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Abstract

The purpose of this study is to develop a test to assess students' level of counterintuitiveness in basic electric circuits. Data from four samples were gathered and used to develop and validate the counterintuitive basic electric circuit test (CBECT). The initial version of the CBECT was administered to the first sample and data collected from this sample were used for the pilot study. The aim of the data collected from the second sample was to comb out the items that were not counterintuitive. The data collected from the third sample were used for concurrent validity issues while data from the fourth sample was used for the test-retest reliability analysis. Finally, 26 items that can be used to determine counterintuitive cases in basic electric circuits at the high school level were constructed.

Keywords: basic electric circuits, counterintuitive physics, test development

1. Introduction

1.1. Counterintuitiveness

The main goal of physics education research is to determine how to assist students in learning physics at any level. This starts by determining at every level the difficulties that students have with physics concepts. If we are able to understand why the students have these difficulties, we may find a way to overcome those difficulties and refine the student's understanding further.

In education research a lot of work has already been done on determining the concepts that students have difficulty with. Soeharto *et al* (2019) gives a recent overview.

Novice students start their education with intuitive physics knowledge. diSessa (1993) describes the structure of this intuitive knowledge elaborately. Chi and Slotta (1993) write that 'Intuitive knowledge is primitive in the sense that it often requires no explanation and provides the basis for higher level reasoning about physical processes and that it is not a highly organized and coherent theoretical view of the world, in which physics novices refer to their own misconceived principles about the underlying structure of the physical world.'

Chi and Slotta asserted that 'retrieval of intuitive knowledge is driven largely by surface

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features (context)' and Upal (2010) confirms that contexts (besides inherent difficulties in concepts) also play a role in allowing students to make sense of (counterintuitive) concepts.

Russell and Gobet (2013) confirm Upal's (2010) summary that there are two main camps: the concept view (putting emphasis on the concepts themselves as the source of counterintuitiveness) and the context view (putting emphasis on the information that preceded counterintuitiveness). We combine both views into one and assume that there are multiple aspects to counterintuitiveness. Various aspects may lead students to have difficulties in applying certain physics concepts both intuitively and correctly in certain contexts. Such applications will be considered suitable for the Counterintuitive Basic Electric Circuits Test (CBECT).

1.2. Concept inventories

After the emergence of the Force Concept Inventory (Hestenes *et al* 1992), which was the first concept inventory to be developed, many other concept inventories have been developed. A limited overview is given in Libarkin (2008) and more recently by Soeharto *et al* (2019).

Various methods have been used to develop such tests (Lindell *et al* 2007) where tests sometimes focus on different constructs (e.g. threshold concepts (Scott *et al* 2012)). Many such tests are still being developed (e.g. Hofer *et al* 2017).

Most of these tests assess students' basic conceptual knowledge by using problems that are both intuitive and counterintuitive for students of a certain level. The results of such assessments may be used to diagnose students' pre-instruction conceptions and to develop a 'treatment' (e.g. Osman 2017).

The results may be used to help students discover inadequacies in their own thinking, to motivate and stimulate their intellectual development. It may also be used to assess educational material designed to improve basic conceptual knowledge and diminish the number of students having or developing misconceptions on the subject.

The majority of these tests have been developed to evaluate conceptual understanding of novice college students (Libarkin 2008). To assess advanced students, experts or teachers such conceptual tests are almost non-existent. Once students have mastered the basic concepts students are mostly tested on their problem solving skills only (locally developed exams) and not on conceptual understanding. Such tests to assess students' problem solving skills have been created by individual teachers for many levels of expertise. However, a conceptual test made up of counterintuitive problems to diagnose students' conceptions at such expert levels is missing.

Singh (2002) showed that it is possible to create counterintuitive problems even for the professor level of expertise. To create a conceptual test for advanced students one should be able to create a consistent set of counterintuitive problems that can be validated in various settings.

Once such a test would become available it could help in developing educational materials to assist students in attaining the expert level. Students that specialize in the subject and teachers that teach it may be trained better with such materials. The test may also prove useful in applications where an expert ability in conceptual understanding is needed. Just as many concept inventories (Madsen *et al* 2017) CBECT can be given at the beginning of a course (pre-test) to gain a sense of students' prior intuitions, and again at the end of the course (post-test) to gauge changes in their intuitions.

This research has focused on developing such a test for the subject of electricity.

2. Theory

Over the years, many conceptual difficulties have been established for the subject of electricity (for a recent overview see for example Frache *et al* 2019 and Mbonyiryivuze *et al* 2019).

There has also been various research in trying to understand certain aspects of why students have these difficulties. For example, Leniz *et al* (2017) conclude that student explanations for dc resistive electricity problems fall into three main categories of reasoning: a relational form of reasoning, a linear causal reasoning, and a simple causal line of reasoning.

Stetzer *et al* (2013) stress that context plays a role in student understanding as well. This is a reason for us to develop a test in which the questions contain as little context as possible.

Level of expertise is another aspect that matters. Beh and Tong (2006), and Stetzer *et al* (2013) show that students' difficulties in understanding are very persistent and still exist in higher level top students. However, we have to be aware that experts may think quite differently (Stocklmayer and Treagust 1996).

As Libarkin (2008) stated, many tests have been created for novice students. This is also the case for the subject of electricity. The most notable examples of conceptual tests based on novice students' difficulties in electricity are the Determining and Interpreting Resistive Electric Circuit Concepts Test (DIRECT) (Engelhardt 1997, Engelhardt and Beichner 2004) and the ECI-test (Simoni *et al* 2004), but there are many more including some very recent ones (e.g. Maloney *et al* 2001, Pesman and Eryılmaz 2010, John 2017). Mostly, these tests make use of both intuitive and counterintuitive problems.

By counterintuitive we mean a lack of conformity with ordinary usage (Rudner 1950) which comes down to a violation of previously held knowledge (Russell and Gobet 2013). Russell and Gobet elaborate on this by saying that 'counterintuitive' is a subjective assessment of a single event (experienced directly or indirectly), where the evaluator has judged that category A is applicable—yet in that instance at least one of the properties of category A are incompatible with previously known exemplars of category A (experienced directly or indirectly)—but the evaluator chooses to continue applying category A in its previously known form.' The various properties of a category they are talking about could contain the aspects we have discussed above like reasoning, context, level of expertise, etc.

To develop a counterintuitive test for higher level students of the subject of electricity we will use counterintuitive physics questions. Campanario (1998) stated various demands on counterintuitive questions: '(a) their solutions yield results that challenge students' expectations, (b) they are worded in such a manner that students obtain a wrong solution by making some standard mistakes, (c) problems with counterintuitive solutions force students to think before rushing ahead into calculations, (d) students become aware of discrepancies between their existing ideas and the solution they find for the problem, and (e) counterintuitive solutions challenge some conceptual errors that are common among students'. Based on these features, Everett and Pennathur (2007) described a design process for developing counterintuitive questions.

To be able to state the above general demands on counterintuitive questions Campanario (1998) had collected many of such questions for a variety of fields in physics. Other examples may be found in Hunt (2007). Electricity-specific examples can be found in the most used conceptual tests mentioned earlier above (Engelhardt 1997, Engelhardt and Beichner 2004, Simoni *et al* 2004, Maloney *et al* 2001, Peşman and Eryılmaz 2010, John 2017).

Some research on how to use counterintuitive physics questions and their effect on student achievement has been performed as well. One of the earliest uses of such questions (Gordon 1991) says such questions can be used to encourage mathematical thinking. They can certainly be used to cause counterintuitive reactions in students (Koumaras *et al* 1997). Campanario (1998) suggested using counterintuitive problems to promote discussion in the classroom by giving the students both the apparent and the real answer. Maylone's (2000) approach elaborates on this by using counterintuitive problems to cause momentary confusion, provoking discussion, and finally guiding the students to understanding. Everett and Pennathur (2007) stated that counterintuitive questions can create learning moments by the sense of surprise and excitement they cause in students. Most recent research shows that the use of counterintuitive problems can engage students while meeting objectives set beforehand (Kumar and Dunn 2018).

There have also been found several constraints in implementing the use of counterintuitive problems. They seem to work best on minimally counterintuitive concepts (Hornbeck and Barrett 2013). Prior knowledge should be activated to be able to refute the underlying preconception (Alvermann and Hague 1989). And students should be provided with a categorical framework to help them overcome the problems stemming from incorrect prior knowledge (Ohst *et al* 2014). Even though we reflect on the use of counterintuitive problems we focus on developing a valid test consisting of such problems and we will compare the results of the newly developed test with results of the DIRECT-test.

The goals of this study are therefore to:

- Develop a test to assess students' level of counterintuitiveness in basic electric circuits.
- Compare the results of this test to that of the DIRECT-test for high school students to validate the counterintuitive basic electricity test (CBECT).

3. Methodology

3.1. Participants

Convenient sampling procedure was employed to find participants of the study. As the author of the current study worked in high schools for 19 years, he used his connections to communicate with the teachers, subsequently found the samples and collected the data.

Data from four samples were gathered and used to develop and validate scores from the CBECT. We had to use different samples because it is difficult to use only one sample for many purposes. Besides, for triangulating data various groups are desired. The first sample composed of 52 high school students from several grades. The initial version of CBECT was administered to this sample and data collected from this sample were used for pilot study. Participants' ages were between16 and 18 and of which 27 were female and 25 were male; 18 were 10th grade, 14 were 11th grade, and 20 were 12th grade students; and their average physics exam score for the previous semester was 79 out of 100.

Data obtained from the second sample were used for content validity of the CBECT. The second version of CBECT was administered to 181 high school students. Students were from three Anatolian high schools in Turkey. More information regarding this type of school in Turkey can be found in the study of Balta *et al* (2016). Participants' ages were between16 and 18 and of which 98 were female and 83 were male; 46 were 10th grade, 63 were 11th grade, and 72 were 12th grade students; and their average physics exam score for the previous semester was 82 out of 100. In Turkey high school students have physics lessons from 9th up to the 12th grade. Each semester they have three exams, and the average of these exams is the students' end of semester score.

Along with the final version of the CBECT, the DIRECT were administered to a third sample composing of 42 high school students. These were all tenth grade students (25 female and 17 male) with an average of 74 physics exam score. The data collected were used for concurrent validity issue.

The fourth sample was used for reliability (test-retest analysis) of the CBECT. These were 35 students (19 female) all from 11th grade. Their end of year physics exam score was 86 out of 100. These were students from a private school who had covered electricity topics during the first semester.

Each participant read and voluntarily signed the written informed consent before taking the test. Ethical approval for the study was obtained from the ethics committee of schools at which we collect data.

3.2. Instruments

This study developed an instrument for counterintuitive basic electric circuits. Below, the *development of the test* section fully describes the construction of the CBECT. Besides, for concurrent validity issue we used the instrument DIRECT, developed by Engelhardt and Beichner (2004). The DIRECT test is a diagnostic instrument that has been designed to evaluate conceptual understanding of high school, college, and university students about DC electric circuits. The authors assessed the validity and reliability of DIRECT through the data they collected from 1135 students of which 681 were at the university level and 454 were at the high school level.

3.3. Data analysis and data collection

As this is a test construction study, data were obtained when each step of the development of test required a data set. Thus, data collection process took approximately one year (2018–2019 academic year). Each ready version of the CBECT was sent to teachers and they administered the test according to the specified rules stated at the top of the questions sheet.

The choices of CBECT were determined through expert review process. Fleiss' kappa (Fleiss and Cohen 1973), an extended version of Cohen's kappa to the case where the number of raters can be more than two, was used to find the inter-rater reliability between the raters.

We collected data from four different samples and a different analysis was carried out for each data set. For the data gathered for pilot study, we calculated difficulty level (p), discrimination index (D), and Point-Biserial Correlation Coefficient (r_{pb}) for each item. The major aim of the data collected from the second sample was to determine the counterintuitive problems. Percentages were calculated for each choice of CBECT item and items whose choices attracted more students than the correct one were determined as counterintuitive problems. For concurrent validity, we calculated the correlation between the CBECT and DIRECT (Engelhardt and Beichner 2004) from the data we collected from the third sample. For the test-retest analysis, we report on the results of the correlation between the scores gathered from the administration of the final version of the CBECT twice to the fourth sample of our study.

3.4. *Development of the test*

Items of CBECT were constructed using regular methods of scale construction (Adams and Wieman 2011, Aydın and Ubuz 2014, Benjamin *et al* 2017, Clark and Watson 1995). We started with determining the purpose and the content for the CBECT. Then, we composed an item pool for the candidates of CBECT. After that we went through expert review process and then we employed a pilot study. Finally, we conducted validity and reliability issues for the CBECT.

3.4.1. Purpose and the content. In the first stage, the purpose and the content of the test was determined. The purpose of the test was to build a counterintuitive test that would mainly elicit students' careless approach to physics problems. Test items were constructed to reflect the basic concepts in electric circuits such as potential difference, connection of resistances and batteries, and brightness of bulbs.

3.4.2. Creating items and response format. As a second step toward the construction of this scale, literature was searched primarily with the key terms 'counterintuitive problems/questions', and 'basic electric circuits'. Thus, approximately 20 pieces of research were closely reviewed and items with counterintuitive nature were considered for adoption. Questions having counterintuitive properties were determined from these sources, appropriate problems were reworded and added to CBECT. Care was taken not to alter the meaning.

A second source of CBECT items were the author's own collection of counterintuitive problems on various physics topics. After publishing the counterintuitive dynamic test (Balta and Eryılmaz 2017) the first author developed many counterintuitive problems during discussing the physics concepts with students. The author drafted questions that addressed the basic electric circuits and once he reached a certain amount he decided to validate them through regular test construction methods (Clark and Watson 1995). The items in the initial draft form of CBECT represented broader and more comprehensive than our target construct; that is, counterintuitive problems. This was done to drop weak, and unrelated items from the emerging test by scale development process.

The two general sources of CBECT questions resulted in 43 test items in a draft form. All these were simple questions about basic electric circuits that would provide an opportunity for students to understand easily. However, due to the counterintuitive nature of questions students were expected to be hunted by their intuitions. The sources of the CBECT items are given in table 1. These are the 34 items kept in test after the expert review process. Furthermore, questions were not taken from these sources as they are, instead, all of them were reworded according to the structure and aim of the CBECT.

A three-point multiple choice response format was used for CBECT, with students indicating whether the correct response is

Table 1. The sources of CBECT items.

Item #	Source
1, 2, 4, 5, 6, 7	Bal and Moğol (2010)
8, 9, 10, 11, 12	Engelhardt and Beichner (2004)
28	Saglam (2015)
34	Picciarelli *et al* (1991)
13	Aksoy (2010)
17, 18, 19, 20, 22	Şahan and Tekin (2015)
3, 12, 24, 28, 20	Randall (2015)
21	Suggested by an expert
14, 15, 16, 23, 24, 25, 26, 27, 29, 30, 31, 32, 33	Authors of this study

'increasing, decreasing, or does not change' most of the time. This type of choice system was used because it had been previously employed in Counterintuitive Dynamics Test (Balta and Eryılmaz 2017) with high success. In CBECT questions, instead of asking for example how much the brightness changed, we asked does the brightness increase, decrease, or stay the same. An example of a counterintuitive problem developed for this study is shown in figure 1 (10th item of CBECT).

3.4.3. Expert review. Expert review process was employed in the third stage of the development of CBECT. To determine the alternatives of the CBECT; to check the content relevance and wording; to remove, add, and reword the items, the test was sent to two academics who were experts in the field and six experienced high school teachers with the format shown in figure 2 (2nd item of CBECT). The reviewers were asked to supply real and apparent responses for each question along with their suggestions for the modification and removal of improper items (figure 3).

From the answers supplied by these experts, we constitute the choices of the CBECT items. While the real answers were same most of the time, the apparent answers diverged sufficiently and allowed us to constitute the other two choices.

We used Fleiss' kappa (Fleiss and Cohen 1973) to find the inter-rater reliability between raters. While the inter-rater reliability between raters was 0.94 for the real answers, that of apparent answers was 0.39. Relatively low inter-rater reliability for apparent answers was expected because it shows the variety in the responses to the apparent answers. This diversity was used to determine the other two alternatives of the questions.

All the items that had been developed were reviewed by the above experts. Depending on the suggestions, some items were removed, some ambiguous or unclear items were reworded, one new was added, the phrasing of some item stem texts was altered, some figures were improved, and some distractors were modified or changed. Depending on the suggestions by the experts, minor changes were made on eight items. For example, 17th item was suggested by one of the experts to be added to CBECT, one of the expert recommended to reword the stem of item 14 such that the points K and L in the item are clearly defined, and for several questions one of the experts suggested to clarify that the batteries do not have internal resistances. We generalized the last suggestion and added an explanation regarding the internal resistances of batteries, voltmeters, and ammeters at the beginning of the test. The 43 initial items (rough version of CBECT) were reduced to 34 items (initial version of CBECT) after expert views.

The removed nine items were determined to have no properties of counterintuitive problems (some of them were relatively difficult problems when compared to the rest of the items). In other words, these items were not appropriate to the structure of the counterintuitive problem. For example, the following item were selected to be removed from CBECT by experts because its apparent and real answers seem to be the same.

3.5. Pilot study

For the fourth stage of developing the CBECT we conducted a pilot study. Pilot studies play an important role in research (Lancaster *et al* 2004). One can use pilot study to pretest the instrument to eliminate inadequacies or ambiguity in the test.

A major reason for conducting a pilot study was to determine the improper items that would be excluded. Using the criteria in Lin Ding's paper (Ding and Beichner 2009) we identified the items having at least two undesired values.

How does the resistance between points X and Y change when the switch is closed?

A. Does not change
B. Decrease
C. *Increase*

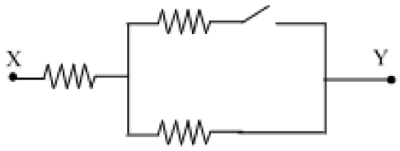

Figure 1. 10th item of CBECT.

The duration the bulb in Circuit 1 light up is t. How does the duration change when an identical battery is added as shown in circuits 2?

Real answer:

Apparent answer:

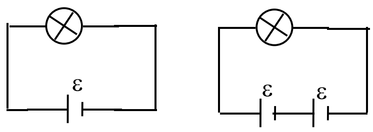

Figure 2. 2nd item of CBECT.

What is the relation between the brightness of the identical K and L bulbs in the circuit shown in the figure?

Real answer:

Apparent answer:

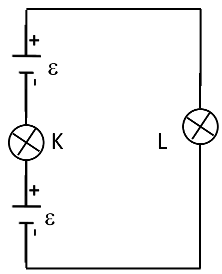

Figure 3. An example of improper item that removed from CBECT.

Item difficulty was taken into consideration for only easy questions because difficult questions stemmed from the counterintuitive nature of the items. It should not be forgotten that naturally difficult questions were removed as suggested by the experts.

As seen in table 2 five questions (2nd, 15th, 18th, 20th, and 29th) have inappropriate test statistics. Except the 2nd and the 29th we exclude all other improper items. The second item was rechecked, and, in terms of a typical question, no problems were found, and it was kept to represent the energy consumption concept in the CBECT. The 29th item was also kept because it has a nice counterintuitive nature.

One further reason in conducting a pilot study was to validate the choices of the CBECT items. In the pilot study, we add other as a fourth choice to each question to see if students have different responses other than suggested ones. Except 3, 4, 7, 8, 10, 14, 16, 30, 31, 32 and 33 items, some students supplied different responses for the other choice (at least one, at most four students supplied different responses for the other choice of some items). However, the only consistency was in the 1st and 16th questions. Where among 52

Table 2. Test statistics.

#	p	D	r_{pb}	#	p	D	r_{pb}
1	0.18	0.31	0.34	**18**	0.96	0.15	0.23
2	0.22	0.08	0.09	19	0.36	0.54	0.54
3	0.36	0.46	0.37	**20**	0.34	−0.15	−0.07
4	0.22	0.31	0.41	21	0.46	0.92	0.65
5	0.30	0.77	0.67	22	0.58	0.69	0.53
6	0.32	0.23	0.27	23	0.28	0.15	0.25
7	0.42	0.38	0.37	24	0.62	0.38	0.39
8	0.64	0.77	0.60	25	0.32	0.46	0.44
9	0.28	0.54	0.49	26	0.36	0.46	0.35
10	0.52	0.54	0.48	27	0.30	0.15	0.21
11	0.62	0.77	0.54	28	0.52	0.92	0.66
12	0.48	0.69	0.54	**29**	0.26	0.08	0.13
13	0.34	0.54	0.48	30	0.42	0.62	0.50
14	0.54	0.69	0.57	31	0.36	0.77	0.59
15	0.60	0.15	0.11	32	0.40	0.85	0.64
16	0.46	0.69	0.56	33	0.48	0.77	0.53
17	0.72	0.15	0.23	34	0.40	0.46	0.36

Note: p = difficulty index, D = discrimination index, r_{pb} = Point-biserial correlation

students three of them suggested increase twice as an alternative for the 1st, and in the 16th question four students suggested none of them as an alternative. However, these responses were relatively few when compared to the other marked alternatives. Thus, this analysis showed the validity of the choices suggested by the experts.

3.6. *Validating the test*

Validity issues were employed as a fifth stage in the development of the CBECT. The general aim of the pilot study was to eliminate improper items by conducting items statistics such as item difficulty and item discrimination. However, this section is devoted to the validity of CBECT and the counterintuitive nature of CBECT items. Yet, the choices of the CBECT suggested by the expert were validated through a pilot study process.

After the analyses done in the pilot study, three items were removed, and 31 counterintuitive electricity problems (second version of the CBECT) were used for the validity processes. These questions were administered to 181 students and analysis was done with the data collected from this sample.

Table 3. The concepts covered by CBECT.

Items	Concepts
1, 7, 9, 10, 12, 15, 17, 33	Power: brightness of lamps
2, 4, 24	Power: energy consumption
3, 21, 25	Current
5, 34	Voltmeter reading-Rheostat
6, 8, 13, 14, 22, 27, 30	Potential difference
11, 16, 31, 32	Resistance
18, 19, 20	Short circuit
23, 29	Current—connection of batteries
26, 28	Voltmeter reading

3.6.1. Content validity. Content validity refers to the extent to which the items on a test are fairly representative of the entire domain the test seeks to measure (Salkind 2010). Another way of saying this is that content validity concerns, primarily, the adequacy with which the test items adequately and representatively sample the content area to be measured (Balta and Eryilmaz 2020).

The concepts covered by the test and corresponding question numbers included on the test are given in table 3.

Table 4. Number of responses for the choices.

Choice	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q16	Q17
A	**36**	92	**47**	31	**57**	49	70	12	83	25	46	58	70	**80**	**36**	**67**
B	98	**36**	76	95	62	40	31	**124**	**49**	**112**	**56**	**82**	**38**	63	126	41
C	22	48	50	**53**	47	**57**	**77**	43	44	43	70	31	64	36	15	61
	Q19	Q21	Q22	Q23	Q24	Q25	Q26	Q27	Q28	Q29	Q30	Q31	Q32	Q33	Q34	
A	75	**86**	24	73	31	**49**	44	55	49	29	**39**	**76**	**87**	71	44	
B	**63**	49	41	**55**	**105**	87	**52**	**75**	67	**53**	49	61	29	**71**	50	
C	41	26	**106**	44	30	34	60	34	**57**	90	88	38	60	36	**76**	

Notes: items 15, 18 and 20 do not appear in the table because they were eliminated after pilot study. Grey colored choices are the correct answers.

Table 3 indicates that each sub area of basic electric circuits is well represented in the final version of the CBECT.

Expert judgments are commonly used as another way to establish content validity, in which experts assess the quality of each item, check the classification in a defined domain, and suggest necessary item revisions (Orion *et al* 1997). To follow test development steps (Kaltakci-Gurel 2021), expert views and related analysis were done in the 'expert review' section. Here we have focused on the elimination of the non-counterintuitive items to have the test to represent the content area being measured, that is, counterintuitive basic electric circuits.

As stated earlier there were three alternatives in CBECT items. When a question's correct choice unexpectedly attracted less students when compared to the other alternatives, those questions were determined to be counterintuitive. In other words, among all possible answer choices for questions, students selected counterintuitive choices more often than the correct answers. This finding can be seen from table 4. For example, for the 3rd item the correct answer is (A), however, while 47 (26%) students marked the choice (A), 76 (42%) and 50 (28%) students chose (B) and (C) choices, respectively (4% of the students did not respond this question). This question was determined to be counterintuitive because both incorrect answers attracted more students than the correct answer. We need to stress once more that the counterintuitive problems were primarily determined by the experts' views. The findings here complement the experts' views.

To visualize table 4, we generated bar graph in the figure 4, and it is used as a basis for the elimination of the non-counterintuitive items. In figure 4, the correct choices are shown with green and the other two alternatives are presented with orange color. We expected the real answer of counterintuitive problems, at least, must have attracted less students than any of the two other choices. Thus, items in which the correct response concerned more students were eliminated. In other words, incorrect choices were selected by the students most frequently.

As indicated by the height of the bars, in items 8, 22, 27, 31 and 34 in figure 4, students chose the correct answer more than the other two alternatives. Since this is not an acceptable result for the counterintuitive problems, we removed these items from the test. Thus, initial 43 item draft version of the CBECT was reduced to a test of 26 items (Final version of CBECT).

A low score on the CBECT indicates high counterintuitiveness. The full test is presented at the end of the paper as an appendix.

3.6.2. Concurrent validity. One evidence for the CBECT was established by conducting concurrent validity analysis. Concurrent validity basically focuses on the extent to which scores on a new scale is related to scores from an already existing, well-established scale administered at the same time.

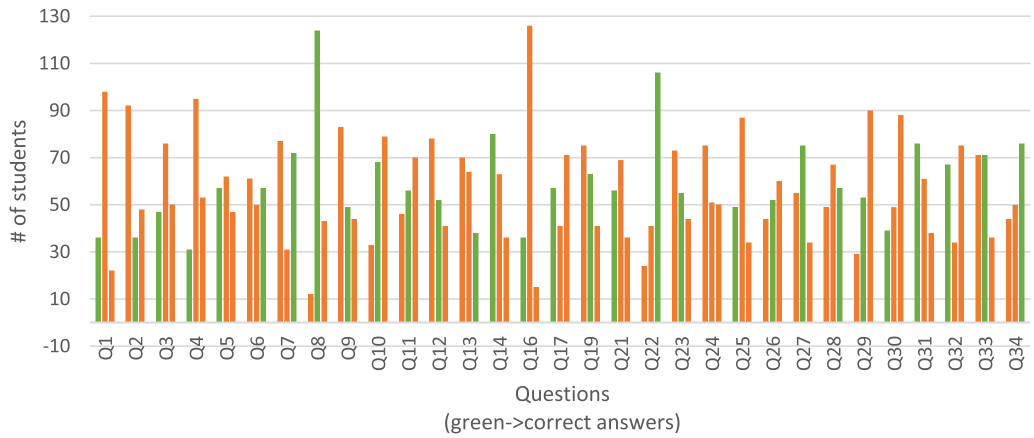

Figure 4. Visualizing the counterintuitive nature of CBECT items.

For concurrent validity we report on the results of the correlation of the final version of CBECT and DIRECT (Engelhardt and Beichner 2004) for a set of 42 students who took both tests. Using the correlation classification; no or very low: r = 0–0.25; low: r = 0.26–0.40; moderate: r = 0.41–0.69; high: r = 0.70–0.89; very high: r = 0.90–1.0 (Munro 2005), the correlations between the CBECT and DIRECT were high (r = 0.74) and significant ($p < 0.05$).

3.7. Reliability

As the final step in constructing the test we assessed the reliability of the CBECT. Reliability is a requirement to validity because if you are not measuring something correctly and constantly, you do not see if your conclusions are valid. Reliability is an index that estimates the extent to which the assessment tool yields consistent scores. The reliability issues related to CBECT were conducted through internal consistency, content sampling error, and the test-retest method.

The most common degree of internal consistency used for a multiple choice test is the Kuder-Richardson's KR-20 (0.84) reliability coefficient and Ferguson's delta (0.96) discriminatory power. When compared to the desired values specified by Ding and Beichner (2009), both values are standing as highly appropriate whole-test statistics.

The chief source of measurement error is due to the sampling of content (Reynolds, Livingston, and Willson). To avoid content sampling error, the term used to label the error that results from selecting test items that inadequately cover the content area that the test is supposed to evaluate, 26 items were used to represent the content of basic electric circuits. Namely, each sub area of basic electric circuits was exemplified, in average, by 3.8 items (see table 3).

For test-retest we report on the results of the correlation between the scores we gathered form the bimonthly administration of the CBECT for a set of 35 students who took both tests. We calculated a high (r = 0.81) and significant (p = 0.00) correlation between the two scores.

4. Discussion

Having valid and reliable tests to assess the success of various instructional efforts is as important as developing students' ability to learn science. In this research, a test that can measure counterintuitivity in electricity was thoroughly established and validated. Carrying out important steps of instrument development overall provide sufficient evidence that the CBECT at this initial stage can be a good basis for measuring students' careless approaches to electricity concepts. A review of some of the available electricity tests was done to identify the initial questions of CBECT, and thus the CBECT items were designed to mirror the basic electricity concepts such as resistance, power, and voltage change. Content experts were involved during the item development stage in reviewing the items, and students' answers

Which bulb is brighter?

A. The 100 W bulb
B. The 60 W bulb
C. Their brightnesses are the same

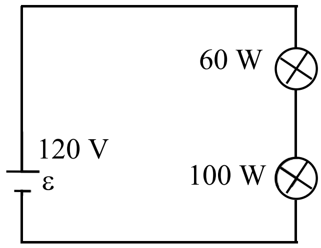

Figure 5. 19th item of CBECT.

provided evidence that the CBECT items were clear and elicited the counterintuitive outcomes. Moreover, the quantitative evidence showed that the CBECT yielded a high inter-rater agreement and acceptable reliability coefficient.

The procedures described in this study to develop and validate the CBECT items are largely in line with the guidelines suggested for the preparation of selected-response and other performance tests (Adams and Wieman 2011, Aydın and Ubuz 2014, Benjamin *et al* 2017). Further validation research that involves a larger and diverse group of participants should be conducted to additionally support the quantitative data set and associated measures.

For a difficult question it is also possible that the correct choice attracts less students. What differentiates a counterintuitive question from a difficult question is that it is easy in nature, and it does not include much mathematics. Its difficulty arises because of students' careless approach and without in depth analysis of the question (Campanario 1998). Students are careless in these questions because they appear so easy that students are very confident in their immediate answers. The significant role of counterintuitive questions is that they force students to supply their answers without conducting sufficient reasoning. For example, in question 19 (figure 5) students are asked to determine the brighter lamp. Since the brightness is proportional to the power and 100 W is more than 60 W students do not go into details and immediately choose the choice (B) as the correct answer.

The difficulties aroused in the simple CBTable ECT questions are not surprising as students are often hunted by their intuitions and careless approach. In other words, the questions are naturally easy but careless approach of the students led to bad results. Shorty, it can be said that the difficulty roused because of the counterintuitive properties of the CBECT items.

Our wish is that the CBECT can be used both for instructional and research purposes. First, CBECT items can be used to start discussions in the class because counterintuitive questions yield solutions away from students' expectations (Balta and Asikainen 2019, Balta *et al* 2019). Second, CBECT can be administered along with conceptual tests, such as Conceptual Survey of Electricity and Magnetism (Maloney *et al* 2001), and Students' Understanding of Direct Current Resistive Electrical Circuits (Engelhardt and Beichner 2004). Students' understanding of direct current resistive electrical circuits, in electricity to reveal the relationship between counterintuitiveness and conceptual understanding in electricity topics. Third, CBECT can enable researchers to develop better learning materials related to counterintuitive concepts in electricity.

5. Conclusion

The CBECT is a comprehensive test of students' knowledge bases in basic electricity. It is a combination of a test of counterintuitivity and knowledge because without knowledge counterintuitivity alone is impossible. Our results indicate that the CBECT is reliable and valid, and it can be used to provide insight into students' understanding of basic electric circuits.

Information about the nature of students' counterintuitive concepts about topics in electricity is not well documented yet. Having said that, the CBECT can provide an estimate of students' difficulties in learning some of the important ideas in basic electricity. We hope, along with CIDT (Balta and Eryılmaz 2017) the CBECT can begin to provide some guidance for research directions into students' counterintuitive ideas in this area. To the best of our knowledge, an exclusively counterintuitive electricity test has not been published yet.

Based on the results presented here we conclude that many students are easily hunted by their intuitions and thus most of the times supply incorrect answers because of careless approach to CBECT items. One very robust result from this study is that the performance of students on this test is much poorer than any instructor would expect.

Finally, in this study we have developed a test that we hope will inspire others to develop new and improved version of CBECT.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

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Conflict of interest

We have no conflicts of interest to disclose.

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Appendix. Counterintuitive basic electric circuits test

Dear students,

In this test, there are questions about electric circuits. These questions will be used for a scientific study. Please answer all questions. By participating in this test, you support scientific research.

Thank you for your contributions.

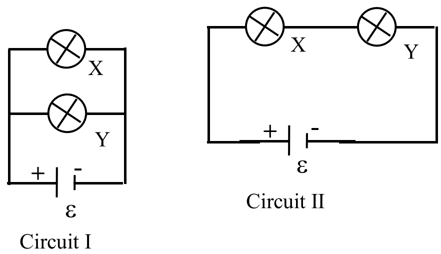
NOTE1: The internal resistances of all batteries and ammeters used in this test are assumed to be zero, and that of voltmeters are very large.

NOTE2: If you have a different answer, please write it to the other option.

NOTE3: In this test, identical bulbs mean they are similar in every detail such as the resistance and power.

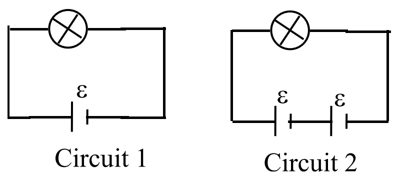
For reader to find the correspondence between the original 34 question numbers and the final set of question numbers, just after each question number we placed the question number (in the parenthesis) of the original test.

1. (1) Identical bulbs X and Y are connected in parallel in Circuit 1. How does the brightness of bulbs change when they are connected in series as shown in circuits 2?



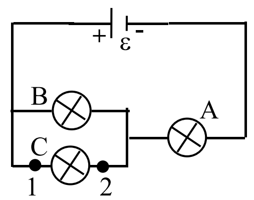
A. Decrease to one forth
B. Decrease to one half
C. Does not change

2. (2) The duration the bulb in Circuit 1 light up is t. How does the duration change when an identical battery is added as shown in circuits 2?



A. Doubles
B. Halves
C. Does not change

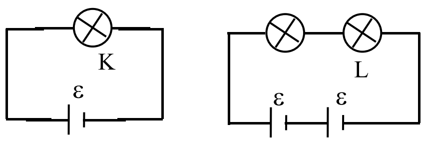
3. (3) Bulbs A, B, and C in figure are identical, and all are glowing.



Suppose a wire is connected between points 1 and 2. What happens to bulb B?

A. Goes out
B. Get brighter
C. Get dimmer

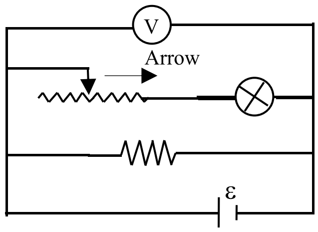
4. (4) The bulbs and the batteries in Circuit 1 and 2 are identical. In the electric circuit 1, the light emitting time of the lamp is t. If the identical lamp is added and circuit 2 is created, how does the lamp's light emitting time change?



Circuit 1 Circuit 2

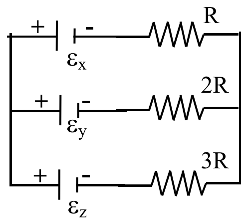
A. Doubles
B. Halves
C. Does not change

5. (5) How does the reading of the voltmeter change when the slider on the rheostat is pulled in the direction of the arrow?



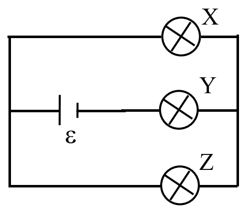
A. Does not change
B. Decrease
C. Increases

6. (6) In the circuits shown below resistances R, 2R and 3R are connected across batteries. If the current through each of the resistance is zero, what is the relation between the voltages of the batteries?



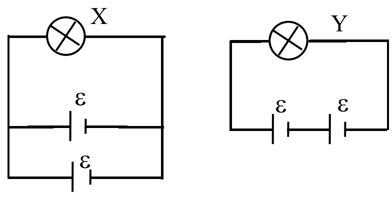
A. $3\varepsilon_x = 2\varepsilon_y = \varepsilon_z$
B. $\varepsilon_z > \varepsilon_y > \varepsilon_x$
C. $\varepsilon_x = \varepsilon_y = \varepsilon_z$

7. (7) What is the relation between the brightness of the identical bulbs in the circuit shown below?



A. X = Y = Z
B. Y < X = Z
C. Y > X = Z

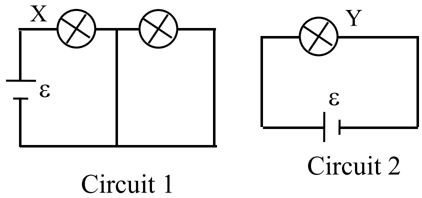
8. (9) What is the relation between the brightness of the identical bulbs X and Y in circuits 1 and 2?



Circuit 1 Circuit 2

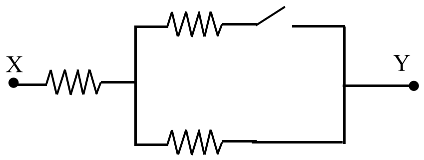
A. Y is two times brighter
B. Y is four times brighter
C. They have equal brightness

9. (10) What is the relation between the brightness of the identical bulbs X and Y in circuits 1 and 2?



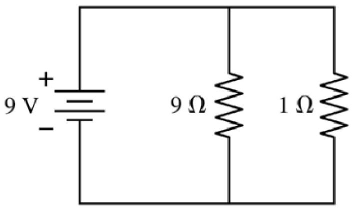
A. X > Y
B. X = Y
C. X < Y

10. (11) How does the resistance between points X and Y change when the switch is closed?



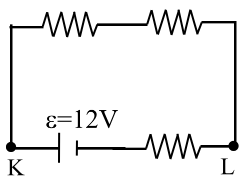
A. Does not change
B. Decreases
C. Increases

11. (12) Which resistor dissipates more power?



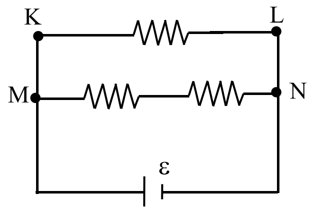
A. The 9 Ω resistor
B. The 1 Ω resistor
C. They dissipate the same power.

12. (13) In the circuit shown below the resistances are identical. What is the potential difference between point K and L?



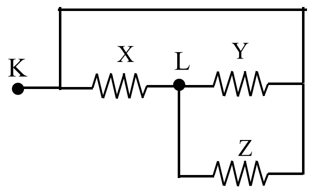
A. 4V
B. 8V
C. 12V

13. (14) The resistances in the electric circuit are identical. What is the relationship between the voltages between KL and MN?



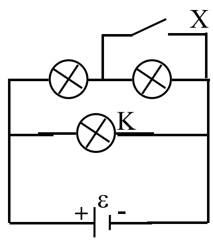
A. MN > KL
B. MN < KL
C. MN = KL

14. (16) Which resistors between K and L are connected in parallel in the electric circuit?



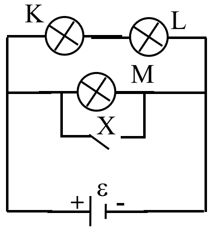
A. X, Y and Z
B. Y and Z
C. None of them

15. (17) How does the brightness of the K lamp change when the X switch is turned on in this electric circuit?



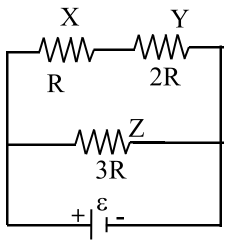
A. Does not change
B. Decreases
C. Increases

16. (19) Which of the K, L and M lamps turn off when the switch is closed in the electric circuit shown?



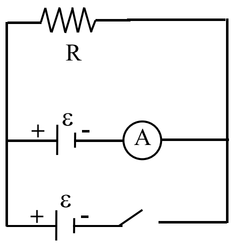
A. All
B. Only M
C. K and L

17. (21) What is the relationship between the currents passing through the X, Y, Z resistors in the electric circuit shown?



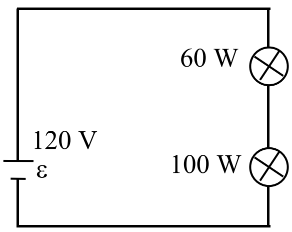
A. X = Y = Z
B. X > Y > Z
C. X = Y > Z

18. (23) How does the ammeter's value change if the switch is closed in the electric circuit?



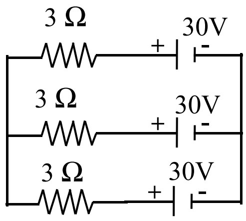
A. Does not change
B. Decreases
C. Increases

19. (24) Which bulb is brighter?



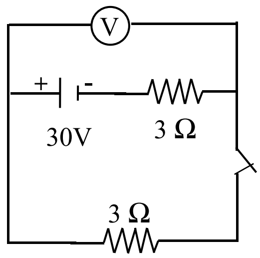
A. The 100 W bulb
B. The 60 W bulb
C. Their brightnesses are the same.

20. (25) In this electric circuit, the voltage of each generator is 30 V and each resistance is 3 Ω. How many amperes are flowing through each resistor?



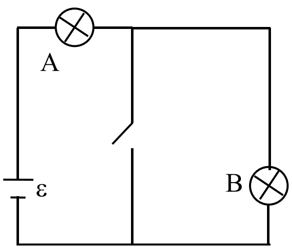
A. 0A
B. 10A
C. 15A

21. (26) The switch in the electric circuit is initially closed. What is the value of the voltmeter when the switch is opened?



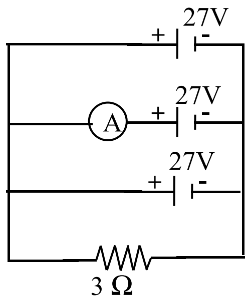
A. 0V
B. 10V
C. 30V

22. (28) The lightbulbs are identical. Initially both bulbs are glowing. What happens when the switch is closed?



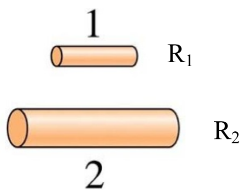
A. A gets brighter; B stays the same
B. Both get dimmer
C. A gets brighter; B goes out

23. (29) How many amperes does the ammeter show in this electric circuit?



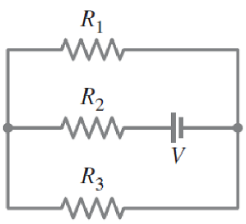
A. 0A
B. 3A
C. 9A

24. (30) Wire 2 is twice the length and twice the diameter of wire 1. What is the ratio R_2/R_1 of their resistances?



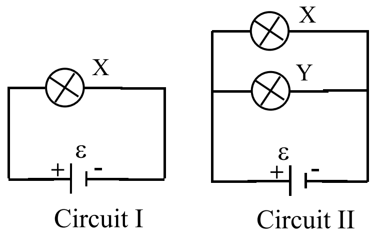
A. 1/2
B. 2
C. 4

25. (32) Which resistances are parallel in the electric circuit?



A. R_1 and R_3
B. R_1 and R_2
C. R_1, R_2, and R_3

26. (33) The Y lamp identical to the lamp X in circuit I is connected in parallel as shown in circuit II. How does the brightness of the X lamp change accordingly?



A. Decreases
B. Does not change
C. Increase

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