when the

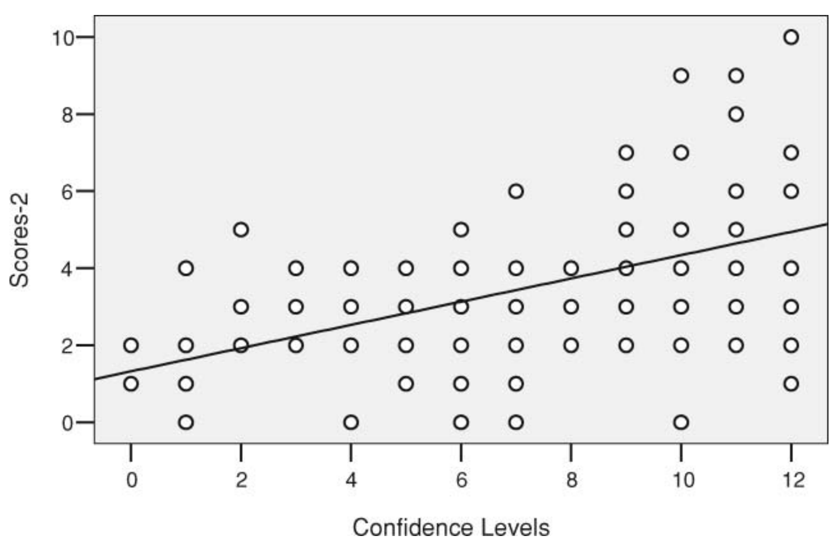


FIGURE 3. Scattergram of Score 2 versus confidence levels.

TABLE 2. Percentages of False Negatives and False Positives

	Item													
Variable	1	2	3	4	5	6	7	8	9	10	11	12	M	SD
False Negatives	0	4	6	10	5	9	5	2	2	0	4	2	4.1	3.2
False positives	31	3	31	4	11	10	5	7	2	10	7	3	10.3	10.1
Lack of knowledge	22	29	33	39	34	38	25	36	64	32	41	33	35.5	10.5

scattergram of Score 2 versus confidence levels (Figure 3) was examined, the existence of some students with high confidence levels in spite of their low scores can be observed at the right-bottom side. It is thought that the existence of such students decreases the value of a correlation coefficient (Pallant, 2001, p. 118). Meanwhile, existence of those students can be a sign that there were some students holding resistive misconceptions in addition to some students having answered the questions by chance.

One of the important advantages of three-tier tests is that they provide researchers with the opportunity to estimate the percentages of false negatives and false positives, which is related to the validity of the test as Hestenes and Halloun (1995) reported. Percentages of false negatives and false positives were estimated by using Score 1, the score based on only the second tier, and confidence levels (score based on only the third tier). The third tier was also used in estimating the percentages of false negatives and false positives because negative responses to the third tier indicated lack of knowledge rather than a false negative or false positive. Table 2 demonstrates the percentages of lack of knowledge item by item as well as the percentages of false negatives and false positives. As Hestenes and Halloun said, the percentages of false positives are higher than the percentages of false negatives because reducing the probability of false positives is more difficult. When the percentages of false negatives are checked, percentages of Items 4 and 6 were the highest. Because the values for these items were not higher than 10%, the false negatives may only be attributed to carelessness of some students as Hestenes and Halloun reported. This means that all items were obvious and unproblematic for the students. In spite of everything, any problem could not be detected for selecting a wrong choice in the first tier despite having the correct reason at Item 6. However, assessing two constructs (comparing currents at different points on the wire and comparing the brightness of the bulbs) in the first tier might be the reason for having high false-negative value for Item 4. It seems that there were students who did not expect the bulbs to be the same in brightness although they knew that currents at different points on the wire were the same due to series connection of the bulbs. When the percentages of false positives were checked, the percentages of Items 1 and 3 drew attention. However, examining these items showed this result to be inevitable because, in these items, even having some misconceptions might have led the examinees to select the correct choice in the first tier. Because the SECDT was designed to elicit student misconceptions, even some misconceptions can cause a student to select the correct choice on a multiple-choice test. However, high percentages of false positives for Items 1 and 3 does not seem to be a problem for the validity of the SECDT.

Additionally, the percentage of lack of knowledge for Item 9 was so large; however, all values were large, and high percentages of lack of knowledge are reasonable, owing to the nature of misconception tests. The reason for such a large percentage for Item 9 may be that it might have been the strangest one among items because the other items were more similar to ones in the students' textbooks. The high percentage of lack of knowledge might also indicate that the instruction students had taken before was deficient in helping students understand the concept of electrical circuits.

Table 3 summarizes the overall statistics, based on Score 3, for the SECDT. The mean, point–biserial indices, and difficulty levels were the important points drawing attention. The mean was 2.93 ($SD = 2.35$) out of 12 and was very small. This can be related to the difficulty of the SECDT because difficulty levels of all items except for Item 7 were below .40, with an average of 0.24 ($SD = 0.14$). Skewness of the Score 3 also supported this claim because positive skewness value indicates scores to be clustered to the left at the low values (Pallant, 2001, p. 53). Point–biserial coefficients of all items except for Item 2 were above .20 with an average of .46. In spite of the small variance due to the difficulty of items, point–biserial coefficients are acceptable values in general (Beichner, 1994) and the Croanbach's alpha reliability coefficient was found to be .69. In case of deletion of Item 2, the reliability coefficient was estimated to be .75 and average point–biserial coefficient increased to .51. Briefly, all these results can be associated with the nature of diagnostic instruments because their distracters were carefully written according to student misconceptions.

TABLE 3. Overall Descriptive Statistics for Score 3

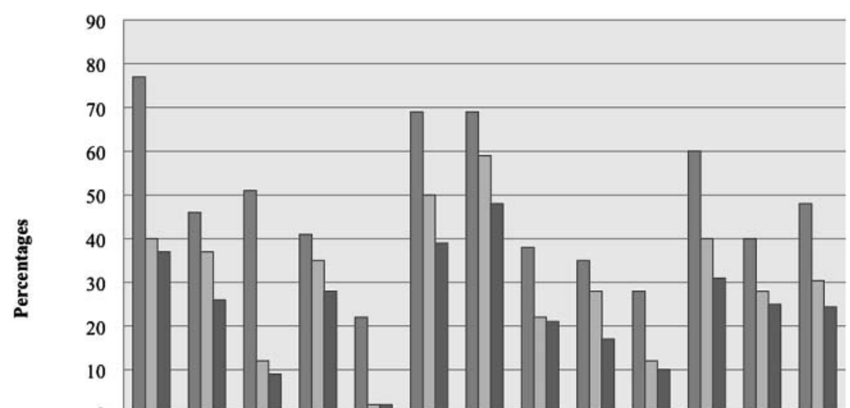
Statistic	*n*	*M*	*SD*
Students	124		
Items	12		
Mean/Maximum possible score	12	2.93	2.35
Minimum score	0		
Maximum score	10		
Median	3		
Point–biserial coefficients		0.46	0.23
<.20	1		
.20–.29	2		
.30–.39	2		
.40–.49	1		
.50–.59	0		
.60–.69	5		
.70–.79	1		
Difficulty level		0.24	0.14
.00–.09	2		
.10–.19	2		
.20–.29	4		
.30–.39	3		
.40–.49	1		

Note. Skewness = 0.72; kurtosis = –0.07; Cronbach's α = .69.

In Figure 4, the percentages of correct responses in terms of number of the tiers (e.g., assuming the first tier represented a conventional multiple-choice test, the first two tiers represented a two-tier test) are demonstrated. Score 1, Score 2, and Score 3 were used for the figure. A comparison of mean percentages revealed that conventional multiple-choice tests and even two-tier tests overestimate the proportion of students who have the correct qualitative understanding of simple electric circuits. The difference between the mean percentages of the one- and two-tier tests was 18%. Around 10% of this magnitude owed to the existence of false positives as mentioned previously. The remaining 8% included the students who gave correct responses to the first tier in spite of having a wrong reason in the second tier and were not sure in the third tier because, in the estimation of the percentages of false positives, responses to third tier were paid attention to, and all responses reflecting no confidence were treated as a lack of knowledge. The difference between the mean percentages of the two-tier test and the three-tier test was 6%. Those students were the ones who gave correct responses to the first and second tiers but were not sure according to the third tier; that is, those students' situation indicated a lack of knowledge.

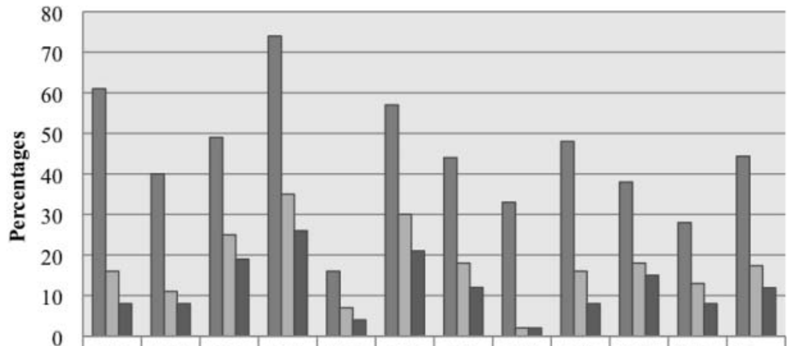
In the same manner, Figure 5 demonstrates the percentages of misconceptions in terms of number of the tiers. The variables, Misconception 1, Misconception 2, and Misconception 3, were used for depicting the figure. Checking the figure reveals that the one- and the two-tier tests overestimated the percentages of misconceptions, and the three-tier test was the best at eliciting the most actual percentages of student misconceptions. Some students might have given wrong answers for the first tier in spite of not having any misconception and that might be due to false negatives or lack of knowledge. Two-tier tests and three-tier tests can reveal the percentages of false negatives. Differing from two-tier tests, three-tier tests can also detect cases of lack of knowledge by means of the third tier.

For example, the difference between the mean percentages of the one- and the two-tier tests was 27%. Some may be because even some correct answers for the first tier may



	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12	Mean
Only first tiers	77	46	51	41	22	69	69	38	35	28	60	40	48
First two tiers	40	37	12	35	2	50	59	22	28	12	40	28	30
All three tiers	37	26	9	28	2	39	48	21	17	10	31	25	24

FIGURE 4. Percentages of correct responses in terms of number of tiers.



	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	Mean
Only first tiers	61	40	49	74	16	57	44	33	48	38	28	44
First two tiers	16	11	25	35	7	30	18	2	16	18	13	17
All three tiers	8	8	19	26	4	21	12	2	8	15	8	12

FIGURE 5. Percentages of misconceptions in terms of number of tiers.

be due to a misconception (false positive). The remaining can be associated with lack of knowledge. The difference between the mean percentages of the two-tier test and the three-tier test was 5% and was again due to lack of knowledge because those students demonstrated no confidence according to third tier. In addition, when the percentages of misconceptions according to the three-tier test were checked, the empirical rule model and parallel circuit misconception were observed to be uncommon among students. According to Table 1, the empirical rule model was assessed by three items. However, the parallel circuit misconception was assessed by only one item, and its percentage may not be accurate. Therefore, the SECDT may need some additional questions, not only for assessing parallel circuit misconception but also for assessing other misconceptions assessed by one item. Besides, the shared current model, clashing current model, short circuit misconception, power supply as a constant current source, and local reasoning seemed to be quite common misconceptions about simple electric circuits according to the three-tier test.

Discussion

There are several reasons for developing a three-tier test in this study. Using interviews for diagnostic purposes is an undeniable method. However, some disadvantages, such as being time-consuming or having an inability to generalize the results, lead science education researchers to find alternative diagnostic instruments. Multiple-choice instruments are the most common ones. Nevertheless, multiple choice-tests cannot reveal what reasons are beyond examinees' choice selections. Therefore, they do not have the ability to disclose if any wrong answer is owing to a misconception or not. This deficiency of conventional multiple-choice tests resulted in the development of two-tier tests. And, at last, we suggested the development and use of three-tier tests in the present study because three-tier tests cannot only reveal if a wrong answer is due to a misconception, as two-tier tests do, but they can also distinguish a misconception from a lack of knowledge. For example, during the interviews students were observed not to know equivalent resistance rather than having a parallel circuit misconception. That is, if a conventional multiple-choice test had been administered to them, wrong answers given by them would most probably be due to lack of knowledge rather than a misconception. The use of three-tier tests also provides some extra advantages. First, inspecting the correlation between Score 2 and confidence levels enabled us to examine the construct validity of the test. Second, three-tier tests provide researchers with the ability to estimate the percentages of false negatives and false positives, which are important for examining the validity of the test. Third, although one-tier tests or even two-tier tests overestimate students' achievement or misconception scores, three-tier tests can estimate students' achievement or misconception scores most accurately. In other words, it can be said that the three-tier tests can assess what they are intended to assess most accurately. As a result, three-tier tests may be the most valid and reliable instruments to assess achievement or misconception. Also, the Cronbach's alpha reliability coefficient of the SECDT was found to be .69. It means that at least 69% of variance in students' total scores was because of the variance in true scores of the students (Crocker & Algina, 1986, p. 139). This value was also consistent with other two-tier tests (Chen et al., 2002; Odom & Barrow, 1995; Tan et al., 2002). Thus, it can be concluded that the SECDT scores are a valid and reliable measure of students' qualitative understanding of simple electric circuits. Associated with students' misconceptions about simple electric circuits, prevalence of shared current model, clashing current model, short circuit misconception, power supply as a constant current source, and local reasoning was observed. In addition to the prevalence of the misconceptions, around 36% lack of knowledge was found, revealing the ineffectiveness of instruction the students had taken before on simple electric circuits.

As a result, the SECDT can be easily used by high school teachers in the purpose of obtaining the most accurate measure of students' misconceptions on simple electric circuits because it can distinguish misconceptions from a lack of knowledge in addition to the advantages of two-tier tests. Besides, the SECDT can be used for monitoring the progress or effectiveness of instruction because the SECDT scores are a valid and reliable measure of students' qualitative understanding of simple electric circuits as well as the ability to estimate the percentages of lack of knowledge item by item. Also, researchers can use the SECDT for testing effectiveness of different instructional treatments with the same reasons.

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APPENDIX
Simple Electric Circuit Diagnostic Test (SECDT)

Directions:

1. There are 12 questions. Please, try to answer each question carefully.
2. The batteries and the bulbs used in this test are identical.
3. The batteries are ideal, that is, the internal resistances are negligible.
4. Also, connection wires have got no resistance
5. If you do not find your answer among alternatives in any second tier, use the blank one for your response.

QUESTIONS

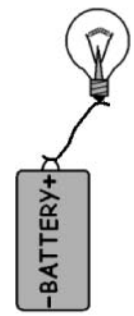

Figure 1

1.1. Will the bulb in Figure 1 light?
  a) Yes, it will.
  b) No, it will not.

1.2. Which one of the followings is the reason of your answer to the previous question?
  a) The battery and the bulb are connected by the wire.
  b) An extra wire must be connected from the negative terminal of the battery to the screw base of the bulb so that the positive and negative charges meet in the bulb.
  c) An extra wire must be connected from the negative terminal of the battery to the screw base of the bulb so that the electric current passes through the bulb.
  d) ....
  ....

1.3. Are you sure about your answers given to the previous two questions?
  a) Sure.
  b) Not sure.

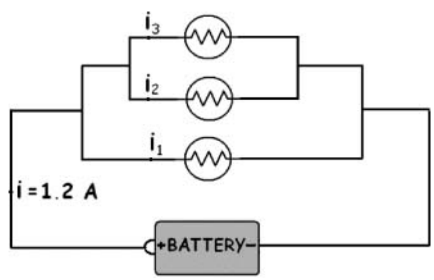

Figure 2

2.1. The current at the main branch is 1.2 A. What are the magnitudes of currents i_1, i_2, and i_3?
  a) 0.6/0.3/0.3
  b) 0.4/0.4/0.4

2.2. Which one of the followings is the reason of your answer to the previous question?
  a) After the current is divided evenly on the first junction, it is again divided evenly on the second junction.
  b) Because the identical bulbs are in parallel, currents with the same magnitude pass through the bulbs.
  c) ....
  ....

2.3. Are you sure about your answers given to the previous two questions?
  a) Sure.
  b) Not sure.

Bulb B is inserted into the electrical circuit in Figure 3 as shown in Figure 4. Answer Questions 3 and 4 according to this information.

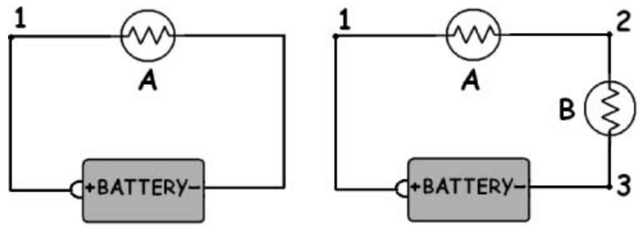

Figure 3 **Figure 4**

3.1. Compare the amount of the current at Point 1 in Figure 3 with the current at Point 1 in Figure 4.
  a) More in Figure 3.
  b) More in Figure 4.
  c) Equal in the both figures.

3.2. Which one of the followings is the reason of your answer to the previous question?
  a) The currents, which come from the batteries with the same magnitude, have not been consumed yet in the both figures.
  b) The potential differences, supplied by the batteries, are the same in magnitude in the both figures, but the total resistance in Figure 4 is larger.
  c) While the current in Figure 3 is consumed by a bulb, the current in Figure 4 is consumed by two bulbs.
  d) ....

3.3. Are you sure about your answers given to the previous two questions?
  a) Sure.
  b) Not sure.

4.1. In Figure 4, compare the magnitudes of the currents at Points 1, 2, and 3 as well as the brightness of Bulbs A and B.

	Current	Brightness
a)	$i_1 = i_2 = i_3$	Bulbs A and B are the same in brightness.
b)	$i_3 > i_2 > i_1$	Bulb B is brighter.
c)	$i_1 > i_2 > i_3$	Bulb A is brighter.
d)	$i_1 > i_2 > i_3$	Bulbs A and B are the same in brightness.

4.2. Which one of the followings is the reason of your answer to the previous question?
  a) The closer the bulb is to the battery, the brighter it is.
  b) In circuits in series, magnitude of the current is the same at any point.
  c) Because the electric current is consumed by the bulbs, it diminishes.
  d) ....

4.3. Are you sure about your answers given to the previous two questions?
  a) Sure.
  b) Not sure.

In Figure 5, an electrical circuit is given. First, Bulb B is inserted into the circuit as shown in Figure 6. Afterwards, Bulb B is replaced with a piece of wire as shown in Figure 7. Answer Questions 5, 6, 7, and 8 using this information.

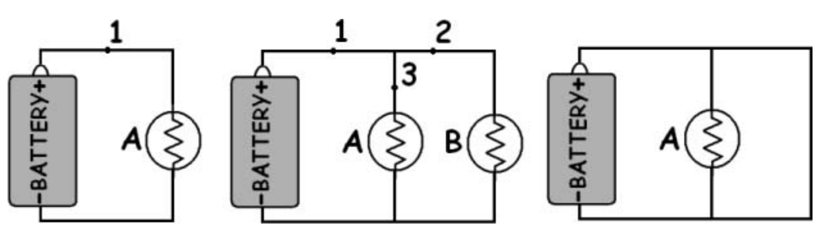

Figure 5 **Figure 6** **Figure 7**

5.1. Compare the amount of current at Point 1 in Figure 5 with the amount of current at Point 1 in Figure 6.
  a) More in Figure 5.
  b) More in Figure 6.
  c) Equal in the both figures.

5.2. Which one of the followings is the reason of your answer to the previous question?
  a) Because there are two bulbs in Figure 6, the total resistance is more.
  b) In Figure 6, the current coming from the battery is divided into two branches.
  c) While the battery supplies one bulb with current in Figure 5, it supplies two bulbs in Figure 6.
  d) The total resistance is smaller in the circuit in Figure 6.
  e) The currents have not been divided into branches in both of the figures.
  f) ....

5.3. Are you sure about your answers given to the previous two questions?
  a) Sure.
  b) Not sure.

6.1. In Figure 6, compare the amount of currents at Points 1, 2, and 3.
  a) $i_1 > i_2 > i_3$
  b) $i_1 > i_2 = i_3$

6.2. Which one of the followings is the reason of your answer to the previous question?
  a) As the split occurs, more current passes through the branch in the same direction with the main branch and less current passes through the bent branch.
  b) The current is divided evenly because the bulbs are identical.
  c) ....

6.3. Are you sure about your answers given to the previous two questions?
  a) Sure.
  b) Not sure.

7.1. In Figure 6, compare the brightness of Bulb A with Bulb B.
  a) Bulbs A and B are equal in brightness
  b) Bulb A is brighter
  c) Bulb B is brighter

7.2. Which one of the followings is the reason of your answer to the previous question?
  a) Most of the current passes through Bulb B.
  b) Bulb A is closer to the battery.
  c) Currents with the same magnitude pass through Bulbs A and B.
  d) ....

7.3. Are you sure about your answers given to the previous two questions?
  a) Sure.
  b) Not sure.

8.1. Compare the brightness of Bulb A in Figures 6 and 7.
  a) Brighter in Figure 6
  b) Brighter in Figure 7
  c) The same in the both figures

8.2. Which one of the followings is the reason of your answer to the previous question?
  a) No current passes through Bulb A in Figure 7.
  b) While the current is consumed by two bulbs in Figure 6, it is consumed by one bulb in Figure 7.
  c) In the both figures, the current is divided.
  d) ....

8.3. Are you sure about your answers given to the previous two questions?
  a) Sure.
  b) Not sure.

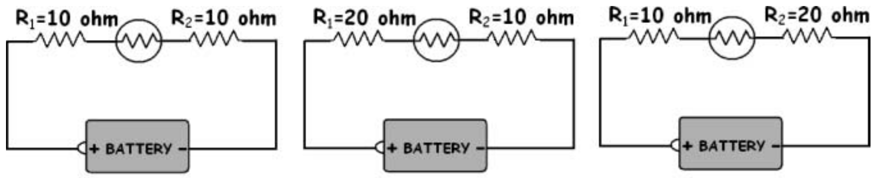

Figure 8 Figure 9 Figure 10

9.1. In Figure 8, a circuit with a battery, a bulb, and two resistors is shown. By exchanging *only* R_1 for a 20 ohm-resistor, the circuit in Figure 9 is obtained. By exchanging *only* R_2 *in Figure 8* for a 20 ohm-resistor, the circuit in Figure 10 is obtained. Does the brightness of the bulbs in Figure 9 and Figure 10 change with respect to the bulb in Figures 8?

	Figure 9	Figure 10
a)	Yes	No
b)	Yes	Yes
c)	No	Yes
d)	No	No

9.2. Which one of the followings is the reason of your answer to the previous question?
a) Before the current reaches the bulb, it is influenced by Resistor-R_1.
b) Before the current reaches the bulb, it is influenced by Resistor-R_2.
c) In both of the figures, the current changes because total resistance in Figures 9 and 10 changes with respect to Figure 8.
d) The currents are the same due to the same batteries.
e) ....
....

9.3. Are you sure about your answers given to the previous two questions?
a) Sure.
b) Not sure.

10.1. Will the bulb in Figure 11 light?
a) Yes, it will.
b) No, it will not.

10.2. Which one of the followings is the reason of your answer to the previous question?
a) + and – charges are able to meet in the bulb because the bulb touches the positive and negative terminals.
b) The bulb is connected to the positive terminal.
c) Electric current passes through the bulb.
d) Electric current does not pass through the bulb.
e) ....
....

10.3. Are you sure about your answers given to the previous two questions?
a) Sure.
b) Not sure.

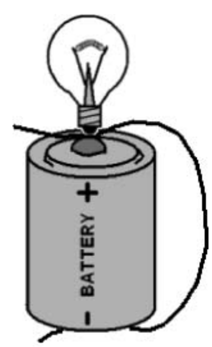

Figure 11

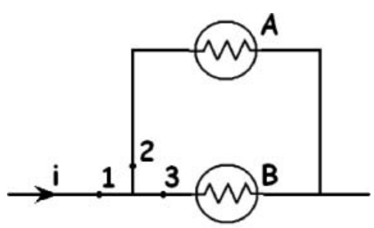

Figure 12

11.1. In the circuit in Figure 12, the direction of the current is shown. Accordingly, rank the currents at Points 1, 2, and 3.
a) $i_1 > i_3 > i_2$
b) $i_1 > i_2 = i_3$

11.2. Which one of the followings is the reason of your answer to the previous question?

a) The current is divided evenly into the branches at the junction because the resistances of the bulbs are equal.
b) When the split occurs, more current passes through the branch in the same direction with the main branch and less current passes through the bent branch.
c) ……………………………………………………………………………………………
……………………………………………………………………………………………

11.3. Are you sure about your answers given to the previous two questions?
a) Sure.
b) Not sure.

12.1. Compare the brightness of Bulb A and Bulb B in the circuit shown Figure 13.
a) Bulb B is brighter.
b) Both are the same in brightness.
c) Both will not light.

12.2. Which one of the followings is the reason of your answer to the previous question?
a) The current passes only through the wire between Bulbs A and B.
b) Bulb B is closer to the battery.
c) When the first split occurs, half of the current passes through Bulb B. Then, when the rest half of the current comes to the second junction, all the current passes through the empty wire and comes back to the battery.
d) Because two bulbs are in parallel, currents with same magnitude pass through them.
e) ………………………………………………………………………
………………………………………………………………………

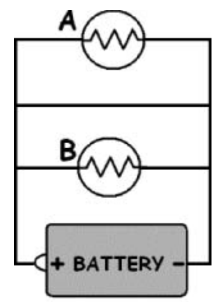

Figure 13

12.3. Are you sure about your answers given to the previous two questions?
a) Sure.
b) Not sure.

Answer Key

1.1 B	3.1 A	5.1 B	7.1 A	9.1 B	11.1 B
1.2 C	3.2 B	5.2 D	7.2 C	9.2 C	11.2 A
1.3 A	3.3 A	5.3 A	7.3 A	9.3 A	11.3 A
2.1 B	4.1 A	6.1 B	8.1 A	10.1 B	12.1 C
2.2 B	4.2 B	6.2 B	8.2 A	10.2 D	12.2 A
2.3 A	4.3 A	6.3 A	8.3 A	10.3 A	12.3 A