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A Comprehensive Analysis of College Students' Understanding of Combination Electrical Circuits Using the Electric Circuits Conceptual Understanding Test (E2CUT)

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Abstract. The research investigates misconceptions about combination electrical circuits among matriculation college students using the E2CUT test. A sample of 441 students was chosen, and the validity and reliability of the test were confirmed with a Cronbach's Alpha coefficient of 0.94 and item reliability of 0.99. After eliminating 13 misfit items, the test was deemed unidimensional. The study highlights significant misunderstandings in circuit diagrams, connections, and core concepts like current, voltage, and resistance. These findings suggest the need for tailored instructional strategies and curriculum adjustments. Additionally, the research paves the way for further exploration into students' misconceptions and related educational challenges.

Keywords: Combination Electrical Circuit, Diagnostic Instrument, Misconceptions, Rasch Analysis.

1.0 Introduction

There are various general perceptions about matriculation college graduates' accomplishments are less encouraging when compared to the achievement of students from other admission channels particularly in engineering courses. To be a competent matriculation college graduate, all students must have a very strong conceptual understanding of science subjects, especially in Physics. One of the pre-requisite modules of the Physics course is basic electricity. Notably, this basic concept of electricity has been universally identified as the most challenging field [1-6]. It has been argued that students need to be equipped with the right knowledge and information to excel in both theory and practice.

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In order to enhance the matriculation college graduates' ability to grasp the fundamentals of basic Physics the root cause of the problem must be recognized as a first step towards that direction. The study of students' misconception in Physics has been the interest of many researchers and consequently became a very important area of research [7]. Prior knowledge brought to the classroom is one of the biggest challenges in conceptual understanding acquisition. Identifying the prior knowledge of students will contribute towards a significant expansion of appropriate learning experiences [8]. It could either be a great 'tool' towards meaningful learning or it could hinder the correct knowledge to be developed. Students go to school with various perspectives, concepts and explanations of their own, which they have learned from their surroundings. The study also mentioned that prior knowledge could lead to pre-conception, children's science, alternative conception, or misconception [7]. The most concerning prior knowledge instilled in students is the one that could lead to misconception.

Rasch Measurement Model (RMM) was first introduced by George Rasch in 1960 which has been applied in various field including education. The RMM is a psychometric method intended to increase the accuracy of a built instrument, to track the efficiency of the instrument and to measure the output of the respondents [9]. It is used to describe the compatibility of the item with the person or vice versa based on mutual latent variables [10]. In other words, any easy items will be correctly answered by all students as compared to difficult items and any highly skillful students will answer all questions correctly than low ability students [10-12]. These are the two foundations of the Rasch Measurement Model.

It can be concluded that the raw test score is non-linear and having no equal intervals. To be able to place the persons and the items on the same scale, an equal interval is a must, or else the process of data fit and statistical analysis cannot be completed [13]. RMM analysis can include the measurement of unequal interval data that are expressed at the same interval scale [11] and contributes an enhanced judgment of students' ability by translating the raw test score into ratio data by using a log-odd-unit (logit) scale [14].

2.0 Methodology

The current study adopts descriptive research design [15] which aims to address the two research questions. As a starting point to the study, the problem was identified through the observation made during class and interaction among the Physics educators of matriculation college. A survey was conducted with the help of a diagnostic test to collect qualitative and quantitative data from the selected student participants in order to identify and confirm any misconceptions they had. The initial conceptions held by each student can be portrayed from the qualitative data. All data collected from the survey is analyzed using Bond&FoxSteps [16], which is consistent with the current study's use of The Rasch Measurement Model as a model.

2.1 Population

The study's target population is all Malaysian matriculation college students studying Physics. As electricity becomes the main focus of this research, only students of Group 1 and Group 2 of SDS (One Year Course) and SES (Two Years Course) are involved in this research study since only these two modules offer Physics as one of their subjects. Approximately 30,000 students are enrolled in these two modules across Malaysia's matriculation colleges.

2.2 Respondents

The sample size for the study was determined using the sample size table. Table 3.1 shows the sample size of 379 students for a total population of 30,000 students. The instrument, on the other hand, was distributed to 500 students from 46 classes of Group 1 SDS, 24 classes of Group 2 SDS, 24 classes of Group 1 SES, and 21 classes of Group 2 SES. A total of 441 responses were successfully obtained out of that number. The sample of students for this research study was selected by using quota sampling. The students who participated in this study were those who had just finished their secondary schools and had their SPM examination. No formal instructions in Physics have been encountered by them upon starting their academic journey in matriculation college.

2.3 Data Collection and Instrumentation

The data collection approach for this study was a quantitative (survey instrument). A newly built instrument had been used to collect data. Because the survey process could not be done face to face owing to the pandemic, researchers delivered the instrument to participants via the internet. E2CUT was series of questions adopted and adapted from the websites of All About Circuits and The Physics Classroom. The questions were chosen and restructured in accordance with the matriculation syllabus and the use of the proper level of grammar by the matriculation students. It consists of a mixture of objective and subjective questions. It was divided into three sections:

Section 1: Series Circuit
Section 2: Parallel Circuit
Section 3: Combination Circuits

Students are tested on the comprehension of circuit diagrams and connections, concepts of current, voltage, and resistance in each section

3.0 Findings

3.1 Research Question 1

What are the misconceptions faced by the matriculation students regarding combination electrical circuits?

3.1.1 Misconceptions of Circuit Diagram and Circuit Connection. Despite the fact that the distinction between series, parallel, and combination circuits was mentioned in the question, almost half of the students struggled with it. Because the circuits were presented in an unconventional manner, this inability to recognize circuit diagrams grew worse.

Table 1. List of items concerning about circuit diagram and connection in combination circuits.

Item	Connection	Type of circuit	Correct responses	Incorrect responses/Misconceptions
Q21	Series Parallel (Combination circuit)	Non-conventional Conventional	56	44
Q22	Series Parallel (Combination circuit)	Non-conventional Conventional	58	42
Q23	Series Parallel (Combination circuit)	Non-conventional Conventional	56	44
Q24	Series Parallel (Combination circuit)	Non-conventional Conventional	55	45

Misconception of electric current

- Current passing through each resistor was determined by assuming voltage across each resistor was the same as total voltage using the assumption that all resistors were in parallel.
- Current passing through each resistor was assumed to be the same as total current because all resistors were thought to be in series.
- Current was the same as total current for parallel resistors and different for series resistors.
- Current for two resistors in parallel was calculated by assuming the voltage across the two resistors were the same as total voltage.
- Current passing through each resistor was determined using the assumption that voltage across each resistor was evenly distributed among the four resistors.
- The current passing through each resistor was calculated based on the assumption that as the resistor was placed further away from the battery's positive terminal, the voltage across it decreased.

Table 2. List of items concerning about current in combination circuits.

Item	Item Content	Correct response	Incorrect response/Misconceptions
Q25	Calculate current passing through R_1 (series) in combination circuits	33	67
Q26	Calculate current passing through R_2 (parallel) in combination circuits	13	87
Q27	Calculate current passing through R_3 (parallel) in combination circuits	12	88
Q28	Calculate current passing through R_4 (series) in combination circuits	34	66
Q29	Calculate total current of combination circuits	40	60

Misconception of voltage

- Voltage across each resistor in circuit combination is the same as total voltage.
- Despite the presence of series resistors in the circuit, the voltage of the parallel resistors is directly equated to the total voltage.
- Voltage across each resistor was evenly distributed among the four resistors regardless of the circuit connection and resistance value.
- Voltage across the resistor closest to the positive terminal of the battery is higher than the voltage across the following resistors.
- Voltage is the same across all series resistors with different resistance.
- The total voltage is divided evenly between the parallel resistors.
- Voltage across each resistor was different because the current passing through each resistor was assumed to be the same as total current regardless of the circuit connection.

Table 3. List of items concerning about voltage.

Item	Item Content	Correct Response	Incorrect Response/Misconceptions
Q30	Calculate voltage across R_1 (series) in combination circuits	33	67
Q31	Calculate voltage across R_2 (parallel) in combination circuits	19	81
Q32	Calculate voltage across R_3 (parallel) in combination circuits	19	81
Q33	Calculate voltage across R_4 (series) in combination circuits	33	67

Misconception of resistance

- Resistors in parallel have unequal voltage across it.
- Despite the presence of resistors connected in series in the same circuit, parallel resistors have the same voltage as total voltage.
- Resistors placed on different line without node (junction) in the circuit diagram were parallel.
- Resistors placed on different line with node (junction) in the circuit diagram were series.
- Even though nodes are present in the circuit diagram, all resistors are connected in series.
- Resistor placed near the positive terminal of the battery received more voltage than the following resistors.

Table 4. List of items concerning about resistance in combination circuits.

Item	Item Content	Correct Response	Incorrect Response/Misconceptions
Q21	Calculate equivalent resistance of resistors in combination circuits	55	45
Q22	Calculate equivalent resistance of resistors in combination circuits	57	43
Q23	Calculate equivalent resistance of resistors in combination circuits	55	45
Q24	Calculate equivalent resistance of resistors in combination circuits	54	46

3.2 Research Question 2

How reliable and valid is the diagnostic instrument, E2CUT, in identifying the misconceptions faced by the matriculation students on combination electrical circuits?

3.2.1 Reliability of the Instrument. Reliability is the degree to which the research instrument reliably has the same outcomes if it is used twice in the same case [17]. As shown in Table 5, the item reliability is +0.99 logit indicating that the items in the latest version of the instrument (E2CUT) have 'excellent' fit [18]. High item reliability means that the replicability of the item level difficulty is high if the same instrument is given to another sample of students [16].

The person reliability is at +0.90 logit which classified as 'very good' by [18]. High person reliability means that the replicability of the persons' ability order is high if the same group of students were given another similar set of items testing on the conceptual understanding of electric circuit [18]. Nevertheless, the Cronbach Alpha (KR-20) coefficient records a slightly higher value of +0.94 logit. Cronbach Alpha of 0.8 and above is very good [19]. The best KR-20 value is 0.9 and above [20]. Thus, it is concluded that the instrument has a very good internal consistency in measuring the desired latent trait [21].

Table 5. Summary statistics for 33 items.

	Raw Score	Count	Measure	Model Error	Infit		Outfit	
					MnSq	ZStd	MnSq	ZStd
Mean	212.0	427.0	0.00	0.13	0.98	-0.7	1.14	-0.3
S.D.	72.3	0.0	1.21	0.02	0.28	4.2	1.00	3.9
Max.	359.0	427.0	2.99	0.18	1.85	9.9	4.63	9.9
Min.	53.0	427.0	-2.37	0.12	0.62	-6.0	0.45	-5.1

REAL RMSE 0.13 ADJ.SD 1.20 SEPARATION 8.99 Item RELIABILITY 0.99
S.E. OF Item MEAN = 0.21
Item RAW SCORE-TO-MEASURE CORRELATION = -0.99
14091 DATA POINTS. APPROXIMATE LOG-LIKELIHOOD CHI-SQUARE: 12814.66

Table 6. Summary of 427 measure (non-extreme) person.

	Raw Score	Count	Measure	Model Error	Infit		Outfit	
					MnSq	ZStd	MnSq	ZStd
Mean	16.4	33.0	0.04	0.49	0.99	-0.1	1.15	0.0
S.D.	8.5	0.0	1.73	0.15	0.35	1.6	1.03	1.4
Max.	32.0	33.0	4.30	1.06	2.22	6.5	9.90	6.4
Min.	1.0	33.0	-3.97	0.39	0.43	-2.6	0.14	-2.2

REAL RMSE 0.55 ADJ.SD 1.64 SEPARATION 3.01 Person RELIABILITY 0.90
S.E. OF Person MEAN = 0.09
Person RAW SCORE-TO-MEASURE CORRELATION = 0.97
CRONBACH ALPHA (KR-20) Person RAW SCORE RELIABILITY = 0.94

3.2.2 Validity of the instrument. Validity is characterized as the degree to which, in quantitative analysis, a designated instrument correctly measures the desired (unidimensional) concept which in this case the misconceptions of combination electrical circuits among matriculation college. From Tables 5 and 6, the values of outfit mean square and infit mean square for the items is at +1.14 logit and +0.98 logit while for students is at +1.15 logit and +0.99 logit, which very near to the best value of 1. The outfit Z standard and infit Z standard of items is at -0.3 logit and -0.7 logit while for students is at +0.0 logit and -0.1 logit where all values are within the range and relatively close to the expected value of 0. Therefore, it can be concluded that both the students and the items for the final study did fulfill the Rasch Fit test which also means that both fits the Rasch Model. Thus, the instrument is validated and reliable to use. This is also a solid indication that the analysis performed demonstrates the study's findings.

4.0 Discussion

4.1 The Matriculation Students' Misconceptions of Combinations Electrical Circuits

The study examined matriculation students' misconceptions in combination electrical circuits through responses to the E2CUT items. Misconceptions, stemming from inaccurate prior knowledge, hindered students' understanding of circuit principles. The assessment focused on circuit diagrams, resistance, current, and voltage across different scenarios. Challenges in accurately identifying circuit connections were evident, signaling a need for intervention. Findings align with prior research and contribute to understanding combination circuit misconceptions. These universal challenges emphasize the importance of tailored instructional strategies and collaborative research for improved electrical circuits education among matriculation students.

4.2 E2CUT Diagnostic Instrument

The E2CUT instrument, comprising 33 items categorized into three sections—series circuits, parallel circuits, and combination circuits—evaluates students' misconceptions about electrical concepts. During pilot testing, five difficult items, two intermediate items, two easy items, and three very easy items were eliminated. The Rasch Model analysis yielded item reliability of +0.99 logit, indicating 'excellent' replicability, and person reliability of +0.94 logit, classified as 'very good.' Students were stratified into 5 strata, and items into up to 12 strata. Notably, item means were near equal to the person mean at 0.00 logit and +0.04 logit, respectively, suggesting fairness. The instrument effectively identifies misconceptions among matriculation students, offering insights for tailored instruction and curriculum improvements. This study's implications extend to educational research, providing a framework for understanding student abilities and informing instructional practices.

5.0 Conclusion & Recommendation

To sum up, this study effectively achieved its objectives by covering crucial concepts of electrical circuits, including circuit diagrams, circuit connections, resistance, current, and voltage within each section. The Rasch Analysis confirmed the reliability and validity of the collected responses, affirming that the E2CUT instrument effectively identifies misconceptions among matriculation college students. The conclusive findings provide valuable insights into students' conceptual gaps in various areas of electricity, offering essential information for students, educators, and curriculum designers. The identification of misconceptions not only aids students in self-assessment but also equips educators with the knowledge to develop targeted intervention programs and teaching strategies. Furthermore, curriculum designers can leverage this information to enhance content, refine phrasing, and incorporate more relevant illustrations, ultimately fostering a better understanding of electricity concepts among matriculation college students.

The outcomes of this study lay a solid foundation for future educational research and interventions, emphasizing the importance of addressing misconceptions early in the educational process. By doing so, educators and curriculum designers can collaboratively contribute to improving the overall quality of electrical education, ensuring that students possess a robust conceptual understanding that aligns with real-world applications.

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