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Developing Physics-Integrated Computational Thinking Skills Assessment Instrument Using Rasch Measurement Model

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Abstract

Computational thinking skills (CT) are an essential skill for young generations. Integration of CT in physics has been studied widely since they are closely related to each other. However, instruments to assess CT in physics problem-solving are still limited. This study aims to develop a physics-integrated CT assessment instrument. Multiple choice items were developed and reviewed by experts in physics education. A pilot study is conducted with 121 undergraduate students. Based on the empirical data on the pilot study, the Rasch analysis using Winstep is conducted. The final instrument consists of 24 multiple-choice items. Each item has MNSQ in the range of 0.82-1.17. The ZSTD is in the range of -1.92-1.99 which can be classified in fit. Calculation with the Rasch model for 24 fit items shows person reliability of 0.81, item reliability of 0.89, and alpha Cronbach of 0.89. Those values can be classified as good.

Keywords: CT; physics; Rasch model; assessment

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INTRODUCTION

In the developed digital era, cultivating computational thinking (CT) skills for young generations has become a growing important need (Acevedo-Borrega et al., 2022; Hsu et al., 2018). CT is necessary to build problem-solving and creativity. Hence, some efforts have been made to incorporate CT development into the college curriculum, especially in Science, Technology, Engineering, and Mathematics (STEM) disciplines (Li et al., 2020; Swaid, 2015).

CT are fundamental skills, just like writing, reading, and arithmetic skills (Barr et al., 2011). CT are problem-solving processes consisting of decomposition, abstraction, algorithmic thinking, generalization, and evaluation (Voon et al., 2022; Yin et al., 2020). Decomposition is a method of breaking down a system or problem into parts that are easier to manage or solve (Kwon & Cheon, 2019; Rijke et al., 2018). Abstraction is the process of eliminating unnecessary information in a system so that the system becomes simpler and focuses on only relevant information (Fagerlund et al., 2021). Algorithmic thinking is the ability to design and execute a sequence of logical steps to produce good performance (Katai, 2015). Generalization is identifying patterns, similarities, and relationships between data or objects (Saxena et al., 2020). Evaluation is the process of ensuring that a solution is appropriate and appropriate for the stated purpose.

CT has become essential for science, technology, engineering, and mathematics (STEM). Problem-solving in STEM requires a lot of CT (Li et al., 2020). The Next Generation Science Standards (NGSS) have included CT as part of core science practices (NGSS, 2013). Developing CT in science classes is something that needs to be considered. Several studies have been conducted to integrate CT into STEM learning. For example, Yin et al (2019) tried to integrate CT with physics and engineering learning through the maker activities they designed. Sengupta & Kinnebrew (2013) have tried to improve students' CT by using simulations and modeling to provide an understanding of kinematics concepts. Hutchins et al. (2020) designed collaborative computational STEM (C2STEM) as a scaffolding in physics learning in secondary schools using a computational modeling approach. Game-based learning has also been used to improve CT (Yoon & Khambari, 2022).

CT and physics are closely related. To solve real physics problems, scientists should have a good CT. CT should be inserted in fundamental physics course in college. There are some teaching approaches and methods which can be implemented such as explained in (Lane et al., 2023; Orban, 2020; Weller et al., 2022)

Besides the teaching approach, assessment is another essential part of the learning process. Assessing CT has become another concern research topic. Several studies have been done to develop CT assessment methods and instruments (Cutumisu et al., 2019; Tang et al., 2020). However, assessment instruments that assess CT in the context of physics problem-solving is still limited. Since assessment is another essential part of the learning process, it is necessary to develop a CT-integrated physics problem-solving assessment instrument with good quality. The objectives of this study are to develop test instruments to assess CT in the context of physics problem-solving, to be specific in the material of electricity. The validity and reliability of the test instruments are investigated in this study.

METHODS

This study aims to develop a test instrument to assess the CT of students in the context of solving physics problems, to be specific on the material of electricity. The test instrument type is multiple choice. There are several steps followed to develop the instruments, i.e.

1. Define the construct and develop the items
2. Conduct pilot testing
3. Applying the Rasch model
4. Review the item fit statistics and revise items if needed
5. Establish validity and reliability

The subject of the pilot testing is 121 undergraduate students who take fundamental physics courses. The Rasch model is employed to determine the validity and reliability of the instruments. We use Winstep to facilitate the calculation of Rasch analysis.

RESULTS AND DISCUSSION

Define the Construct and Develop the Items

The construct in this test instrument is measuring CT aspects in the electricity material context. There are 5 main aspects of CT to be measured, i.e. abstracting, decomposition, algorithmic thinking, pattern generalization, and evaluation. The formal definitions of CT aspects in the physics context are defined in Table 1. Based on 5 main aspects, indicators are developed as shown in Table 2. Initially, there were 30 items developed. Figure 1-5 shows the sample item for each CT aspect.

Table 1. *CT Aspects in Physics Context*

No	CT aspects	Definitions
1	Abstraction	Modeling physical systems with representations that are simpler and easier to understand by removing unnecessary details and preserving the important parts.
2	Decomposition	Break down a physical system into several parts that can be handled easier
3	Algorithmic thinking	Solving problems or achieving goals through systematic and well-defined steps
4	Pattern generalization	Identifying patterns, similarities, and relations among quantities and applying them to understand related phenomena
5	Evaluation	Valuating the correctness of the algorithm, abstraction, model, experimental design, or simulation based on the purpose and assumption set.

Table 2. *CT aspects, physics topics covered, and indicators*

Topics	Aspect	Item indicator	Number of items	Item code
Modeling electrical phenomena on direct current (DC) circuits and applying them to solve problems related to current, resistance, ohm’s law, power, energy Kirchhoff’s rules, and simple DC circuits.	abstraction	Identify the type of circuit in the breadboard	2	A1, A2
		Draw the circuit in the breadboard diagrammatically	2	A3, A4
		Identify closed circuit in the breadboard	2	A5, A6
	Decompositions	Break down a complex resistor circuit into series or parallel circuits to determine the total resistance	2	D1, D2
		Using Kirchhoff’s rule to analyze current in a multiloop circuit	2	D3, D4
		Using Kirchhoff’s rule to analyze voltage in a multiloop circuit	2	D5, D6
	Algorithmic thinking	Design a circuit that has a specific voltage or current	2	AT1, AT2
		Compile the steps for using the most appropriate measuring instrument to measure electrical quantities	2	AT3, AT4
		Implementing the RC circuit controller program flowchart	2	AT5, AT6
	Pattern generalization	Analyzing changes in the resistance of an electrical circuit component based on the V-I graph pattern	1	PG1
		Predicting the V-I relationship in a combined circuit of several resistors	2	PG3, PG4
		Estimate the magnitude of current in a circuit based on the experimental data presented	1	PG6
		Construct a mathematical model of Ohm's law	1	PG2
		Construct a mathematical model of capacitor voltage	1	PG5
	Evaluation	Comparing time constants in RC circuit	2	E1, E2
		Compare the energy dissipated in each resistor	2	E3, E4
		Evaluate the how-to-use of electrical measuring instruments correctly	2	E5, E6

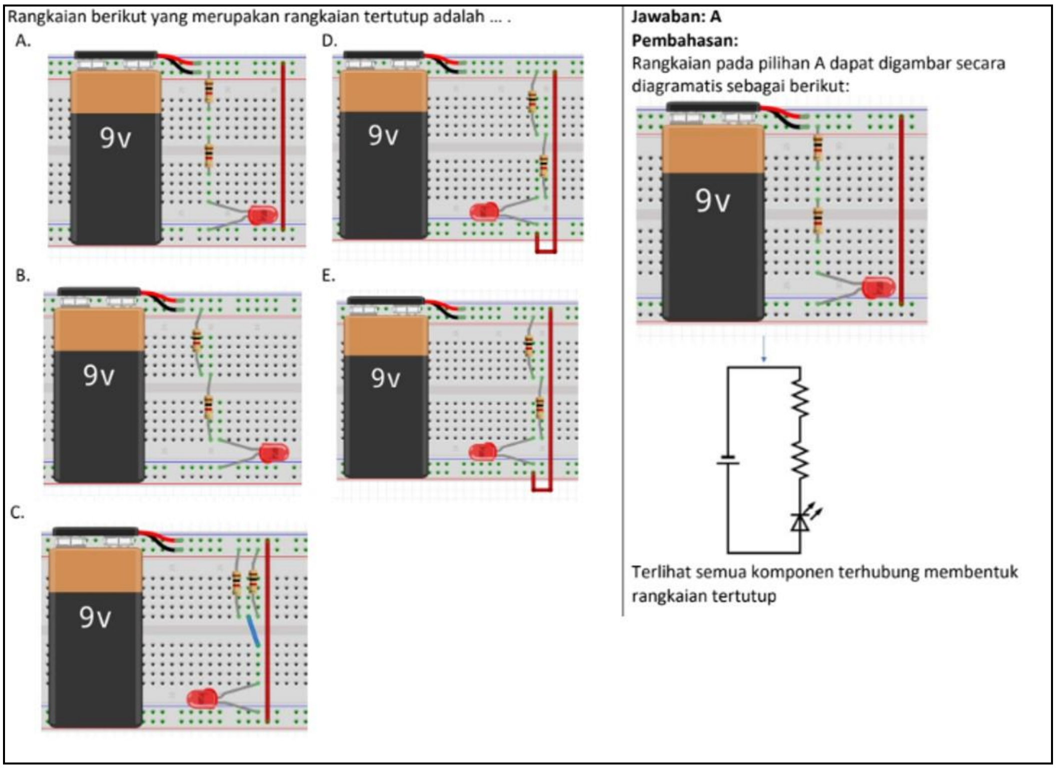


Figure 1. Sample of Items Measuring Abstracting Aspect

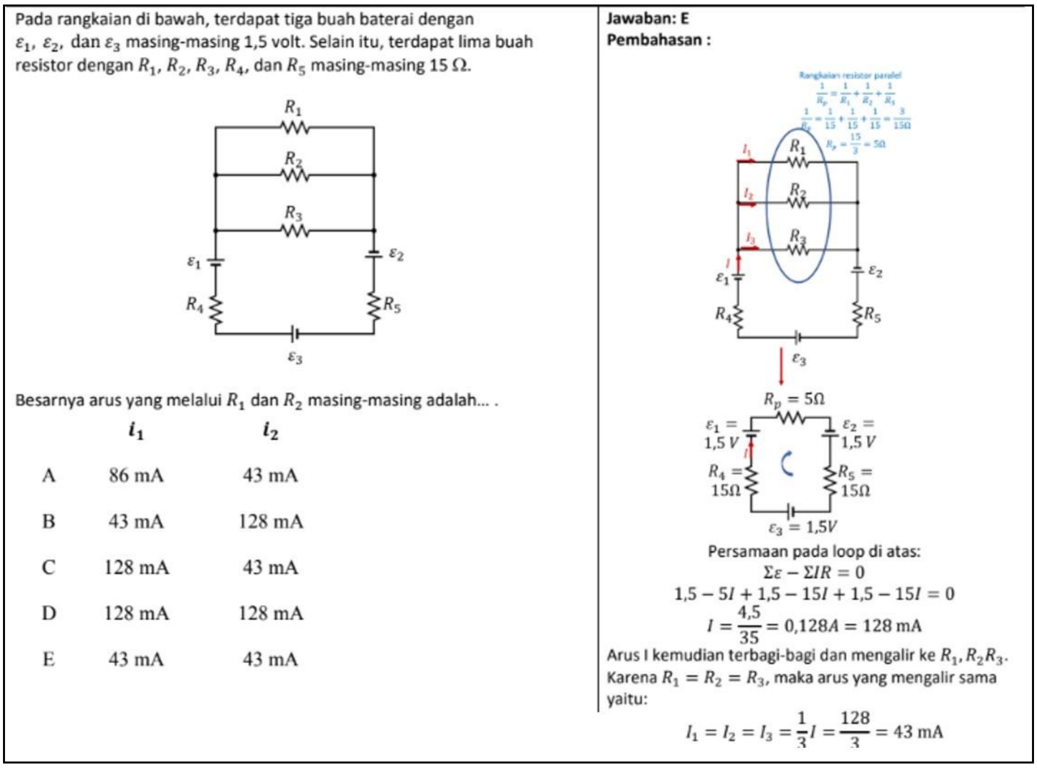
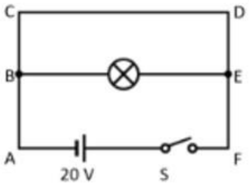


Figure 2. Sample of Items Measuring Decomposition Aspect



Sebuah lampu dengan hambatan 25 ohm dipasang pada rangkaian seperti gambar di atas. Agar lampu tersebut menyala optimal, besar suplai daya listrik yang diperlukan adalah 16 Watt. Langkah yang paling optimal dan aman untuk menyalakan lampu adalah... .

A.
1. Melepas kawat penguhubung B-C.
2. Memåsang resistor 100 Ω di antara titik B-C.
3. Menutup saklar.

B.
1. Melepas kawat penghubung antara titik B dengan lampu.
2. Memasang resistor 100 Ω secara seri dengan lampu.
3. Menutup saklar.

C.
1. Melepas kawat penguhubung A-B.
2. Memasang resistor 100 Ω di antara titik A-B.
3. Menutup saklar.

D.
1. Menutup saklar.
2. Melepas kawat penguhubung F-E.
3. Memasang resistor 100 Ω di antara titik F-E.

E.
1. Menutup saklar.
2. Melepas kawat penghubung antara titik A dan baterai.
3. Memasang resistor 100 Ω secara seri dengan baterai.

Jawaban: A
Pembahasan :

Dengan keadaan rangkaian seperti pada soal, bila saklar S ditutup, maka arus akan mengalir melalui F-E-D-C-B-A tanpa melalui cabang E-B. Hal ini karena pada cabang CD tidak ada hambatan. Bila dibiarkan maka lampu tidak akan menyala.
Agar arus juga ada yang melalui cabang E-B maka perlu ditambahkan resistor antara ED, CD, atau BC.
Dengan demikian, jawaban A adalah yang paling tepat.

Figure 3. Sample of Items Measuring Algorithmic Thinking

Seorang mahasiswa hendak mencari tahu faktor-faktor yang mempengaruhi hambatan (R) penghantar listrik. Ia melakukan percobaan dengan batang tipis yang terbuat dari 3 jenis bahan dengan berbagai ukuran panjang (x) dan diameter (d). Hambatan berbagai kawat tersebut diukur dengan menggunakan ohmmeter. Berikut adalah hasil percobaan mahasiswa tadi.

Jenis Bahan	Panjang x (cm)	Diameter d (mm)	Hambatan R (ohm)
Bahan A	10	0.05	4.8
	20	0.05	9.6
	30	0.05	14.3
	30	0.1	3.6
	30	0.2	0.9
Bahan B	10	0.05	111
	20	0.05	222
	30	0.05	333
	30	0.1	83.2
	30	0.2	20.8
Bahan C	10	0.05	10.1
	20	0.05	20.2
	30	0.05	30.3
	30	0.1	7.6
	30	0.2	1.9

Model matematis yang sesuai untuk mendeskripsikan data di atas adalah ... .

A. $R = \Im \frac{x}{d^2}$, dengan $\Im$ merupakan konstanta yang bergantung pada bahan
B. $R = \Im \frac{x}{d^2}$, dengan $\Im$ merupakan konstanta universal dan tidak dipengaruhi oleh bahan
C. $R = \Im \frac{x^2}{d^2}$ dengan $\Im$ merupakan konstanta yang bergantung pada bahan
D. $R = \Im \frac{d}{x^2}$, dengan $\Im$ merupakan konstanta universal
E. $R = \Im \frac{d}{x}$, dengan $\Im$ merupakan konstanta yang bergantung pada bahan

Jawaban: A

Pembahasan:

Berdasarkan percobaan dengan bahan A, B, dan C, batang yang diameternya sama, panjang batang (x) berbanding lurus dengan hambatan (R):

$$x \sim R$$

Saat x dinaikan menjadi 2 kali, hambatan juga naik 2 kali. Saat x dinaikan menjadi 3 kali, hambatan juga naik 3 kali.

Sementara itu, dengan panjang yang sama, saat diameternya dinaikan, hambatan justru turun. Saat diameter dinaikan 2 kali, hambatan turun menjadi ¼ kali semula. Sehingga dapat disimpulkan,

$$\frac{1}{d^2} \sim R$$

Dua relasi di atas digabung menjadi:

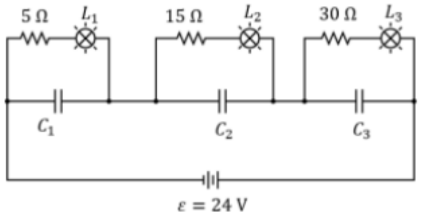
$$R \sim \frac{x}{d^2}$$

$$R = \Im \frac{x}{d^2}$$

$\Im$ merupakan konstanta yang nilainya bergantung pada jenis bahan. Ini dapat dilihat dari data yang ditampilkan bahwa walaupun panjang dan diameter batang sama, nilai hambatan berbeda untuk bahan yang berbeda.

Figure 4. Sample of Item Measuring Pattern Generalization

Perhatikan desain rangkaian berikut ini.



Rangkaian tersusun atas 3 buah resistor, 3 buah lampu, dan 3 buah kapasitor. Sumber tegangan yang dipakai adalah 24 volt. Lampu dan kapasitor yang dipakai semuanya identik.

Setelah ketiga lampu menyala cukup lama, tiba-tiba sumber tegangan mati. Pernyataan manakah yang benar sesaat sumber tegangan mati?

a. Ketiga lampu akan langsung mati.
b. Ketiga lampu tidak langsung mati, tapi meredup bersama.
c. Lampu L2 akan tetap menyala sesaat, L1 dan L3 langsung mati.
d. Seluruh lampu akan tetap menyala sesaat, L1 akan bertahan paling lama.
e. Seluruh lampu akan tetap menyala sesaat, L3 akan bertahan paling lama.

Jawaban: E

Pembahasan:

Saat sumber tegangan dimatikan, maka akan terjadi pengosongan muatan pada setiap kapasitor. Ini mengakibatkan tegangan kapasitor berkurang hingga mencapai nol. Cepat tidaknya tegangan berkurang bergantung pada konstanta waktu τ yang besarnya RC. Jika τ besar, pengurangan tegangan lambat sehingga lampu lebih lama dapat menyala.

$$\tau_1 = (R_1 + R_L)C_1 = 5C + R_L C$$
$$\tau_2 = (R_2 + R_L)C_2 = 15C + R_L C$$
$$\tau_3 = (R_3 + R_L)C_3 = 30C + R_L C$$

Konstanta waktu yang paling besar dimilki oleh rangkaian C_3 sehingga lampu L_3akan bertahan paling lama.

Figure 5. Sample of Item Measuring Evaluation Aspect

The developed items are then reviewed by physics and physics education experts to determine each item's quality. There are 5 experts involved. Experts are asked to give scores between 1-4 for each item based on the given rubrics. As shown in Table 3, expert judgment on all items can be classified as very good. The judgments from the 5 experts all are consistent with the acceptable V Aiken index (Aiken, 1985).

Table 3. *Experts' Appraisal of the Developed Items*

No	**Code**	**Scores**					**Average**	**Classification**	**Index *V***	**V's Aiken Interpretation**
		Val 1	**Val 2**	**Val 3**	**Val 4**	**Val 5**				
1	A1	4	4	4	4	4	4.00	very good	1.00	fulfilled
2	A2	4	4	4	4	4	4.00	very good	1.00	fulfilled
3	A3	4	4	4	4	4	4.00	very good	1.00	fulfilled
4	A4	4	4	4	4	4	4.00	very good	1.00	fulfilled
5	A5	4	4	4	4	4	4.00	very good	1.00	fulfilled
6	A6	4	4	4	3	4	3.80	very good	0.93	fulfilled
7	D1	4	3	4	4	4	3.80	very good	0.93	fulfiled
8	D2	4	4	4	4	4	4.00	very good	1.00	fulfiled
9	D3	4	4	4	4	4	4.00	very good	1.00	fulfiled
10	D4	4	4	4	4	4	4.00	very good	1.00	fulfiled
11	D5	4	4	4	4	4	4.00	very good	1.00	fulfiled
12	D6	4	4	4	4	4	4.00	very good	1.00	fulfiled
13	AT1	4	4	4	4	4	4.00	very good	1.00	fulfiled
14	AT2	4	4	4	4	4	4.00	very good	1.00	fulfiled
15	AT3	4	4	4	4	4	4.00	very good	1.00	fulfiled
16	AT4	4	4	4	4	4	4.00	very good	1.00	fulfiled
17	AT5	4	4	4	4	4	4.00	very good	1.00	fulfiled
18	AT6	4	4	4	3	4	3.80	very good	0.93	fulfiled
19	PG1	4	3	4	4	4	3.80	very good	0.93	fulfiled
20	PG2	4	4	4	4	4	4.00	very good	1.00	fulfiled
21	PG3	4	4	4	4	4	4.00	very good	1.00	fulfiled
22	PG4	4	4	4	4	4	4.00	very good	1.00	fulfiled
23	PG5	4	4	4	4	4	4.00	very good	1.00	fulfiled
24	PG6	4	4	4	4	4	4.00	very good	1.00	fulfiled
25	E1	4	4	4	4	4	4.00	very good	1.00	fulfiled
26	E2	4	4	4	4	4	4.00	very good	1.00	fulfiled
27	E3	4	4	4	4	4	4.00	very good	1.00	fulfiled
28	E4	4	4	4	4	4	4.00	very good	1.00	fulfiled
29	E5	4	4	4	3	4	3.80	very good	0.93	fulfiled
30	E6	4	4	4	4	4	4.00	very good	1.00	fulfiled

Pilot Test and Analysis Using Rasch Measurement Model

A pilot test is done by administering the prototype measurement instrument to a sample of the target population. The result of the pilot test is used for Rasch analysis. There are 121 undergraduate students, who are taking fundamental physics courses, participated in this pilot test. Calculations with the Rasch model for initial items are presented in Table 4.

Table 4*. Results of MNSQ, ZSTD, and Point Measure Correlation Calculations in the Initial Design of CT Instruments*

Item	Infit MNSQ	Infit ZSTD	Point Measure Correlation
A4	1.73	6.90	-0.15
E3	182	6.96	-0.03
D3	1.75	5.98	0.02
A5	1.04	0.42	0.37
PG6	1.11	1.19	0.39
PG2	1.08	0.94	0.43
A3	1.07	0.50	0.31
AT6	1.06	0.67	0.45
PG5	1.00	0.01	0.41
PG3	1.02	0.28	0.47
E4	1.02	0.24	0.49
D6	0.99	-0.07	0.50
PG1	0.95	-0.45	0.53
D5	0.93	-0.71	0.53
PG4	0.90	-1.13	0.49
A6	0.91	-1.07	0.55
A2	0.88	-1.36	0.57
A1	0.87	-1.47	0.59
D2	0.87	-1.49	0.59
E1	0.86	-1.62	0.58
AT3	0.85	-1.29	0.48
AT1	0.84	-1.81	0.56
AT2	0.84	-1.90	0.59
AT4	0.83	-2.04	0.58
E5	0.83	-1.94	0.56
E2	0.82	-1.93	0.55
E6	0.82	-1.92	0.55
D1	0.76	-2.80	0.60
D4	0.76	-2.91	0.66
AT5	0.74	-3.17	0.62

The infit MNSQ and ZSTD are presented in Table 4. Some items are not fit, i.e. A4, E3, D3, AT4, D1, D4, and AT5. We decided to remove A4, E3, D3, AT4, and AT5 since their respective indicator has been represented by another item. Items D3 and D4 represent the same indicator, hence we decided to remove only one of them, that is D3. After the removal of some items, there are 24 items in the instrument draft. Rasch analysis is conducted again, the results are presented in Table 5.

Table 5. *Results of MNSQ, ZSTD, and Point Measure Correlation Calculations on CT Instruments After Non-Fit Items Were Removed*

Item	Infit MNSQ	Infit ZSTD	Point Measure Correlation
A5	1.05	0.59	0.37
PG6	1.17	1.99	0.40
E4	1.17	1.44	0.53
PG1	1.12	0.87	0.60
PG2	1.14	1.46	0.48
A6	0.95	-0.53	0.56
A3	1.05	0.39	0.31
D6	1.06	0.75	0.51
PG5	1.04	0.49	0.40
AT6	1.10	0.96	0.54
PG4	1.00	0.07	0.45
D5	1.05	0.51	0.56
PG3	1.05	0.60	0.54
D2	1.00	-0.01	0.58
AT3	0.93	-0.61	0.41
E1	1.00	0.05	0.54
A1	0.95	-0.38	0.62
A2	0.90	-1.08	0.61
AT1	0.87	-1.69	0.53
E2	0.87	-1.57	0.51
E5	0.87	-1.61	0.52
AT2	0.86	-1.62	0.61
E6	0.85	-1.76	0.51
D4	0.82	-1.92	0.66

As presented in Table 5, all items have MNSQ in the range of 0.82-1.17. The MNSQ between 0.5 and 1.5 is productive for the measurement (Linacre, 2012). The ZSTD is in the range of -1.92-1.99 which can be classified in fit. Point measure correlation determines the item discrimination. As shown in Table 5, all items have a point measure correlation between 0.31-0.66. Point measure correlation above 0.4 is very good, and between 0.30-0.39 is good (Utari et al., 2021). Calculation with the Rasch model for 24 fit items shows person reliability of 0.81, item reliability of 0.89, and alpha Cronbach of 0.89 (see Table 6). Those values can be classified as good (Dzin & Lay, 2021; Fisher, 2018).

Table 6. *Cronbach's Alpha (KR-20), Item Separation, Item Reliability, Person Separation, and Person Reliability Values of the Instrument*

	Separation Index	Reliability Index
Cronbach's alpha (KR 20)		0.89
Item	2.86	0.81
Person	2.07	0.89

CONCLUSION

In this study, we have developed multiple-choice test items to evaluate students' CT in the context of electricity material. The 24 items in the physics-integrated CT test were accepted and validated by Rasch analysis. This evaluation instrument can be used for further research studying the CT development in undergraduate fundamental physics classes.

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