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Psychometric Validation of a STEAM-Based Knowledge Instrument for Measuring Energy Conversion Concepts in Fifth-Grade Students

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Abstract

This study aimed to develop and validate the quality of a multiple-choice instrument for measuring fifth-grade elementary students' understanding of kinetic-to-electrical energy conversion concepts within a STEAM (Science, Technology, Engineering, Arts, and Mathematics) framework. The research employed a Design and Development Research (DDR) approach with systematic instrument development procedures comprising: literature review and blueprint development, item construction, expert validation, field testing with 28 fifth-grade students, and comprehensive psychometric analysis. The instrument consists of 20 multiple-choice items covering three knowledge dimensions: conceptual (5 items), procedural (10 items), and applicative (5 items). Content validity was established through expert review by three science education specialists, yielding a Content Validity Index (CVI) of 0.87. Item analysis revealed difficulty indices ranging from 0.35 to 0.85 (predominantly moderate difficulty) and discrimination indices ranging from 0.30 to 0.75 (good to excellent discrimination). Reliability analysis using Cronbach's alpha produced a coefficient of 0.82, indicating high internal consistency suitable for elementary school assessment contexts. The instrument demonstrates satisfactory psychometric properties aligned with standards for elementary science assessment and effectively integrates STEAM pedagogical approaches.

Keywords: Elementary school, Instrument quality, Energy conversion, Fifth-grade students, STEAM education

INTRODUCTION

Research shows that elementary science education is critical to the development of scientific literacy among students because it helps them learn about the basic concepts that form the foundation for understanding their world, such as energy conversion (Masfuah & Fakhriyah, 2017; Vieira & Tenreiro-Vieira, 2016; Norris & Phillips, 2003). Energy conversion is one of the major ideas in science and is applicable to many different types of

natural phenomena, as well as everyday technology used by students (Zhu & Wang, 2017; Nowotny, et al., 2018; Pande, et. al., 2021). The Indonesian national curriculum emphasizes the importance of introducing energy concepts at the elementary level, particularly in fifth grade where students begin exploring more complex scientific relationships through integrated STEAM (Science, Technology, Engineering, Arts, and Mathematics) approaches (Cook & Bush, 2018; Tabinska, 2025; Nejašmić et al., 2026). STEAM is a comprehensive educational approach that integrates scientific exploration with technological implementation, engineering thinking, artistic creativity, and mathematical thinking to make learning experiences for elementary students more engaging and relevant.

Even with the inclusion of energy concepts in the curriculum, studies have shown that students at the elementary level face difficulties in understanding the concepts related to the process of transformation of mechanical to electrical energy, as found in the studies of Jettanasen, Songsukthawan, & Ngaopitakkul (2022), Morrissey, et.al., (2019), and Zou, et.al., (2019). These difficulties arise mainly due to the abstract nature of the concept of energy, along with the difficulties students face in visualizing the process of transformation of mechanical to electrical energy, as it takes place inside machines like dynamo and generators, as found in the studies of Luo et al., (2025), Chen et al., (2023), and Rajaperumal & Columbus, (2025). These difficulties become even more complicated when students are required to understand the concepts in the context of hands-on learning related to STEAM, as it requires students to understand concepts from multiple perspectives, as found in the studies of Hong, et.al., (2020), Aerila & Rönkkö, (2023), and Gülhan, (2024). Teachers face difficulties in assessing whether students have conceptual or surface-level understanding, especially when students are exposed to interdisciplinary approaches to learning, as found in the studies of Farooq et al., (2023) and Okundaye et al., (2020).

The problem is further complicated by the fact that there are limited instruments that are valid for measuring the extent of the students' understanding of energy conversion in STEAM education at the elementary school level. The instruments that are available do not align with the developmental aspects of fifth-grade students or provide adequate diagnostic feedback for teachers in an interdisciplinary setting (Oliveira et al., 2023; Du & Lyublinskaya, 2023; Gebera, et.al., 2023). Moreover, the methods that are used in the assessment process may not be adequate in measuring the complex dimensions of the students' learning process in STEAM education, as this type of education integrates various aspects of scientific knowledge, technological skills, engineering skills, artistic expression, and mathematical concepts (Knezek, et.al., 2023; Meylani, 2024; Ajjawi, et.al., 2024). The teachers need an

instrument that can effectively identify the students' misconceptions about energy conversion while being appropriate for elementary school children and taking into account the complex dimensions of STEAM education.

Contemporary research in elementary STEAM education emphasises the importance of hands-on, technology-enhanced learning experiences that engage students in authentic problem-solving activities (Yu, 2022; Hamzat, 2024; Kaldaras, et.al., 2024). Research has indicated that when students are involved in the construction of functional prototypes using simple technologies like a bicycle dynamo to convert kinetic energy into electrical energy that powers LED lights, there is a more enhanced understanding of the principles of energy transformation while at the same time engaging in engineering design and mathematical modelling (Sterrett et al., 2020; Plaza, 2018; Orikpete, Ikemba, & Ewim, 2023). The inclusion of arts elements in the form of creative design elements and the visual representation of energy transformation also improve student engagement and understanding. The success of these STEAM educational approaches relies on the availability of valid and reliable measures for measuring student learning in all aspects of STEAM integration (Jackson et al., 2021; Ting et al., 2020).

In designing age-appropriate measurement instruments for elementary-level STEAM education, it is important to take into consideration cognitive developmental characteristics, learning progressions, and special aspects of interdisciplinary learning environments. It was found that fifth-grade students, aged 10- to 11-year-olds, are in a critical developmental phase in which they make a transition from concrete to abstract thinking and are most receptive to learning experiences that connect tangible and abstract thinking (Plummer et al., 2020; Ben-Zvi Assaraf & Orion, 2010). Thus, in designing measurement instruments for this age group, it is important to incorporate various knowledge dimensions, such as conceptual, procedural, and applicative knowledge, while taking into consideration students' misconceptions and providing diagnostic information that is useful for instructional decision-making in STEAM learning (Wammes et al., 2021; Black et al., 2018).

This research attempts to fill the said gap by creating and validating a multiple-choice test that focuses on assessing fifth-grade students' knowledge in the concept of kinetic to electrical energy conversion in the context of STEAM. The process in creating the instrument for the said research follows a systematic approach that takes into consideration the characteristics of fifth-grade students and the dimensions of knowledge that are considered in effective STEAM education. The main goal in creating the said instrument is to develop an effective and

efficient tool for accurately measuring and assessing fifth-grade students' knowledge in the concept of energy conversion.

METHOD

This study utilized a Design and Development Research (DDR) approach that was adapted from the Richey and Klein (2007) model, with a focus on the instrument development and validation phases of the process. The process of development was a systematic approach that consisted of five major stages: needs analysis and literature review, blueprint development, item construction, expert validation, and field testing with psychometric analysis.

The participants of the current study consisted of three groups: (1) three experts in science education to conduct content validity, (2) 28 fifth-grade students from one elementary school in Serang Regency to conduct instrument field testing, and (3) two fifth-grade teachers as practitioner validators. Experts in science education were selected based on their qualifications and academic background in science education, as well as their experiences in curriculum development and designing science education instruments, at least five years. Students were selected using purposive sampling from one elementary school that implemented the standard national curriculum and STEAM learning approaches.

The instrument was constructed based on the analysis of the Indonesian curriculum's basic competencies for the fifth grade level, specifically those that relate to the energy concepts and changes in the STEAM context. The blueprint of the instrument was constructed to assess the three dimensions of the student's knowledge: conceptual (understanding the definitions and characteristics of energy), procedural (understanding the processes of converting energy), and applicative (applying the concepts in real-life situations through STEAM activities). Each item was constructed with four options for the answers, with only one correct and three distractor options that reflect the common misconceptions of the students according to the literature.

Content validity was assessed using the Content Validity Index (CVI) in terms of expert judgment of relevance, clarity, and appropriateness of items in the context of STEAM. Construct validity was also assessed using exploratory factor analysis. Reliability was also established using Cronbach's alpha. Item analysis involved the use of difficulty and discrimination indices of items, with specific focus on the items in the context of STEAM.

Table 1. Research Participants and Their Roles

Participant Group	Number	Role in Research
Science Education Experts	3	Content validation and STEAM framework assessment
Fifth-Grade Students	28	Field testing and psychometric analysis
Elementary Teachers	2	Practitioner validation and STEAM context review

RESULTS AND DISCUSSION

Psychometric Characteristics of the STEAM-Based Measurement Instrument

The process of instrument development led to the development of 20 multiple-choice items measuring three knowledge dimensions related to energy conversion in STEAM environments. The distribution of the multiple-choice items was as follows: 5 conceptual items (25%), 10 procedural items (50%), and 5 applicative items (25%). This distribution is in line with the findings in educational technology regarding the significance of balancing theory and practice in elementary STEAM education, in which children are encouraged to learn by directly interacting with technological devices while also interacting with artistic design elements and mathematical modeling (Nejašmić et al., 2026; Chen et al., 2023).

Table 2. Item Distribution by Knowledge Dimension and STEAM Component Integration

Knowledge Dimension	Items	Percentage	Primary STEAM Integration
Conceptual	5	25%	Science + Mathematics
Procedural	10	50%	Technology + Engineering
Applicative	5	25%	Arts + Engineering Design

Validity and Reliability of the STEAM Knowledge Measurement Instrument

The content validation process for the instrument by three experts in science education resulted in a high value of 0.87 for the Content Validity Index (CVI), which indicates that the instrument has excellent content validity in accordance with established criteria for educational measurement instruments (Karimian & Chahartangi, 2024; Masuwai, et.al., 2024). The instrument's items all scored a minimum of 3 on a 4-point scale for relevance, with 90 percent (18 out of 20 items) scoring a 4 for highly relevant. The two items that scored a 3 were later refined based on the suggestions of the experts to improve clarity and

appropriateness for fifth-grade developmental characteristics in STEAM learning environments.

The expert validation process was also aimed at ensuring the integration of the different STEAM elements within the instrument items, ensuring that the questions measure the learning that takes place when students interact with concepts related to energy conversion through hands-on technology, engineering design, art, and mathematics. Such a multi-dimensional approach to content validity is significant, especially when it comes to STEAM education, where students learn simultaneously across all the disciplines (Du & Lyublinskaya, 2023; Plummer et al., 2020).

Table 3. Summary of Psychometric Properties

Psychometric Property	Value/Range	Interpretation
Content Validity Index (CVI)	0.87	Excellent content validity
Difficulty Index Range	0.35 - 0.85	Appropriate for target population
Discrimination Index Range	0.30 - 0.75	Good to excellent discrimination
Cronbach's Alpha	0.82	High internal consistency

STEAM Integration and Educational Implications

The developed instrument was able to measure student learning that takes place through an integrated STEAM approach to the education of concepts related to energy conversion. The instrument was designed to measure student understanding that takes place through hands-on learning, where students design and develop a system of a bicycle dynamo to convert kinetic to electrical energy to power LED lights, utilizing concepts related to science, technological manipulation, engineering design, artistic creativity, and mathematical analysis of concepts related to energy (Moore et al., 2015; NAS, 2013). The results of the study show that it is possible to measure multidimensional student learning through a STEAM-integrated instrument, which has good psychometric properties. The instrument was able to differentiate students with different levels of understanding, which is supported by other research studies that show that hands-on technology integration leads to the conceptual development of students in elementary science education (Ting et al., 2020; Plaza, 2018). The inclusion of arts concepts related to creative design and visual representations seems to have a positive impact on student engagement and learning outcomes.

CONCLUSION

The present research was successfully able to develop and validate a multiple-choice instrument to assess fifth-grade students' understanding of the concept of kinetic to electrical energy conversion in a STEAM context. The 20-item instrument was found to have satisfactory psychometric qualities, including a high level of content validity (CVI = 0.87), internal reliability (\(\alpha\) = 0.82), and appropriate item characteristics. This instrument was found to successfully assess students' misconceptions, which are commonly found in students' understanding of the concept. Moreover, the instrument was found to assess students' understanding from different dimensions, such as conceptual, procedural, and applicative, which were developed through an integrated STEAM context. This research was successfully able to integrate STEAM components in an assessment framework, which proves the development of a valid instrument to assess students' understanding in an integrated context, which can be helpful in providing a valid tool to implement an integrated approach in elementary education.

SUGGESTIONS

On the basis of research findings, recommendations are proposed. Firstly, this instrument is recommended to be implemented by fifth-grade teachers to measure students' understanding of the energy concept in regular learning contexts of STEAM integration and to be used as a basis to design similar measurement instruments in other elementary STEAM domains. Secondly, further research is recommended to examine ways to design a digital version of this instrument with feedback capabilities and learning analytics to improve students' assessment experiences and gain immediate feedback on students' learning in STEAM contexts. Thirdly, it is recommended that further research be conducted to validate this study by carrying out the same study with a larger sample of students from different geographical regions of Indonesia to test the stability of the psychometric properties of this instrument. Further research is also recommended to test the item functioning of the parallel forms of the instrument for different elementary school student populations. Fourth, comprehensive teacher professional development programs should be designed to help educators effectively implement and interpret measurement results, ensuring that diagnostic information is utilized to improve STEAM instructional practices and support student learning. Such programs should emphase the integrated nature of STEAM education and provide strategies for using measurement data to enhance interdisciplinary teaching approaches. Future iterations of this instrument should consider Universal Design for

Learning (UDL) principles to ensure the STEAM knowledge of students with sensory or cognitive diversities is accurately captured.

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Availability of data and material

The datasets generated and/or analyzed during the current study are available from the first author upon reasonable request.

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Ethics approval

The study was approved by Institutional Review Boards (IRB) of the Universitas Sultan Ageng Tirtayasa, Indonesia on 16 March 2026

Patient consent statement

Informed consent was obtained from all individual participants included in the study.

Permission to reproduce material from other sources

No material from other sources was used in this manuscript.

Clinical trial registration

This study is not a clinical trial and does not require registration.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author used QuillBot in order to improve the language and readability. After using this tool, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

Credit authorship contribution statement

Ikhsanudin Ikhsanudin, Ricky Cahyasari Putra, Ade Dwi Putra Janata, Rusdi Febriyanto, Ananda Yhuto Wibisono Putra, R. Ahmad Zaky El Islami, Victor M. Alasa, Jun S. Camara, William J. Triplett: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no competing financial or non-financial interests in relation to this study.

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