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Development of an Arduino-Based Solar Pv Tracking Energy Learning Kit for the Electronic Design Topic In Education

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ABSTRACT

This study was conducted to address the shortage of interactive and practical teaching aids for the Form 2 Design and Technology (RBT) subject, specifically regarding the topic of Electronic Design. The primary aim of this study was to develop and evaluate an innovative, kit-based teaching aid named the "Arduino-based Solar PV Tracking Energy Learning Kit," which utilizes Arduino technology. Specific objectives included identifying the requirements for the kit's development, designing and developing the product based on the ADDIE Instructional Design Model, and evaluating the kit's usability among RBT teachers. The research employed a qualitative design and development (R&D) approach, involving semi-structured interviews with an instrument expert and three secondary school teachers experienced in teaching RBT. Qualitative data were analyzed using thematic and descriptive analysis methods. The results indicated that the average functional and content validity, based on expert evaluations, reached 100%. Furthermore, usability findings from the teachers demonstrated that the Arduino-based Smart Solar-Track Edu Kit enhances active student engagement, facilitates the understanding of abstract circuit concepts, and enables teachers to deliver lessons more interactively and effectively compared to conventional methods. This study contributes to the creation of a teaching aid based on automation and renewable energy technologies that aligns with 21st-century learning (PAK-21) requirements.

Keywords: Smart Solar-Track, Arduino, Electronic Design, ADDIE Model, Green Energy

INTRODUCTION

In line with the global transformation of education, the United Nations (UN) Sustainable Development Goals (SDGs) specifically SDG 4 (Quality Education) emphasize the importance of providing equitable, inclusive, and effective learning opportunities. This aspiration is further supported by the National Philosophy of Education (FPK) and the Malaysia Education Blueprint (PPPM 2013–2025), both of which place a strong emphasis on enhancing the quality of Science, Technology, Engineering, and Mathematics (STEM) education. Recognizing the importance of fostering creative, critical, and inventive mindsets, the Ministry of Education

Malaysia (MOE) introduced the Design and Technology (RBT) subject to replace the Integrated Living Skills (KHB) subject in secondary schools. RBT is a discipline within the Technical and Vocational field that prioritizes project-based learning and practical skills. However, the introduction of Content Standard 2.4 Electronic Design into the Form 2 RBT syllabus has presented significant pedagogical challenges for educators. This topic requires fourteen-year-old students to grasp concepts such as automation control, microcontrollers, input and output devices, and programming code writing. A current issue in schools is that teaching methods remain conventional and purely theory-based due to the lack of interactive teaching aids. Textbooks are insufficient to explain concepts such as energy conversion, sensor responses, or feedback control logic. Furthermore, given the time constraints teachers face in preparing practical materials from scratch, they tend to rely on theoretical teaching methods. Although the market offers educational kits such as remote-controlled cars these are often considered outdated, lacking in green technology elements, and frequently supplied without comprehensive assembly manuals from vendors. Therefore, the development of the "Smart Solar-Track Edu Kit" represents a highly significant innovation aimed at bridging this gap, enabling students to simultaneously explore basic electronics concepts, Arduino programming, and solar energy sustainability.

LITERATURE REVIEW

The development of this learning kit is grounded in a robust conceptual framework based on the ADDIE Model, Constructivist Learning Theory, and Cognitive Learning Theory. According to Constructivist Theory, students actively construct their own knowledge through direct experience and social interaction, with learning viewed as an active, environment-centered process (Piaget, 1973). Furthermore, Lev Vygotsky introduced the concept of the Zone of Proximal Development (ZPD), which explains how students learn effectively through the assistance of adults or more skilled peers (Vygotsky et al., 1978). The kit's development approach aligns with constructivist principles that prioritize experience-based learning and active student discovery, ensuring they can systematically link solar energy to real-world applications (Mohamad Yusof Yusriza et al., 2020). Additionally, Cognitive Learning Theory emphasizes the active role of students' mental processes—such as attention, memory, information processing, comprehension, and metacognitive strategies—in fostering effective learning (Abdul Ghani Mohd Latifi, 2024). In the context of educational technology, this cognitive framework is applied through a structured sequence of instructional activities designed to ensure that the information load during the programming process does not hinder student comprehension. The use of a physical kit, such as a solar tracker, serves as a cognitive aid that transforms abstract logic into concrete, easily understood mechanical movement. This stimulates logical thinking skills and design strategies for problem-solving (Coban & Erol, 2025). The ADDIE Model is the most widely used instructional design framework for creating technology-based teaching materials. This model divides the development process into five structured phases: Analysis, Design, Development, Implementation, and Evaluation. Through the ADDIE approach, each phase is systematically managed—from gathering user requirements to evaluating product usability—thereby ensuring the quality and suitability of the kit for use in school RBT workshops. The conceptual framework for this study is grounded in two primary learning theories: Constructivism and Cognitive Learning Theory.

1. Constructivism Theory: Introduced by Jean Piaget and Lev Vygotsky, this theory emphasizes that students actively construct knowledge through direct experience and hands-on activities. By assembling the kit's physical components, connecting jumper wires, and testing sensor responses, students do not merely memorize theory but build a deep understanding of automation control systems.

2. Cognitive Learning Theory: This theory focuses on how information is processed within a student's working memory. To prevent cognitive overload when learning Arduino programming code and complex circuit schematics, the kit's instructional design incorporates a layered media support structure. The use of three support media—a physical manual, an assembly e-book, and step-by-step video guides (accessed via QR codes)—serves as a cognitive scaffolding mechanism, allowing students to learn at their own pace. Previous Studies: Past research demonstrates that the use of microcontrollers like the Arduino Uno can engage students and stimulate critical thinking skills. Research by Musta'amal et al. (2024) highlights that project-based learning is the optimal approach in the RBT (Design and Technology) subject for developing students capable

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of solving real-world problems. Furthermore, studies on solar tracker systems reveal that integrating Light Dependent Resistor (LDR) sensors with servo motors as mechanical actuators is a highly efficient method to introduce early on, exposing students to the efficiency of renewable energy technology.

METHODOLOGY

This study employs a qualitative Research and Development (R&D) approach to produce a systematic and valid draft of an educational product. Regarding the study population and sample, purposive sampling was used to select the RBT (Design and Technology).

Study Instruments: This study involved three main instruments developed meticulously in accordance with the ADDIE phases.

1. Needs Analysis Interview Protocol (Analysis Phase): Used to identify teachers' challenges and the specific design requirements for the kit.

2. Expert Evaluation Checklist (Development Phase): A form featuring a two-point agreement scale (Agree/Disagree) and a comments section to evaluate functional validity (Part A), content (Part B), design (Part C), curriculum integration (Part D), and accessibility (Part E).

3. Usability Interview Protocol (Evaluation Phase): Used to gather thematic feedback from the three SABS teachers after they utilized the kit during an RBT workshop simulation. To ensure content validity, all three protocols and the checklist were reviewed and validated by three academic experts (doctoral-level lecturers from the Department of Engineering Technology, Faculty of Technical and Vocational Education, UPSI).

This study used purposive sampling to select a sample of RBT teachers who have teaching experience at Sultan Abu Bakar School, Kuantan. The selection of these three teachers was to ensure that the data obtained came from educational practitioners who have in-depth practical experience in handling the subtopic of Electronic Design. These three teachers were selected to ensure that the data obtained came from educators with extensive practical experience in teaching the "Electronic Design" sub-topic in Table The demographic profile of the teachers is detailed in Table 1 while Figure 1 shows the research flowchart.

Table 1: Demographics of RBT Teacher Respondents

Responds	Gender	Experience Teaching RBT	Academic Qualifications & Options
R1	Male	18 years	Diploma in Mechatronics Engineering; Bachelor's Degree in Technical and Vocational Education (Mechanical)
R2	Male	13 years	Bachelor of Education (Life Skills), Minor Agriculture
R3	Female	14 years	DPLI Life Skills (ERT), Bachelor of Science Human Development

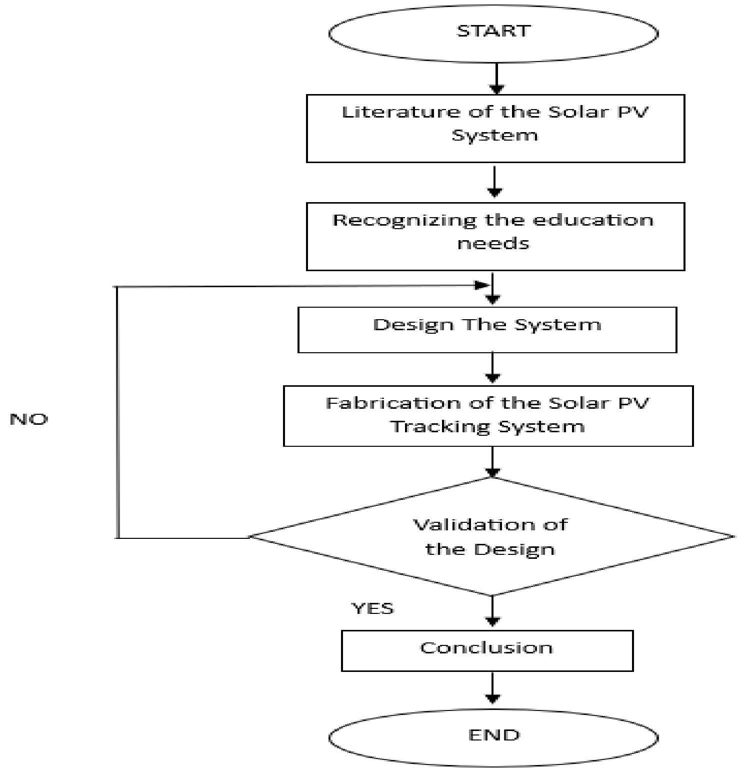

Figure 1: Research Flow Chart

ANALYSIS AND DISCUSSION

The study findings are presented according to the sequence of the research objectives and the implemented phases of the ADDIE Model. Interview data were analyzed using the thematic analysis method. Interview transcripts were processed to identify key themes describing current teaching issues and the product's usability assessment. Subsequently, data from expert checklists were analyzed using the percentage of agreement method to determine the kit's technical and pedagogical validity. This section presents and interprets the study findings in relation to the research objectives. Regarding the needs analysis phase, a summary of teaching issues is provided in Table 1, which displays the thematic analysis of interviews conducted with RBT teachers.

Based on research, all three respondents unanimously confirmed that the primary existing constraints were the lack of a structured guidebook and the very limited number of physical kits available in schools. This issue compelled teachers to conduct lessons through passive lecturing, which reduced student motivation.

Furthermore, regarding the product development phase, data from expert evaluation forms recorded 100% agreement concerning mechanical functionality validity and alignment with the Form 2 RBT DSKP (Curriculum and Assessment Standard Document). In terms of usability assessment, teachers agreed that the integration of a light-dependent resistor (LDR) sensor and a servo motor—designed to automatically track light intensity—successfully fostered a dynamic and user-friendly practical learning environment. Figure shows 2: a) Mechanical Schematic and Structural Plan of the Solar Tracker System b) Diagram of the solar system.

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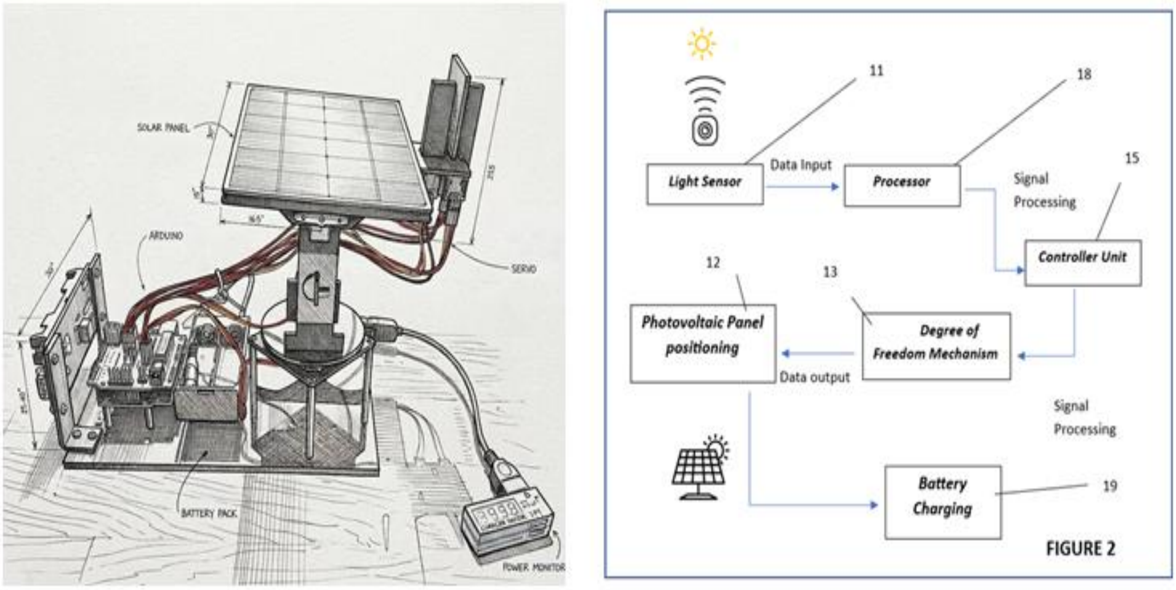

(a) (b)

Figure 2: (a) Mechanical Structural Plan of the Solar Tracker System (b) Diagram of the solar system

The technical sketch shown in Figure 2 (a) serves as a visual reference within the practical operation manual. This structural plan details the layout of key components, including the solar panel, light-dependent resistor (LDR) light sensors, servo motor, and Arduino microcontroller. The system's dimensional drafts and labeling are designed to help students translate abstract programming logic into concrete physical movement during the assembly process.

Based on this technical plan, the physical hardware was constructed to meet the requirements for interactive learning and green automation. Figure 3 shows the actual physical appearance of the kit, which has been developed for use in teaching and learning activities.

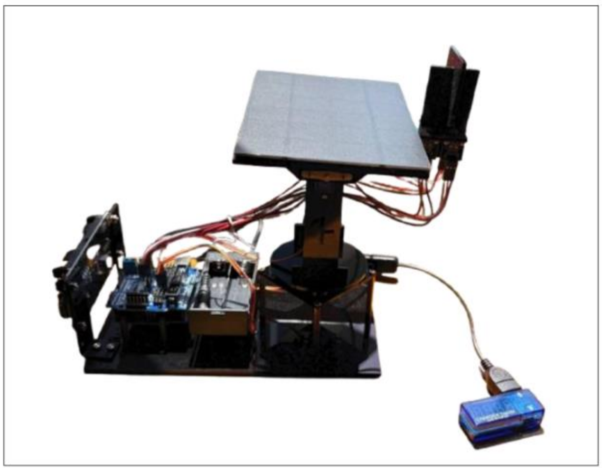

Figure 3: Complete hardware of the Smart Solar-Track Edu Kit, ready for use in the RBT workshop.

The product features a simple, compact structure built upon a neatly cut black MDF frame, designed for easy classroom storage. Its mechanical structure allows the mini solar panel to automatically adjust its position and rotate in response to the intensity of ambient light. Additionally, the kit includes an external blue digital Power Monitor connected via a USB cable, enabling teachers and students to view voltage and solar-generated current parameters in real-time during group experiments.

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CONCLUSION

This R&D study successfully achieved all its outlined objectives: identifying development needs, developing the Smart Solar-Track Edu Kit based on the ADDIE model, and demonstrating the kit's high level of usability among RBT (Design and Technology) teachers. Integrating Constructivist and Cognitive theories into the kit's design proved effective in translating abstract electronic control concepts into concrete mechanical movements that are easily understood by Form 2 students. Indirectly, the kit supports the aspirations of the National Education Philosophy (FPK) to produce highly skilled students prepared to face the challenges of the modern automation industry. Regarding strategic improvements, several recommendations were proposed to ensure the Smart Solar-Track Edu Kit's quality and usability are optimized for school environments. Based on feedback from experts and teachers, strategic suggestions were identified to enhance the kit's physical quality and safety. These include rounding off sharp edges on the frame structure to ensure student safety in the workshop. Furthermore, experts noted that the kit's color scheme should be considered to better capture students' interest and attention during testing, while teachers suggested improvements to the storage box to ensure components remain secure and are not lost. These findings align with the study by Arpaci et al. (2023), which found that Arduino-based educational kits can enhance students' conceptual understanding and motivation. Overall, this study highlights the potential of the Smart Solar-Track Edu Kit as a teaching aid to support teachers during the teaching and learning process for the "Electronic Design" topic in the Form 2 Design and Technology (RBT) subject. This is consistent with research findings by Rahman et al. (2020), which asserts that a well-planned Arduino-based module design can enhance students' understanding and focus. From result, the solar panel it can charged the power up to 5watt/hour and it is sufficient for the Mini kit. Furthermore, the inclusion of physical support elements such as step-by-step instruction manuals within the learning kit has been found to reduce cognitive load and improve students' practical learning performance, as demonstrated by Chang and Yang (2023). Through the development of this teaching aid, instruction can be delivered in a more effective, interactive, and enjoyable manner by integrating practical exposure to renewable energy, instructional modules, and collaborative group activities that help students grasp renewable energy technology concepts more effectively.

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