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Development and Validation of Two-Tier Multiple Choice to Identify Measure Students' System Thinking Skills in Dynamic Electricity

Endang Susilawati, Ida Hamidah*, Nuryani Rustaman, and Winny Liliawati
Universitas Pendidikan Indonesia, Bandung, Indonesia
*idahamidah@upi.edu

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Abstract

Dynamic electricity is important due to its function as a thinking tool for further electronic circuit analysis. It is an abstract concept that must be understood by students as well as by physics teachers. A study about developing a set of two-tier multiple-choice questions was conducted to measure the system thinking skill of a number of student-teachers using Design Development Research (DDR). The instrument has been tested for its validity through expert judgment and field testing on a number of student teachers (n=62). After studying dynamic electricity learning material that had been prepared before. Based on the r table, which is 0.2108, it was obtained that out of 25 two-level tests, 23 were valid and can be used to measure students' and teachers' systems-thinking skills. In addition, the instrument showed high reliability, with a Cronbach's alpha coefficient of 0.840.

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INTRODUCTION

Dynamic electricity is a subject with abstract concepts that students must understand. Fundamental laws in studying electricity are Ohm's law and Kirchhoff's law. Discussion of these fundamental laws is crucial because they serve as thinking tools for further analyzing electronic circuits. Concepts (electric current, voltage, resistance, power, and Kirchhoff's laws) are not only fundamental to mastering physics but also serve as a foundation for understanding more complex electrical systems, such as power distribution systems, electronic equipment, and renewable energy systems. However, various studies have shown that students still experience difficulties in understanding the interrelationships among variables in dynamic electrical systems due to their abstract nature and the involvement of many interacting components (Gunawan et al., 2021).

Students' mastery of electricity is still low (Viard & Langlois, 2001; Wahyudi, 2015). Research reveals that students face difficulties in analyzing electrical circuits (Mcdermott & Shaffer, 2015; Wahyuni & Mukhaiyar, 2022) . The abstract, dynamic nature of electricity, involving cause-and-effect relationships that are not always immediately apparent, demands a learning approach that can help students understand the relationships among variables in a circuit.

Systems thinking skills are highly relevant in studying dynamic electricity because electrical concepts do not stand alone but operate as a system composed of interacting components. As Arnold and Wade (2015) define systems thinking, something can only be

considered systems thinking if it has three components: elements, interconnections, and goals. These elements will provide input or be connected to each other, thus achieving a clear purpose and relevance to daily life.

In this context, systems thinking skills are a very important skill that needs to be developed in physics learning. Systems thinking enables students to understand the relationships among components, energy flows, and causal relationships within a system as a whole, not as a single entity. This ability not only helps students solve complex physics problems but also fosters analytical, predictive, and reflective abilities within the context of dynamic systems (Assaraf & Orion, 2010; Hmelo-Silver et al., 2007). Therefore, systems thinking is a highly relevant 21st-century skill to develop in modern science and physics learning. Systems thinking can be used to review and decompose a system into its components and further analyze how these components work and interact with each other to achieve their goals (Casnan et al ., 2022).

Furthermore, the relationship between dynamic electricity and systems thinking skills lies in the shared characteristics of both, which require an understanding of the functional relationships between system elements. For example, changes in resistance values will affect the magnitude of the current and voltage in the entire circuit; this condition reflects the interaction between components that require systematic analysis. Thus, learning dynamic electricity can be an ideal context for training students' systems thinking skills through the analysis of cause-and-effect relationships, feedback, and system equilibrium.

To assess the extent of students' systems thinking skills, a valid and reliable instrument is needed. One suitable instrument is the two-tier multiple-choice test. This format was introduced by Treagust (1988) and consists of two parts: the first level contains questions about concepts, while the second level asks students to provide reasons for their chosen answers. This format not only measures students' final answers but also reveals the reasons or reasoning behind their choices. It provides a more in-depth picture of students' understanding of structure and systems thinking patterns (Treagust, 1988; Chandrasegaran et al., 2007). Thus, two-tier questions allow researchers to assess both conceptual aspects and systems thinking skills simultaneously, as well as identify potential misconceptions. Two-tier multiple-choice questions are similar to traditional multiple-choice questions, but in general, they contain two interconnected levels of questions (Culinane & Liston, 2011).

This two-tier approach has been shown to provide deeper insights into students' conceptual understanding and scientific reasoning (Chandrasegaran et al., 2007; Tuysuz, 2009). Furthermore, this instrument is effective in identifying misconceptions, measuring higher-order thinking skills, and developing complex reasoning skills, including systems thinking (McClary & Bretz, 2012; Rahmawati et al., 2022). Through this two-tier analysis, instructors can gain a comprehensive picture of students' cognitive structures and the interconnections between their understanding of dynamic electricity concepts.

However, despite the widespread use of two-tier multiple-choice instruments in science education research, studies specifically designed to measure systems thinking skills in dynamic electricity at the university level are still limited. Previous studies have commonly used two-tier multiple-choice tests to assess conceptual understanding (Chandrasegaran et al., 2007; Widiyatmoko & Shimizu, 2018), identify misconceptions (Tuysuz, 2009; Femintasari et al., 2015), and measure critical thinking skills (Dumayanti et al., 2022). Other studies have also applied this instrument format to evaluate scientific reasoning and higher-order thinking skills (McClary & Bretz, 2012; Rahmawati et al., 2022). Nevertheless, instruments that specifically integrate systems thinking skill indicators in the context of dynamic electricity learning for university students are still underdeveloped. Therefore, there is a need to develop a valid and reliable two-tier multiple-choice

instrument that can comprehensively assess university students' systems thinking skills in learning dynamic electricity.

To ensure reliable measurement results, the developed instrument must meet validity and reliability criteria. Validity indicates the extent to which an instrument accurately measures the intended construct, while reliability indicates the consistency of the measurement results (Cohen et al., 2018). Valid and reliable instruments not only provide accurate results but can also be used to diagnose misconceptions and design more effective learning interventions (Fraenkel et al., 2019). Therefore, the development and validation of two-tier multiple-choice questions to measure systems thinking skills in dynamic electricity is an important step in identifying students' systems thinking skills.

This research aims to produce a valid, reliable, and representative two-tier multiple choice for systems thinking skill indicators so that it can be used to evaluate and improve the quality of dynamic electricity learning at the tertiary level. The validity and reliability of the instrument are essential to ensure that the test accurately measures student teachers' systems thinking skills and provides consistent results for evaluating learning outcomes.

METHODS

This research is design and development research (DDR). The type of research used in this study is product and tool research, with the main focus on the development and validation of a two-tier multiple-choice test instrument to measure students' systems thinking skills in dynamic electricity content. In this study, DDR stages consisted of analysis, design, development, and evaluation. In the analysis stage, the researcher identified the need for an instrument capable of measuring students' systems thinking skills in dynamic electricity learning through literature studies, curriculum analysis, and the identification of students' learning difficulties related to dynamic electricity concepts. The design stage involved constructing a two-tier multiple-choice instrument based on systems thinking skill indicators and dynamic electricity concepts, including the preparation of test specifications, question grids, answer options, and reasoning tiers. In the development stage, the instrument was validated by experts and revised based on suggestions and feedback from validators. Afterward, the instrument was tested on university students to examine its validity and reliability. Finally, in the evaluation stage, the results of the validity and reliability were analyzed to determine the quality and feasibility of the instrument for measuring students' systems-thinking skills in dynamic electricity learning.

The focus of the research is directed at the validity and reliability of the instrument as an indicator of the quality of the measuring instrument. The instrument developed covers two main topics, namely, (1) current, voltage, and resistance, and (2) electrical circuits. This instrument is arranged in a two-tier format: the first level measures conceptual answers, and the second level measures the reasons or justifications for the answer choices (Chandrasegaran et al., 2007; Treagust, 1988). Table 1 shows the blueprint of the question instrument based on the indicators of systems thinking skills and the scope of dynamic electricity.

The research procedure began with the development of questions and their blueprint, based on indicators of systems thinking skills and basic competencies in dynamic electricity. Validity testing was conducted through content validation and field testing.

Content validation was conducted by five expert validators with backgrounds in physics education, educational measurement and evaluation, and systems thinking. Content validity was conducted to assess the extent to which the instrument items represented the entire domain of systems thinking skills being measured. Assessment was conducted using a dichotomous scale, with 1 = relevant and 0 = irrelevant. Validation results were then calculated using the Content Validity Index (CVI) and Scale Level Content Validity (S-

CVI) (Polit & Beck, 2006). The criteria are I-CSI ≥ 0.78 is stated as a valid indicator, while S-CVI ≥ 0.80 means the instrument is valid as a whole.

Table 1 Blueprint of the two-level multiple choice instrument

Systems Thinking Skills Indicators	**Material/Question Number**				**Number Per Indicator**
	Ohm's Law and Non-Ohmic	Series and Parallel Circuits	Electrical Power and Energy	Kirchoff's Law	
Exploring Multiple Perspectives	1	8	14	20	4
Considering Issues Appropriately	2	-	15	21	3
Getting to Know the System	3	9	16	22	4
Maintaining Boundaries	4	11	17	-	3
Distinguishing and Measuring Elements	5	12	18	25	4
Identifying Relationships	6	10	-	23	3
Characterizing Relationships	7	13	19	24	4
Total Number of Questions					25

After the two-tier multiple-choice instrument had been validated, a limited trial was conducted to determine empirical validity. This trial was administered to 62 students who had studied the topic of dynamic electricity. Validity was obtained through direct testing towards the students. The assessment rubric is presented in Table 2.

Table 2 Assessment rubric

Score	**Category**
0	Didn't answer the question
1	Wrong answers and reasons
2	Correct answer or reason.
3	The answer and reason are correct.

This limited trial was assessed based on the established test criteria, and the results were processed using SPSS 26. The validity test was conducted using Pearson's product-moment correlation, while the reliability test was conducted using Cronbach's Alpha. The validity test criteria were compared with the calculated r and the table r. Based on the calculation results, the obtained correlation coefficient (r) was then categorized according to Guilford's (1956) classification.

RESULTS AND DISCUSSION

The results of the two-level instrument validation are shown in Table 3. The instrument was given to experts. Revisions were made based on the improvement from the experts until the item was correct. As a result, a score of "highly relevant" was obtained. The following are the results of the validation by five experts.

Table 3 Expert validation results

Aspect	Indicators	V1	V2	V3	V4	V5
Material	Questions according to indicators	1	0	1	1	1
	Questions according to the indicators of systems thinking skills	1	0	1	1	1
	The physics concepts tested are in the context of dynamic electricity.	1	1	1	1	1
	The depth of the material is appropriate to the student's level.	1	1	1	1	1
	Homogeneous and logical answer choices	1	1	1	1	1
	There is only one correct answer	1	0	1	1	1
	Questions measuring high-level thinking skills	1	1	1	1	1
	The topic of the question is formulated clearly	1	1	1	1	1
	Complete data/information on the questions	1	1	1	1	1
Construction of Systems Thinking Skills Test	Exploring multiple Perspectives	1	1	1	1	1
	Consider issues appropriately	1	1	1	1	1
	Get to know the system	1	1	1	1	1
	Maintaining boundaries	1	1	1	1	1
	Distinguishing and measuring elements	1	0	1	1	1
	Identifying relationships	1	1	1	1	1
	Characterizing the relationship	1	1	1	1	1
Language and Presentation	Using language that complies with Indonesian language rules	1	1	1	1	1
	Using communicative language	1	1	1	1	1
	Do not use local/taboo language	1	1	1	1	1
	The answer choices do not repeat the same words/groups of words.	1	1	1	1	1
	The question sentence is not ambiguous	1	0	1	1	1
	The length of the answers is relatively the same	1	1	1	1	1
	Standard and consistent writing format	1	0	1	1	1

From the data in Table 3, after calculations were carried out, the S-CVI value was 0.97, indicating a very high level of agreement between validators (very valid category). Based on Table 3, the results of content validation (content validity) by five expert validators for the two-tier multiple-choice test instrument developed to measure systems thinking skills in dynamic electricity. Based on the analysis results, the Content Validity Index (CVI) value obtained was 0.97, which is included in the very high category (Waltz et al., 2010). This value indicates a very strong agreement among experts on the suitability of the instrument's content, construct, and language for the measurement objectives. Thus, this instrument can be conceptualized to represent the domain of systems thinking skills comprehensively.

In terms of content, the validator assessed that all questions reflected the interconnectedness of basic concepts of dynamic electricity, such as current, voltage, resistance, series-parallel circuits, Ohm's and Kirchhoff's laws. Experts agreed that each question met the indicators of systems-thinking skills, used an appropriate physics context, and had material depth appropriate to the students' characteristics. This finding aligns with the research findings of Etkina, Gentile, and Van Heuvelen (2019), which emphasized that understanding dynamic electricity requires the integration of concepts, representations, and the structure of electrical systems as a whole.

The construct of systems thinking skills also got high ratings from the validators. This indicates that the seven indicators measured—exploring multiple perspectives, considering issues appropriately, recognizing systems, maintaining boundaries, distinguishing and measuring elements, identifying relationships, and characterizing relationships—were well

represented in the test items. This alignment indicates that the instrument assesses not only conceptual understanding but also students' ability to relate elements and understand system dynamics. This approach aligns with Richmond's (1993) view, which states that systems thinking involves the ability to understand the structure, relationships, and patterns of interaction within a complex system.

Meanwhile, the language and presentation aspects showed that all validators assessed the instrument using communicative, consistent language in accordance with Indonesian linguistic rules. Good language in assessment instruments plays a crucial role in ensuring readability and preventing misunderstandings (Downing, 2006). Thus, the overall content validation results indicate that the instrument is worthy of empirical testing to determine the correspondence between theoretical data and field data.

After being validated in terms of content, an empirical validation was conducted on 62 students who had studied dynamic electricity. The results of the product-moment validity test using SPSS are presented in Table 4.

Table 4 Results of pearson product-moment validity test

Question Number	Person Correlation	Information
Question 1	0.315	Valid
Question 2	0.445	Valid
Question 3	0.434	Valid
Question 4	0.158	Invalid*
Question 5	0.480	Valid
Question 6	0.478	Valid
Question 7	0.563	Valid
Question 8	0.342	Valid
Question 9	0.493	Valid
Question 10	0.645	Valid
Question 11	0.627	Valid
Question 12	0.606	Valid
Question 13	0.309	Valid
Question 14	0.438	Valid
Question 15	0.515	Valid
Question 16	0.675	Valid
Question 17	0.585	Valid
Question 18	0.503	Valid
Question 19	0.584	Valid
Question 20	0.510	Valid
Question 21	0.395	Valid
Question 22	0.343	Valid
Question 23	0.180	Invalid*
Question 24	0.305	Valid
Question 25	0.522	Valid

Based on the calculated r value (Table 4), it is known that the r table is 0.2108. The results of comparing the calculated r and the r table show that questions 4 and 23 are declared invalid because the calculated r is smaller than the r table. However, both questions have positive values, indicating that the questions can still be improved.

Table 4 shows the results of the empirical validity test using Pearson correlation (r) between item scores and total scores. Of the 25 items tested for 62 students, 23 items were found to be valid, while 2 items were invalid, namely items 4 (r = 0.158) and 23 (r = 0.180). Based on the criteria proposed by AERA, APA, & NCME (2014), items with correlation values below 0.30 are considered less able to distinguish between participants with high and low abilities. This indicates that the two items may have unclear statements or answer alternatives, or the indicators do not fully correspond to the construct being measured.

Based on the correlation values, most test items had r values between 0.40 and 0.67, indicating a moderate-to-strong correlation between item scores and the total test score. The item with the highest correlation was number 16 (r = 0.675), indicating that the item had very good discriminatory ability. This means that the item was effective in distinguishing students with high and low systems thinking skills, especially in the context of understanding the interactions between electrical circuit components. This finding supports the research results of Pesman and Eryilmaz (2010) and Gurel et al., (2015), which stated that two-tier questions could evaluate the level of conceptual understanding more accurately than regular multiple-choice questions because they required logical reasoning at the second level.

Two invalid items (numbers 4 and 23) need to be revised or eliminated. Items 4 and 23 have low correlation values (r < 0.20), which is due to distractors (distracting answer choices) that are not functioning properly or statements at the reason level that do not fit the context of the question. A review of the item content indicated that several distractors were ineffective, as they were rarely selected by students. In addition, the reason-tier statements were found to be insufficiently aligned with the context of the first-tier questions, which may have reduced the discriminatory power of the items. Therefore, revisions should focus on improving the effectiveness of the distractors and strengthening the alignment between the first-tier questions and the corresponding reason-tier statements. Meanwhile, item number 24, with r = 0.305, is at the minimum validity limit, so it can still be considered for retention after editorial revision. Revisions can be made by improving the context or clarifying the relationship between statements and reasons to strengthen the concept representation (Johnson & Christensen, 2019).

In addition to validity testing, the instrument was also tested for reliability. The results of the item reliability (Cronbach's alpha value) are 0.840. This value indicates a "very high" reliability criterion (Kimberlin & Winterstein, 2008). Reliability is used to evaluate the consistency of a measurement administered at different times to the same individual or using the same standard.

Overall, the empirical validity test results strengthen the content validation results. The high number of valid items indicates that the developed instrument has good discriminatory power and is in line with the theoretical construct of systems thinking. Furthermore, the stable distribution of correlation values above 0.40 indicates that students responded to the questions according to their level of understanding of electrical systems. Thus, the combination of content validity (S-CVI = 0.97) and item validity results (23 out of 25 valid items) suggests that the instrument is appropriate for assessing systems thinking skills in future studies.

Based on the results of these two analyses, it can be concluded that the instrument development process has successfully produced a conceptually and empirically valid measurement tool. With good validity and reliability, this two-tier instrument is expected to be widely used to measure students' systems thinking skills in dynamic electricity, while also assisting lecturers in designing learning strategies oriented towards developing higher-order thinking skills.

CONCLUSION

Based on the result and discussion, it can be concluded that the two-tiered multiple-choice tests were deemed valid by the experts. The empirical validity test results showed that 23 questions were valid, while 2 were invalid. These two invalid questions could not be used in the research instrument. Meanwhile, the reliability test results for all questions showed a very high reliability rating. Therefore, this two-tiered question instrument can be used as a data collection tool to measure students' systems thinking skills.

This study still has several limitations. The instrument developed was focused only on specific subject matter; therefore, its application to other topics or learning contexts requires further investigation. In addition, the empirical testing of the instrument was conducted on a sample with limited size and characteristics, meaning that the findings cannot yet be broadly generalized. Furthermore, the measurement of students' systems thinking skills in this study relied solely on a two-tier multiple-choice instrument, which may not fully capture students' deeper understanding when compared to the use of other assessment methods, such as interviews or essay-based tests.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

The first, second, third, and fourth authors jointly conducted the experiments and prepared this manuscript. All authors also collaboratively reviewed and revised the entire manuscript.

AI DISCLOSURE STATEMENT

The author used ChatGPT during the preparation of this manuscript to assist with language refinement, grammar improvement, and translation into an appropriate academic style. All AI-generated suggestions were carefully reviewed, verified, and revised by the author as necessary. The author takes full responsibility for the content, interpretation, and conclusions presented in this publication.

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AUTHOR PROFILES

Endang Susilawati
endsusiawati001@gmail.com
Student, Universitas Pendidikan Indonesia
Lecturer, STKIP Taman Siswa Bima
SINTA ID: 6180725

Ida Hamidah
idahamidah@upi.edu
Lecturer, Universitas Pendidikan Indonesia
SINTA ID: 5978332

Nuryani Rustaman
nuryanirustaman@upi.edu
Lecturer, Universitas Pendidikan Indonesia
SINTA ID: 5991811

Winny Liliawati
winny@upi.edu
Lecturer, Universitas Pendidikan Indonesia
SINTA ID: 257924