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Development of a Self-Propelling Motor Model Based on the Principle of Electromagnetic Induction as a Teaching Aid for the Invention Subject

Muhammad Nasrul Hakim Badrol Ihsan[1], Mohd Firdaus Mustaffa Kamal[1,*], Mohamed Nor Azhari Azman[1], Wan Nurlisa Wan Ahmad[1]

[1] Faculty of Technical and Vocational, Sultan Idris Education University, 35900 Tanjong Malim, Perak, Malaysia

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ABSTRACT

This study aims to develop and evaluate the validity of a teaching aid, the "Self-Propelling Motor" kit, which is based on the principle of electromagnetic induction. The development of this kit was initiated to address a significant challenge in STEM education, specifically in the Form 5 Invention (*Reka Cipta*) subject, where students have difficulty visualizing abstract physics concepts such as Fleming's Left-Hand Rule and the Lorentz Force. This lack of visual reference often results in memorization without genuine understanding. The study employed the ADDIE (Analysis, Design, Development, and Evaluation) instructional design model. The Implementation phase was excluded, as the research scope focused specifically on expert validity evaluation. A qualitative approach was utilized, involving purposive sampling of three Subject Matter Experts (SMEs) with extensive experience in Physics, Engineering, and Invention education. Data were collected through live product demonstrations, semi-structured interviews, and observation checklists, followed by an inductive thematic analysis. The findings demonstrate that the developed kit possesses high content validity; it accurately complies with scientific principles and aligns perfectly with the Standard Curriculum and Assessment Document (DSKP) requirements. The experts confirmed that the "open concept" kit is safe, practical, and highly effective in bridging the gap between theoretical knowledge and visual application. To further enhance the educational value and support self-directed learning, the experts suggested integrating QR codes linked to digital notes and adding directional arrow stickers to visualize current flow.

1. Introduction

In the rapidly evolving era of globalization, STEM (Science, Technology, Engineering, and Mathematics) education has become a key foundation in developing competitive and innovative human capital. This aligns with the demands of the Fourth Industrial Revolution (IR 4.0), which

* *Corresponding author.*
E-mail address: firdaus.mk@ftv.upsi.edu.my

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requires students to master 21st-century skills such as critical thinking, problem-solving, and creativity [16]. However, a major challenge in Invention (*Reka Cipta*) education is ensuring that students truly comprehend abstract physics concepts, particularly electromagnetic induction [17]. This concept is crucial as it forms the basis of many modern technologies, including electric motors, generators, and renewable energy systems. Despite its importance, students often struggle to grasp these principles because teaching remains overly focused on theoretical explanations and traditional methods like lectures and slide presentations. Consequently, students tend to memorize formulas without developing a genuine understanding of the underlying physical phenomena [9]. Studies have shown that students fail to build a clear mental picture of how electrical current and magnetic fields interact to produce mechanical movement, leading to high failure rates when answering application-based questions in examinations. Furthermore, educators themselves acknowledge the challenges in teaching this subtopic effectively due to its invisible and abstract nature [14]. The lack of interactive teaching resources and exposure to hands-on experiments significantly contributes to this weak mastery, ultimately hindering the development of higher-order thinking skills [7].

A significant factor exacerbating this issue is the limitation of existing teaching aids [14]. Current commercial kits available in the market are often too general, expensive, or difficult to acquire, particularly for rural schools. More importantly, they are typically enclosed, concealing internal components such as coils and commutators, which completely restricts functional analysis. This lack of transparency limits inquiry-based and project-based learning opportunities, as students cannot visually connect theoretical concepts—like Fleming's Left-Hand Rule and the Lorentz Force—to real-world physical applications [15].

Therefore, there is an urgent need to introduce an innovative teaching approach utilizing a functional, dynamic physical model. This study focuses on the development of a "Self-Propelling Motor" model tailored specifically for the Form 5 Invention syllabus. Grounded in constructivist theory, this open-concept model aims to provide dynamic visual and kinaesthetic learning experiences by allowing students to directly observe the conversion of electrical energy into mechanical kinetic energy [7]. By bridging the gap between abstract theory and tangible application, the model supports inquiry-based pedagogy, boosts student motivation, and fosters collaborative learning and soft skills. The specific objectives of this study are to identify the development needs for this teaching aid, develop the model guided by the ADDIE instructional design framework, and evaluate the content validity and usability of the model through expert evaluation.

2. Materials and Methods

The methodology of this study utilizes Design and Development Research (DDR) guided by the ADDIE Instructional Design Model [11,18].

2.1 Research Design and Approach

The ADDIE Model was adapted to include four main phases: Analysis, Design, Development, and Evaluation. The Implementation phase was excluded because the scope of the study was limited to expert validity evaluation rather than large-scale classroom testing [13]. A qualitative approach was employed because it allows for an in-depth exploration of the model's technical specifications, mechanical functionality, and pedagogical value, providing rich descriptive data that cannot be captured through numerical statistics alone [5,12].

2.2 Study Participants

This study utilized purposive sampling to select three Subject Matter Experts (SMEs) [4].The criteria for expert selection included an academic qualification of at least a Bachelor's Degree in Invention Education, Physics, or Electrical Engineering, more than five years of teaching experience, and technical expertise in electromagnetic applications.

2.3 Research Procedure (The ADDIE Framework)

Phase 1: Analysis The initial phase involved a needs analysis focusing on the challenges of teaching electromagnetic concepts and a thorough review of the Form 5 Invention Curriculum and Assessment Standard Document (DSKP) to ensure the product strictly aligns with the syllabus requirements [8].

Phase 2: Design The mechanical structure of the model was planned using Computer-Aided Design (CAD) software to ensure precision, especially the alignment between the shaft and the bearings. The electrical system was designed as a hybrid commutator "make-and-break" circuit. Copper tape was utilized over a dielectric insulating layer, covering only 180 degrees of the shaft to allow the rotor's momentum to complete the rotation without magnetic drag.

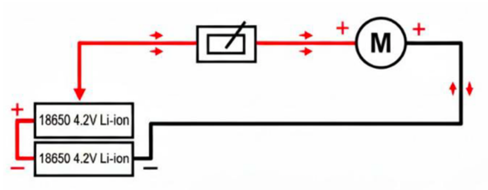

Fig. 1. Self-propelling motor circuit schematic

Phase 3: Development (Hardware)

The development phase involved the integration of digital fabrication and precision mechanical assembly.

- Structure: The bearing housing and base were fabricated using 3D printing with Polylactic Acid (PLA) filament at a nozzle temperature of 200°C. PLA was chosen for its environmental friendliness and dimensional stability [3].
- Mechanical Components: Grade 316 stainless steel rod was selected for the main shaft because it is non-magnetic, preventing it from sticking to the strong Neodymium stator magnets and causing friction. Series 623zz ball bearings were utilized to minimize rotational friction.
- Rotor & Stator: The rotor coil was symmetrically wound with 15-20 turns of SWG 27 enamelled copper wire to maintain a low weight while providing sufficient electromagnetic force. Neodymium magnets (20mm x 10mm x 5mm) were embedded securely in the base to act as the stator.

Phase 4: Evaluation

The evaluation involved a live demonstration (alpha testing) of the physical model to the experts, allowing them to observe the mechanical rotation, stability, and safety features directly, followed by a data collection session.

2.4 Instruments and Data Collection

Two main qualitative instruments were utilized: an observation checklist used during the non-participant live demonstration, and a semi-structured interview protocol conducted face-to-face with the experts.

2.5 Data Analysis

The data gathered from the interviews were processed using inductive thematic analysis [5]. The audio recordings were transcribed verbatim, and researchers generated initial codes which were then systematically categorized into main themes regarding content validity, practicality, and areas for refinement. Data from the observation checklist were triangulated with the interview themes to ensure high reliability and consistency in the findings [12].

3. Research Findings

The research findings are presented based on an inductive thematic analysis of the qualitative data gathered from semi-structured interviews and observation checklists involving three Subject Matter Experts (SMEs). The analysis was divided into pre-development (Needs Analysis) and post-development (Evaluation) phases.To visually summarize the core findings of this study, Figure 2 outlines the primary themes identified during both phases of the expert interviews.

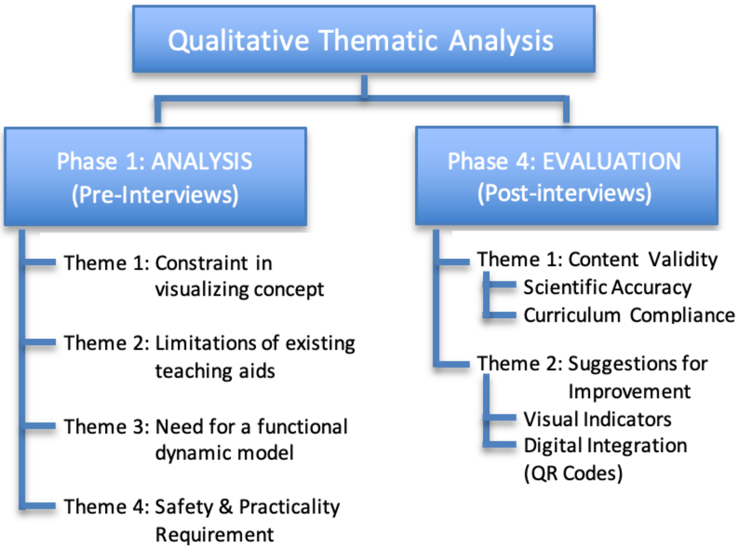

Fig. 2. Thematic analysis map for the self-propelling motor study

3.1 Needs Analysis (Pre-Development)

The initial pre-interviews with the experts identified several critical gaps in current teaching practices, which were categorized into key themes:

- Constraints in Visualizing Abstract Concepts: Experts highlighted that electromagnetic induction is often perceived as an "invisible" phenomenon, causing students to struggle with applying Fleming's Left-Hand Rule [9]. Without a clear physical reference, students tend to memorize textbook diagrams without genuinely understanding how the mechanical components function.

• Limitations of Existing Teaching Aids: Current commercial kits are frequently expensive, enclosed, or overly complex. Experts noted that enclosed kits hide crucial internal components like coils and commutators, which completely restricts students from conducting functional analysis [14].
• Need for a Dynamic, Functional Model: The SMEs emphasized the urgent necessity for a functional model that demonstrates stable and consistent movement. A static image is insufficient; students need to physically observe the direct conversion of electrical energy into mechanical kinetic energy.
• Safety and Curriculum Alignment: The model needed an "open-concept" design for visibility alongside strict safety measures, effectively bridging the gap between theoretical textbook knowledge and the practical application demanded by the Form 5 Invention curriculum [8].

3.2 Content Validity Evaluation (Post-Development)

Following the development of the "Self-Propelling Motor", post-interviews were conducted to evaluate its validity
Table 1 summarizes the post-interview themes and categories.

Table 1
Summary of themes and categories from expert evaluation

Theme	Category	Brief Description
Content Validity	Curriculum Compliance (DSKP)	Expert confirmation that the product meets the Content Standards and Learning Standards for the Invention and Physics subjects.
	Scientific Fact Accuracy	Confirmation that the product's mechanism operates in parallel with actual physical laws (Electromagnetic Law & Fleming's Left-Hand Rule) without any conceptual contradictions.
Improvement Suggestions	Addition of Visual Indicators	Expert suggestion to add directional arrow stickers to the circuit to help visualize the direction of current more clearly.
	Integration of Additional Information	Suggestion to create a digital 'Info Board' or use QR Codes to include comprehensive notes and guides.

The experts reached a strong consensus that the model possesses high content validity. Based on these themes, the experts confirmed the following:
• Scientific Accuracy: The experts confirmed that the physical operation of the motor accurately demonstrates the Lorentz Force. One expert stated, "When current enters in the labelled direction, the rotation of the coil is consistent with Fleming’s Left-Hand Rule."
• Curriculum Compliance: The kit successfully aligns with the Form 5 Invention Standard Curriculum and Assessment Document (DSKP) [8]. It effectively visualizes theoretical concepts, leaving no room for conceptual contradictions.
• Language and Terminology: The labels and technical terms utilized on the model’s base were verified as appropriate and easily comprehensible for secondary school students.

3.3 Technical Functionality, Safety, and Practicality

Data triangulated from the observation checklist and expert feedback confirmed the high functional reliability of the model. The integration of a transparent acrylic protective box was highly praised for allowing a 360-degree view while ensuring absolute safety from moving components and potential heat [2]. While the model functioned smoothly, one expert raised a practical concern regarding its physical scale for large-scale classroom demonstrations. For safety features, the integration of a transparent acrylic protective box was highly praised by the experts. It allows students to maintain a 360-degree view of the internal electromagnetic mechanisms while ensuring absolute safety experts confirmed the following:

• Scientific Accuracy: The experts confirmed that the physical operation of the motor accurately demonstrates the Lorentz Force. One expert stated, "When current enters in the labelled direction, the rotation of the coil is consistent with Fleming's Left-Hand Rule."
• Curriculum Compliance: The kit successfully aligns with the Form 5 Invention Standard Curriculum and Assessment Document (DSKP) [8]. It effectively visualizes theoretical concepts, leaving no room for conceptual contradictions.
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The expert evaluation phase further solidifies the product's educational value, confirming its high content validity and scientific accuracy [6]. The experts verified that the motor's physical rotation accurately demonstrates the Lorentz Force, effectively bridging the gap between theoretical textbook knowledge and the Form 5 Invention Standard Curriculum and Assessment Document (DSKP) [8].

Moreover, the constructive feedback provided by the experts highlights the growing necessity for hybrid learning approaches in 21st-century education. Ultimately, this study proves that self-developed, cost-effective educational innovations can achieve exceptionally high academic, functional, and safety standards. The integration of green technology elements, such as rechargeable batteries and PLA 3D-printed materials, further adds value to the product in line with sustainable education goals [3,10].

5. Conclusion

This study successfully achieved its primary objective of designing, developing, and validating the "Self-Propelling Motor" teaching kit utilizing the ADDIE instructional design framework [11]. By translating abstract and invisible electromagnetic principles—such as Fleming's Left-Hand Rule and the Lorentz Force—into a tangible, dynamic physical model, this innovation effectively addresses the visualization barriers that students frequently encounter in STEM and Invention education.

The expert evaluation phase robustly confirmed that the kit possesses high content validity, functioning with complete scientific accuracy without any conceptual contradictions [6]. Furthermore, it strictly aligns with the Form 5 Invention Standard Curriculum and Assessment Document (DSKP) while meeting stringent safety and practicality standards for school workshop environments [8]. The implications of this study are highly positive; it empowers educators with a confident demonstration tool and fosters a broader culture of cost-effective innovation within technical and vocational education institutions.

While the current model is highly effective for classroom use, it is recommended that future iterations integrate the experts' suggestions, namely adding visual directional arrows for current flow and embedding QR codes linked to digital tutorials. Finally, to empirically validate the kit's educational impact, future research should transition from expert validation to conducting quasi-experimental testing to quantitatively measure the model's direct effect on students' academic achievement and comprehension in an actual classroom setting.

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