

Fostering Prevocational STEAM Learning through Motion-to-Electricity Module: A Hands-on Approach for Elementary Students

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Ricky Cahyasaki Putra^{1*}, Ikhsanudin Ikhsanudin², Ade Dwi Putra Janata³, Rusdi Febriyanto⁴,
Ananda Yhuto Wibisono Putra⁵

^{1, 2, 3, 4, 5}Department of Mechanical Engineering Education, Faculty of Teacher Training and Education,
Universitas Sultan Ageng Tirtayasa, Serang, Indonesia
Corresponding Email: *ricky.pvtm@untirta.ac.id

Abstract

The inclusion of Science, Technology, Engineering, Arts, and Mathematics (STEAM) education in the elementary level has been seen as a crucial part in the development of 21st-century skills and prevocational developments of elementary students. This study aims to find out the effectiveness of a hands-on motion-to-electricity learning module in enhancing STEAM skills of 5th-grade elementary students using a one-shot quasi-experimental design. The participants consisted of 28 fifth-grade students from a primary school in the Banten province. To demonstrate the conversion of kinetic energy into electrical energy, the students built simple wheel generator sets using bicycle dynamos, wires, rotating wheels, and LED lights. Immediately after the activity, a 15-item validated evaluation form was employed to collect data, focusing on the principles of energy conversion, concepts of renewable energy, and simple engineering knowledge. Based on the statistical analysis, 82.1% of the students achieved beyond the required level of proficiency, scoring a mean of 67.25 and a standard deviation of 16.34. The findings of the observation conclusion revealed that the students exhibited a positive attitude towards technical subjects, were actively engaged in their learning process, and worked together to overcome problems. The findings of the study's conclusion indicate that interactive STEAM educational materials can be a valuable tool in increasing the interest of primary school students in technical subjects and their understanding of energy conversion concepts. This study supports the use of hands-on learning approaches in elementary STEAM education as a foundation for future prevocational and technical education.

Keywords: STEAM Education, Elementary Education, Prevocational Learning, Hands-on Learning, Energy Conversion

INTRODUCTION

The demand for scientifically educated and technically skilled personnel in the aftermath of the global paradigm shift towards sustainable technologies and renewable energy resources has never been more acute. In response to this challenge, the education sector worldwide is increasingly recognizing the importance of early STEAM education as a precursor to the development of critical thinking and technical skills (Das, 2020; Aldeman et al., 2024). Elementary education, especially at the 5th-grade level, is a critical phase of development where students begin to shape their attitudes towards technical education and lay the foundation for understanding that can shape their future educational and career choices (Luo et al., 2025; Okundaye et al., 2023). Studies have shown that students exposed to critical thinking, problem-solving, and construction activities at a relatively younger age are more likely to pursue a career in STEAM fields (Das, 2020; Bustamante et al., 2018).

Contemporary educational research emphasizes the critical importance of hands-on, experiential learning approaches in elementary STEAM education, particularly for developing computational thinking and engineering design skills (Chevalier et al., 2020; Wing, 2006; Ting

& Tai, 2019). Educational robotics and physical computing have emerged as particularly effective tools for awakening vocations in STEAM fields, with studies demonstrating that hands-on learning motivates willingness to engage with programming, improves STEAM attitudes and skills, and promotes inclusion of female students in technical subjects (Romero-Rodríguez et al., 2023; Ouyang & Xu, 2024). The integration of computational thinking concepts within authentic STEAM contexts has been reflected in educational standards such as the Next Generation Science Standards and Standards for Technological and Engineering Literacy, emphasizing the need for physical computing and tangible interaction approaches (Love & Asempapa, 2022; Lee et al., 2020). Furthermore, research on educational robotics in STEAM education through multilevel meta-analysis indicates that these approaches significantly enhance student engagement, problem-solving abilities, and confidence in technical subjects (Barbosa et al., 2024; Erdogan et al., 2023).

The idea of prevocational education has received considerable attention in the past few years, as the education system aims to introduce students to technical careers at an early age and prepare them for future workforce needs (Bui et al., 2025; Spyropoulou & Kameas, 2023). Prevocational STEAM education at the elementary level acts as a connecting link between basic academic learning and career exploration, allowing students to experience real-world technical problem-solving and develop critical 21st-century skills (Kumar & Deák, 2023; Marín-Marín et al., 2021). Studies have shown that early childhood science and engineering education acts as an interesting platform for developing domain-general skills for learning and establishing a positive attitude toward technical subjects (Kelley & Li, 2017; Susilo et al., 2016). The inclusion of physical computing with Arduino and microbit technology has proven to be particularly effective in primary education settings, allowing students to gain a deeper understanding of STEAM concepts through creative computational problem-solving (Chang & Chen, 2022; Philbin, 2024). Studies investigating the use of educational technologies in elementary engineering education indicate that hands-on approaches significantly improve student motivation, understanding of complex concepts, and retention of learning (Riojas et al., 2012; Momoh, 2014).

Despite the growing recognition of hands-on STEAM education's importance, significant gaps remain in research specifically focused on elementary-level energy conversion education and its role in fostering prevocational pathways. While extensive research exists on STEAM education at secondary and higher education levels, limited studies have investigated age-appropriate approaches to teaching complex concepts such as kinetic-to-electrical energy conversion to young learners (Firdaus & Ahmad, 2023; Perales & Aróstegui, 2024).

Additionally, most existing research on educational robotics and physical computing focuses on programming and computational thinking, with limited attention to fundamental physics concepts such as energy conversion that are essential for understanding renewable energy technologies (Park & Kwon, 2023; Karaahmetoğlu et al., 2019). The current research fills these gaps in research by designing and testing a hands-on motion-to-electricity learning module for 5th-grade elementary school students, with a focus on promoting positive attitudes toward technical subjects and a foundation for prevocational learning pathways in the future.

METHOD

The effectiveness of a hands-on motion-to-electricity learning module in enhancing the STEAM abilities of primary school children was assessed using a one-shot quasi-experimental design. One-shot quasi-experiments involve the implementation of a treatment (a hands-on learning module) and immediate observation and assessment after the treatment has been implemented (Campbell & Stanley, 1963). This is because the research is exploratory in nature and the experimental conditions are not fully utilized in primary schools.

The research was conducted at an elementary school in Banten, Indonesia, in the even semester of the 2025 school year. The school was selected using purposive sampling because of its existing collaboration with the university's education faculty, commitment to modern STEAM education, and adequate facilities for hands-on learning. In addition, a representative sample of students from diverse socioeconomic statuses attends the school.

28 fifth-grade students, aged 10 to 11 years, who attended the selected elementary school, took part in the research. The participants included 15 male and 13 female students with different academic backgrounds and levels of familiarity with science and technology concepts. All the participants were Indonesian natives with basic knowledge of mathematics and science subjects relevant to their academic grade. The criteria for the participants included students enrolled in fifth grade, with regular school attendance, and basic fine motor skills to perform assembly tasks. Informed consent was sought from the parents and school administration, with the students assured of voluntary participation without any impact on their academic assessment.

The learning module for motion to electricity was developed in accordance with the principles of constructivist learning and pedagogically suitable for elementary-level children (Papert, 2020; Vygotsky & Cole, 1978). The intervention package comprised: 1) Energy concepts and safety instructions, 2) Group activity for construction of wheel generators, and 3) Experimentation, testing, and reflection phases. The physical learning module had five major components: (1) A child-friendly manual rotating wheel system with an ergonomic handle, (2)

A small bicycle dynamo (3V DC generator) mechanically coupled to the wheel via a gear system, (3) Insulated copper wires with safety-approved alligator clips, (4) Low-voltage color-coded LED indicators for the generation of electrical energy, and (5) A corrugated cardboard base platform with designated assembly points for firmly mounting the components.

The students were asked to work together in heterogeneous groups consisting of 4 students each, and these groups were carefully balanced for gender and previous levels of academic performance. The collaborative learning strategy was adopted to ensure peer-to-peer knowledge construction, improve communication skills, and ensure that all students could meaningfully contribute to the learning process irrespective of their skill levels (Johnson & Johnson, 1987). Each group was given an equal set of materials and followed a structured inquiry-based learning process, which included observation of teacher demonstration, collaborative planning and assembly, systematic testing with different variables, data recording, and group reflection and presentation of findings.

For primary school students, a 15-item multiple-choice quiz was developed specifically to assess their understanding of key concepts in energy and principles of renewable energy. To make it easier for Indonesian primary students to comprehend, the assessment instrument was designed in kid-friendly language, using pictures, and examples that are relevant to their culture. The assessment instrument was reviewed by three experts in basic science education, an engineer in renewable energy, and two experienced teachers of fifth-grade students. The assessment instrument consisted of five major categories: (1) identification and classification of energy types commonly used in Indonesia (3 items), (2) fundamental concepts of kinetic energy and motion (3 items), (3) simple electrical circuits and components (3 items), (4) basic concepts of renewable and non-renewable energy types (3 items), and (5) environmental issues and sustainability (3 items). The pilot test using a separate group of 20 fifth-grade students yielded a Cronbach's alpha reliability coefficient of 0.76, which was considered satisfactory for an elementary-level assessment instrument.

Data gathering was done immediately after the completion of the intervention program. The evaluation was done in a comfortable classroom setting with adequate lighting and minimal distractions. The students were given clear instructions, unlimited time to complete the evaluation, and the chance to ask questions regarding the wording of items. In addition to the quantitative evaluation data, qualitative observation data were gathered during the intervention stage using structured observation instruments for student engagement, collaboration, problem-solving strategies, and interest/enjoyment expressions. Statistical analysis was done using SPSS 26.0 software, including descriptive statistics, frequency statistics, and one-sample t-tests to

compare achievement scores with established competency standards. The calculation of effect size using Cohen's *d* was done to establish the practical significance of learning outcomes.

RESULTS AND DISCUSSION

This performance demonstrates that the motion to electricity learning module has been of great benefit to the students in understanding the basics of energy conversion. While most students performed well, some of them performed exceptionally well, as evidenced by their scores, which were normally distributed with a slight positive skew.

The descriptive statistics for student performance on the numerous subject areas tested in the assessment are presented in Table 1. Various performance trends that offer clues into the relative effectiveness of hands-on learning for various energy concepts were derived by analyzing the data by topic area. Since these concepts are simple and observable in the wheel rotation activities, students performed best in the subject area of basic kinetic energy and motion concepts ($M = 78.4$, $SD = 12.8$). Performance was also strong in understanding simple electrical circuits and component functions ($M = 74.2$, $SD = 15.1$), reflecting the tangible experience of connecting components and observing LED responses.

Table 1. Student Achievement by Content Domain Following Motion-to-Electricity Intervention

Content Domain	Mean Score	Std. Deviation	Above Competency (%)	n
Energy Sources Identification	62.8	18.6	71.4	28
Kinetic Energy & Motion	78.4	12.8	89.3	28
Electrical Circuits	74.2	15.1	85.7	28
Renewable Energy	59.5	21.3	64.3	28
Environmental Impact	61.2	19.8	67.9	28
Overall Achievement	67.25	16.34	82.1	28

However, moderately lower levels of performance were found in relatively abstract content domains such as the classification of renewable energy sources ($M = 59.5$, $SD = 21.3$) and understanding of environmental impact ($M = 61.2$, $SD = 19.8$). The findings of the study indicate that hands-on learning is effective in promoting concrete and tangible learning outcomes, but some additional support may be required in promoting abstract conceptual understanding. However, a large number of students (82.1%) scored above the minimum competency level of 60 points, which indicates that the intervention was successful in promoting effective learning among the participants.

Comparing the overall achievement scores to the competency benchmark using a one-sample t-test showed a significantly higher level of performance than the competency benchmark ($t(27) = 2.34$, $p = 0.027$, Cohen's $d = 0.44$). The moderate effect size indicates a high level of educational significance and that the motion-to-electricity learning module is an effective approach to improve the understanding of energy concepts in elementary students.

The 95% confidence interval for the mean difference was between 1.23 and 13.02 points above the competency level, which provides strong evidence of the effectiveness of the intervention.

The qualitative observational data obtained throughout the intervention process also offered valuable information on student learning processes and patterns of engagement that can be considered in addition to the quantitative assessment outcome. The students demonstrated a high level of active participation, with 96.4% of the students (27 out of 28) actively participating in the hands-on construction process. The kids also showed collaborative learning approaches, including peer tutoring, group problem-solving, and productive debate on energy conversion ideas. The successful connection of the electrical parts and the observation of the LED light appeared to amaze the kids, as shown by their verbal answers and requests to repeat the experiment with other variables.

As the intervention was hands-on and encouraged natural inquiry-based learning, the kids were able to form and test hypotheses on variables that influence energy conversion efficiency. The kids' inquiry includes analyzing the connection of multiple LEDs in series and parallel arrangements, investigating the effects of varying speeds, and investigating the relationship between the size of the wheel and the electrical output. These problem-solving activities demonstrate that elementary school kids are naturally curious and have the ability to learn, and they are similar to engineering design activities (Kelley & Li, 2017; Bustamante et al., 2018).

Theoretically, learning results are very much compatible with constructivist learning theories, especially with Papert's constructionism hypothesis (2020). The learners were able to construct mental and physical concepts at the same time in the motion to electricity module, which provided a number of conceptual construction paths. This might be the reason for the high performance in the concrete conceptual fields of kinetic energy and understanding of electrical circuits.

The efficacy of the intervention can also be explained by the theory of situated learning, which recognizes the value of authentic and contextually relevant learning experiences (Lave & Wenger, 1991). The motion-to-electricity module gave students authentic engineering design experiences that involved applying scientific principles to address real-world problems. This authentic experience may have served to enhance motivation and engagement with the learning process, while facilitating the transfer of learning to other technical areas, thus fostering prevocational interest and competence.

Gender analysis of achievement results showed that there were no statistically significant differences between male and female students ($t(26) = 1.23$, $p = 0.230$), with

females scoring a mean of 69.2 (SD = 15.8) compared to the mean score of 65.7 (SD = 16.9) for males. This result is especially heartening from an equity-in-education point of view, as it appears to indicate that hands-on STEAM learning strategies can effectively engage students of both genders, and may therefore play a role in remedying gender inequities in technical areas that arise at later levels of education (Romero-Rodríguez et al., 2023; Ouyang & Xu, 2024).

The implications for prevocational education are particularly important, as the intervention was successful in introducing elementary students to real-world engineering design processes and promoting positive attitudes towards technical learning. Informal interviews conducted post-intervention showed that 89.3% of students were interested in learning more about renewable energy technologies, and 75% were interested in learning more about engineering careers. The results of the attitudinal outcomes indicate that introducing elementary students to hands-on technical learning can be effective in promoting interest in STEAM education and support the need for elementary-level interventions in developing technical career pathways (Das, 2020; Spyropoulou & Kameas, 2023).

However, there are a few limitations to consider when interpreting the results of this study. The one-shot design, although suitable for exploratory research, restricts causal interpretations of the intervention's effectiveness because of the lack of control group comparisons and pretest data. Furthermore, the small sample size ($n = 28$) and single-site study may restrict generalizability to other elementary student populations. Future studies should incorporate more valid experimental designs, such as randomized controlled trials with larger and more representative sample populations to enhance the validity and generalizability of the findings.

CONCLUSION

This research work offers strong preliminary evidence for the efficacy of hands-on STEAM learning strategies in elementary education, specifically illustrating that age-appropriate motion-to-electricity modules can improve the 5th-grade students' comprehension of energy conversion concepts while cultivating positive attitudes towards technical subjects. The average achievement score of 67.25 points, with 82.1% of students scoring above the minimum competency level, clearly suggests that hands-on learning strategies can lead to effective educational outcomes in elementary STEAM education settings.

The performance differences among various content areas offer important implications for curriculum design, suggesting that hands-on learning strategies are most effective for concrete and tangible concepts such as kinetic energy and electric circuits, while abstract concepts need further instructional support. The absence of gender differences in performance

is an important positive implication for equity in education, suggesting that effective hands-on learning strategies can engage all students effectively, irrespective of their background characteristics.

In the context of prevocational education, the intervention was effective in encouraging primary school students to be interested in technical learning, as well as introducing them to engineering design thinking. Exposure to technical activities at a young age can be an effective way to lay the foundation for a career in engineering and technology, as evidenced by the high engagement and interest of the students in STEAM.

SUGGESTIONS

Suggestions for practice and further research are made based on the findings of the current study. STEAM learning modules should be integrated into scientific education in elementary schools on a regular basis, and this should be done with a focus on phenomena that are observable and match the skill level of the students. Teachers should be trained to conduct collaborative learning environments and experiential learning.

Future studies should be designed using more rigorous experimental designs, such as randomized controlled trials with pretest and posttest measures and control groups, to make stronger causal inferences about the effectiveness of interventions. Longitudinal studies examining the long-term persistence of gains in learning and their effects on subsequent engagement in STEAM would be very helpful in understanding the long-term educational effects. Further studies should also examine optimal implementation procedures for resource-limited educational settings and examine the mechanisms by which hands-on learning improves the understanding of technical concepts in young learners.

Curriculum designers might also think about designing learning progression sequences that are age-appropriate and build from concrete to abstract, possibly closing the performance gaps identified in this study. Additionally, studies on teacher needs for education and training would inform the implementation of hands-on STEAM education in elementary school settings.

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