Using certainty response index to differentiate lack of knowledge and misconception about basic electrical concepts

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Abstract. The objective of this study was to examine pre-service physics teacher understanding related to physics content knowledge by investigating knowledge of the Basic Electrical Concepts (BECs) test and the student’s certainty in their physics knowledge. Data was collected from 57 preservice physics teachers with the BECs test and Certainty of Response Index (CRI) values. The BECs test with CRI was administered to pre-service physics students following accomplishment of a unit of study on electricity and simple circuit. The results of diagnostic test were classified into correct and incorrect answers, and CRI values were classified into certain and uncertain. High CRI value in incorrect answer on the BECs test implied that 26% preservice physics teachers had misconceptions about basic electrical concepts. Low CRI value in correct or incorrect answer on the BECs test indicated there were 53% preservice physics teachers providing the answer by guessing; due to no understanding or confusion about their understanding. There were 21% preservice physics teachers providing the answer correctly on the diagnostic test with high CRI value. It was concluded that the majority of preservice physics teachers (79%) were either guessing or had misconceptions about every item related to the electric basic concepts.

1. Introduction
A growing body of research in science education has proved that many students come to science class with intuitive concepts in understanding of nature which they perceive from their daily experience [1]. A number of term was coined to explain students’ understanding that differ from scientists’ conceptions such as children’s ideas [2], alternative conceptions [3], naïve beliefs [4], mental models [5], misconceptions [6] and so forth. In this present study, the word “misconceptions” is used for those conceptions that contradict the scientifically accepted concepts due to the most common usage in the literature [6].

Throughout diagnostic process, students having misconceptions were known [7]. An effective diagnostic instrument has been created and exercised to evaluate students’ misconceptions on physics concepts namely interviews, open-ended test and Multiple-Choice Test (MCT). Regardless of some advantages and disadvantages over the others, the MCT are reported to be the ones commonly used in research to identify misconceptions on various physical areas such as kinematics (TUG-K test), force and motion (FCI test), DC circuit (DIRECT test), waves (WCI test), electricity and magnetism (CSEM test). A study conducted by Gurel, at.al [8] reported that one of advantage of multiple-choice tests are the provision of valuable diagnostic information and feasible substitutes to interviews and open-ended
tests in determining the predominance of misconceptions across a population. However, as said by Chang, at.al. [9], there are certain shortcomings of MCT such as:

- The lucky guessing contributes to the error variance and degrades the reliability of the test;
- The deep insight into students’ conceptual understanding is not depicted by students’ opted choices; and
- Students have to select every answer from amongst a very limited list of option. With the intention of lessening its’ shortcoming, it was extended the ordinary multiple-choice test with two, three, or four tiers multiple-choice test employed to diagnose students’ conceptions [8].

The two-tier test multiple-choice test was developed and administered to assess student’s misconception about, for example, biology [10], chemistry [11] and physics [12]. Although the use of two-tier diagnostic test was practised in many studies since Treagust’s seminal work on development of two-tier test was published [13], large number of researchers reviewed the effectiveness of two-tier test. Many scholars argued that one of disadvantages of MCT as a diagnostics instrument was to differentiate misconceptions with a lack of knowledge. However, the MCT can be maximized to reveal the student’s misconceptions and student’s a lack of knowledge, when the CRI is used in conjunction with the answer to a question [14,15]. Therefore, the primary intention of this study was to develop and validate a research-based MCT can be used in distinguishing students who have misconceptions and a lack of knowledge about the electric basic concepts.

To minimize the limitations of two-tier tests in in differentiating lack of knowledge from misconception, mistake, or scientific knowledge [8], the MCT added with a Certainty of Response Index (CRI) which is associated with every answer on the diagnostic test [14]. The CRI equips a measure of the degree of certainty in student’s ability to select and utilize his knowledge, concepts or law to attain the wanted answer.

In regard to the degree of certainty or confidence in content knowledge, a number of studies was carried out the correlation in student’s confidence, overconfidence and under-confidence on science concepts. For instance, Lundeberg [16] evaluated undergraduate students’ degree of confidence in their ability to respond test questions. The results of Ludenberg’s study pointed out that after answering the exam tests, students were overconfident that their answer to every question was correct after answering each item. However, both men and women were overconfident in their incorrect answers. Two hundred and ninety-one students participated in this study which acknowledged that they were not strong enough in science content knowledge, but they were certain that the content knowledge was understood [16].

Recently, there has been a growing interest in evaluating students’ conceptions by the use of CRI [14]. For instance, Odom and Barrow [15] developed and validated two-tier diagnostics test combined with the CRI to examine students’ understanding about knowledge of diffusion and osmosis and the student’s certainty in their content knowledge. Hasan, at.al [14] added CRI to diagnostic test developed by Halloun and Hestenes [17]. Results of these studies stated that the CRI was a simple and an effective means for distinguishing a lack of knowledge from misconceptions.

Electricity is considered one of the basic areas in physics taught in many schools from elementary school to college and university. But many students have conceptions related to it and they develop beliefs and imagery unlike from scientific ones [18]. The common misconceptions about electricity in an extensive literature are the succeeding:

- The sink model [19];
- The attenuation model [19];
- The shared current model [20];
- The sequential model [19];
- The clashing current model [19];
- The empirical rule model [19];
- The short circuit misconception [19];
- The battery as constant current source [20];
The parallel circuit misconceptions [19];
- Local reasoning [19].

Although, the concepts of electricity has been investigated by the use of multiple-choice tests (MCT), two-tier multiple-choice tests, three-tier multiple-choice tests, or four-tier multiple-choice tests, the basic electrical concepts (BECs) has been less investigated by using multiple choice tests combined with certainty of response index (CRI) values. Therefore, this study is focus on investigating students’ misconceptions on BECs diagnostics test by the use of MCT with CRI.

2. Methods

Participants involved in this study were 57 pre-service physics teachers (the ages range 20–21 year old) who studied physics. We have designed a 34-item Multiple Choice Test (MCT) that was adopted from Ambarwati’s diagnostics test [21] and Engelhardt’s diagnostics test [22]. Following field testing, the number of items in the test reduced 29 items. The 29-item MCT combined with the CRI called as the BECs diagnostics test was administered to the 57 students after they had completed their study of electricity as part of topics in introductory to physics subject.

The BECs is a validated two-tier diagnostic test intended to identify pre-service physics teachers who have lack of knowledge and misconception about basic electrical concepts. Every item on the BECs has two tiers; the first tier consists of a content question with five alternative choices and the second tier provides the CRI value from 0 to 5 (Figure 1).

![Figure 1](image.png)

**Figure 1.** Direction for answering the BECs diagnostic test and for entering a CRI value.

The question in Figure 1 are adopted from DIRECT version 1.1 [22]. For every question, students are asked to circle the selected answer and write a CRI value in the box presented below the answers.

The matrix presented in Table 1 is employed to indicate pre-service physics teachers who get lack of knowledge or misconception on the BECs. Matrix of CRI (Certainty of Response Index) is utilized as a quantity of the degree of certainty with which the subject of research answer every question. The CRI index is based on the six-point scale (0-5) in which 0 designates no knowledge (complete guess) whereas 5 indicates entirely certainty in knowledge of the principles and laws needed to the selected answer (14).

| Table 1. Decision matrix for every student (a group of students) and for a given question determined by composition of correct or wrong answer and high CRI or low CRI. |
|-----------------------------------------------|
| High CRI (> 2.5) | Low CRI (< 2.5) |
| Correct answer | Correct answer and high (mean) CRI (Wanted knowledge of concepts) | Correct answer and low (mean) CRI (Lack of knowledge or guess) |
| Incorrect answer | Incorrect answer and high (mean) CRI (Misconceptions) | Incorrect answer and low (mean) CRI (Lack of knowledge or guess) |
As shown on Table 1, there are four probable combinations of the answer, that is, (a) correct answer with the CRI high; (b) correct answer with the CRI low; (c) incorrect answer with the CRI high; (d) incorrect answer with the CRI low. For example, a student choose the correct answer with a high CRI, she/he categorizes as an individual who has the wanted knowledge of concepts. Conversely, if the incorrect answer with a high CRI is for a given question, it is indicated the presence of misconceptions. A correct answer with the low CRI and an incorrect answer with the low CRI point to a lack of knowledge or guess. Regarding a group of students (a class) follows the similar way as depicted above for an individual student excluding that the mean values of the CRI are used. In the current study, the criteria of differentiating students who have misconception and lack of knowledge based on Table 1.

The BEC diagnostic test was administered to 57 pre-service physics teachers immediately after they learned basic electrical concepts topics such as current, voltage, resistance, electric charge, electric potential, direct current electrical circuit. Student answered 29 multiple choice questions for 45 minutes.

Data collected from students were tabularized, and each of student’s answer was marked 1 if it is correct or 0 if wrong and relating to (from 0 to 5). A fraction of total number of students who gave correct answers was calculated by the total number of students answered a question correctly that was divided by the total number student provided the number of correct answer [14]. For a wrong answer, the total of CRI was calculated by adding the CRI of entirely student who had given a wrong answer for the question.

Prior to the BECs diagnostics test administered to 57 students, the field-testing was conducted to improve the validity of instrument particularly its usability and clarity. As Creswell [7] has argued, pilot testing of an instrument is important in establishing content validity and in improving the questions, format, and scales. Content validity was established by presenting the test and objectives to independent panel of expert to confirm the BECs cover the appropriate material. The panel consisted of one experienced physics teachers and one senior physics lectures as ratters. The panel matched every item of the BECs with objectives. This process generated 84% agreement between two ratters in terms of matching objectives with items. Based on item analysis, the test items were modified further and the number of items in the BECs diagnostic test became 29 items (Table 2). There were five items excluded from a pool items, namely, Q3, Q4, Q13, Q14 and Q18.

Table 2. Results for the BECs for each question and statistical results for the BECs diagnostics test.

| Question | Before try-out | After try-out | Fraction selecting letter choice | Point Biseral Correlation | Discrimination Index | Difficulty Index |
|----------|----------------|---------------|----------------------------------|--------------------------|----------------------|------------------|
| Q1       | Q1             | 0.18          | 0.09                             | 0.48                     | 0.07                 | 0.18             |
| Q2       | Q2             | 0.05          | 0.02                             | 0.68                     | 0.21                 | 0.18             |
| Q5       | Q3             | 0.07          | 0.45                             | 0.18                     | 0.18                 | 0.12             |
| Q6       | Q4             | 0.18          | 0.31                             | 0.23                     | 0.19                 | 0.09             |
| Q7       | Q5             | 0.09          | 0.04                             | 0.71                     | 0.12                 | 0.04             |
| Q8       | Q6             | 0.09          | 0.11                             | 0.16                     | 0.48                 | 0.16             |
| Q9       | Q7             | 0.61          | 0.04                             | 0.21                     | 0.02                 | 0.12             |
| Q10      | Q8             | 0.18          | 0.26                             | 0.23                     | 0.08                 | 0.25             |
| Q11      | Q9             | 0.35          | 0.4                              | 0.07                     | 0.11                 | 0.07             |
| Q12      | Q10            | 0.23          | 0.21                             | 0.23                     | 0.12                 | 0.21             |
| Q15      | Q11            | 0.21          | 0.33                             | 0.25                     | 0.19                 | 0.02             |
| Q16      | Q12            | 0.32          | 0.18                             | 0.30                     | 0.11                 | 0.09             |
| Q17      | Q13            | 0.18          | 0.42                             | 0.19                     | 0.16                 | 0.05             |
| Q19      | Q14            | 0.21          | 0.16                             | 0.48                     | 0.11                 | 0.04             |
| Q20      | Q15            | 0.22          | 0.16                             | 0.14                     | 0.18                 | 0.30             |
| Q21      | Q16            | 0.33          | 0.12                             | 0.21                     | 0.3                  | 0.04             |
| Q22      | Q17            | 0.16          | 0.21                             | 0.31                     | 0.07                 | 0.25             |
Table 2. Cont

|   | Q23  | Q24  | Q25  | Q26  | Q27  | Q28  | Q29  | Q30  | Q31  | Q32  | Q33  | Q34  |
|---|------|------|------|------|------|------|------|------|------|------|------|------|
|   | 0.12 | 0.42 | 0.14 | 0.21 | 0.05 | 0.23 | 0.11 | 0.09 | 0.09 | 0.11 | 0.05 | 0.12 |
|   | 0.05 | 0.33 | 0.04 | 0.32 | 0.44 | 0.12 | 0.05 | 0.18 | 0.12 | 0.32 | 0.45 | 0.18 |
|   | 0.23 | 0.12 | 0.03 | 0.25 | 0.25 | 0.08 | 0.07 | 0.58 | 0.07 | 0.00 | 0.45 | 0.07 |
|   | 0.49 | 0.05 | 0.13 | 0.24 | 0.15 | 0.11 | 0.09 | 0.51 | 0.14 | 0.12 | 0.67 | 0.09 |
|   | 0.11 | 0.42 | 0.11 | 0.26 | 0.11 | 0.21 | 0.11 | 0.55 | 0.07 | 0.18 | 0.48 | 0.09 |
|   | 0.64 | 0.05 | 0.13 | 0.38 | 0.11 | 0.44 | 0.11 | 0.57 | 0.14 | 0.18 | 0.40 | 0.09 |
|   | 0.53 | 0.42 | 0.58 | 0.40 | 0.44 | 0.33 | 0.55 | 0.47 | 0.48 | 0.40 | 0.47 | 0.47 |
|   | 0.60 | 0.40 | 0.43 | 0.53 | 0.40 | 0.53 | 0.53 | 0.53 | 0.53 | 0.43 | 0.47 | 0.57 |

Average: 0.45, 0.42, 0.50

Note: The fraction choosing the correct answer in bold

Reliability is used as an indicator of how precisely and consistently the test measure what it is supposed to measure. The Kuder-Richardson formula 20 (KR-20) was employed to determine the reliability of the instrument. The KR-20 formula was used to examine the internal consistency of the BECs and it yields 0.89. Test having a KR-20 ≥ 0.70 are considered to be reliable for group measurement [22].

In addition to computing of item validity and reliability, the item analysis included item difficulty index, discrimination index and point bi-serial correlation. Item difficulty index (p-value) is represented as a proportions value of the number of correct answers or incorrect answers on the item compared to the total number of students taking the test in a scale of 0.00 to 1.00 but the accepted values are 0.30 ≤ p ≤ 0.9 [22]. Based upon Table 2, the item difficulties ranged from 0.30 to 0.67 with average of 0.50 as categorized acceptable values.

The discrimination index (D) provides a comparative analysis of the upper 27% and lower 27% on comparative scale of -1.00 to 1.00. The item discrimination index of BECs has good discrimination because of D value ≥ 0.30 [22] excluding Q4 and Q27.

The point bi-serial correlation (rpbis) measures correlation between an exam-taker’s response on a given item and how the exam-taker performed against the overall exam form. In other words, the rpbis coefficient, called as the geniality index for each item, is a measure of consistency of a single test item with the whole test. The criterion widely adopted for measuring the consistency of a test item is rpbis ≥ 0.2 but if values of the rpbis coefficients are 0.40 ≤ rpbis ≤ 0.59 the item is very good. As seen in Table 2, the rpbis coefficient for each item ranged from 0.37 to 0.67 with average of 0.45 (categorized as very good items). However, there are five items (Q4, Q6, Q13, Q21, Q29) which has the rpbis coefficients ≤ 0.40.

3. Results and discussion

Figure 2 displays the average CRI values for correct and wrong answers for every question, with the fraction of correct answers. The criterion of whether a CRI is low or high uses a limit value of 2.5 (14). In other words, a CRI is more than or less than 2.5 counted to be high or low correspondingly.

As seen in Figure 2 and Q13 item, the average CRI for correct answer 4.10, but that for wrong answer is 2.57, relatively high average CRI compared to threshold of 2.5, and the correct answer as a fraction of total are 0.18. Based upon decision matrix in Table 1, students can be identified as misconception. This assertion is verified by low percentage (18%) of correct answers. In other words, the majority of students (82%) select the incorrect answer for Q13 item because of misconception.

For Q11 item, the mean CRI-correct answer is 1.29 (low CRI) but the mean CRI for wrong answer is 2.4 (low CRI) and the correct answers as fraction of total are 0.25. Using the threshold of 2.5, the data indicates that students select the correct answer due to a lucky guess. As shown in Table 1,
incorrect answer and a low average CRI (WL) imply a lack of knowledge. This statement is supported by only 25% or 14 students of correct answer.

For Q1 item, the average CRI for correct answer is 2.75 and the mean CRI of 1.97 for wrong answers (< 2.5). It means that students have a lack of knowledge as opposed to misconceptions. Furthermore, there are 51% of 57 students who have selected the incorrect answer because of a lack of knowledge related to electric charge.

Using the above enquiry, Q3, Q6, Q12, Q14, Q19, Q21, Q23, Q24 and Q28 have high mean CRI values for correct answer. For these questions, less than 50% of 57 pre-service physics teachers have certainty about their knowledge and skill related to the basic electrical concepts. Based on Table 1, this relates to correct answer and low average CRI. It can be stated that students selected the correct answers due to the lucky guess rather than a lack of knowledge.

A low mean CRI for incorrect answers deals with Q11, Q15, Q16 and Q20. Consequently, as indicated by Table 1, this low mean CRI points out a lack of knowledge caused by a lack of certainty in the ability to apply the wanted concepts, principles and laws. This assertion is strengthened by less than 30% of 57 students have provided the correct answer for four questions.

![Figure 2. The bar graph and the value of the average CRI for correct and wrong answers.](image)

For questions which the average CRI for correct answer was relatively close to 2.5, the fraction of correct answer was employed to determine whether or not the mean CRI value should be counted high or low [14]. Q25 and Q28 have the average CRI for correct answers that is approximately 2.5, were considered to be high since more than 50% of students have given the incorrect answers for both questions. The large number of students and the average CRI around 2.5 indicate that considerable number of student probably have given a high CRI value for their incorrect answer. Although the average CRI values are not significantly higher than 2.50 than 2.5, students have the symptoms of misconceptions [14] and they need to be taught by the specific teaching strategy such as constructivist approach [1]. Similarly, the item Q7 has the mean CRI values for wrong answers that are relatively close to threshold of 2.5, but it was categorized as low average CRI because 61% of students has selected the correct answer. Since there are 22 students (39%) having misconception about the electric field lines, remedial instruction needs to be done for them [23].

4. Conclusion
This study revealed the certainty of response index (CRI) can be used to distinguish a lack of knowledge from misconceptions. The Basic Electrical Concepts (BEC) diagnostics test was multiple choice test with CRI enable to identify 57 pre-service physics teachers' conceptions about electric
charge, Coulomb law, electric field, electric potential and electrical circuit. The results of BEC were classified into correct and incorrect answers, and CRI values were classified into certain and uncertain. High CRI value in incorrect answer implied that 26% students had misconception. Low CRI value in correct or incorrect answer indicated 53% preservice physics teachers selected the answer by a lack of knowledge.

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