JPPIPA 12(2) (2026)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

STEM Learning Transformation: Solar Cell–Based Robotic Ship as an Innovative Medium for Student Creativity

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Received: December 10, 2025
Revised: January 11, 2026
Accepted: February 25, 2026
Published: February 28, 2026

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DOI: 10.29303/jppipa.v12i2.13821

Abstract: This study aims to examine the validity, practicality, and effectiveness of a STEM-based robotic solar cell ship as a learning medium to enhance students' creative thinking skills. The research employed a Research and Development (R&D) approach using the ADDIE development model, which consists of the Analysis, Design, Development, Implementation, and Evaluation stages. The participants were 64 tenth-grade students from SMK Negeri 1 Dumai, selected through random sampling. Data were collected using questionnaires, observation sheets, and creative thinking skills tests. The validity results showed that the robotic solar cell ship met the valid criteria, with average scores of 3.75 for device functionality, 3.67 for learning components, 3.58 for ease of use, and 3.59 for aesthetics and construction. In terms of practicality, positive responses were obtained from teachers (3.89), prospective teachers (3.68), and students (3.10), indicating that the media was easy to use and suitable for classroom learning. Furthermore, the effectiveness of the STEM robotic solar cell ship was proven through improvements in students' creative thinking indicators: elaboration (51.25%), originality (46.09%), fluency (86.75%), and flexibility (71.45%). These findings demonstrate that the media supports students in understanding renewable energy, technological design, and the working principles of solar-powered electrical systems. Overall, the robotic solar cell ship serves as an innovative STEM learning tool that promotes creativity, environmental awareness, and sustainable technology literacy to address future global challenges.

Keywords: Creative thinking skills; Solar cell ship robotics; STEM

Introduction

Education in the 21st century increasingly emphasizes the importance of developing creative and critical thinking skills among students (Sumarni & Kadarwati, 2020; Madyani et al., 2020; Tang et al., 2020), especially in facing various global challenges. Creative thinking is the ability to generate new and innovative ideas that can be used to solve complex problems in everyday life (Hobri et al., 2020; Khalid et al., 2020; Yayuk et al., 2020). According to Aguilera et al. (2021) creative thinking encourages individuals to find innovative, unconventional solutions in solving complex problems. In the educational context, developing creative thinking skills is increasingly relevant with the application of the STEM (Science, Technology, Engineering, and Mathematics) approach, which focuses on the interdisciplinary nature of science and technology in everyday life (Gao et al., 2020; Sirajudin et al., 2021). The application of the STEM approach in education not only increases students' understanding of scientific concepts but also encourages them to think creatively in finding solutions to various problems faced in society, including environmental issues (Kartini et al., 2021).

Indonesia is an archipelagic country (Ahmad Syauqi, 2021; Djunarsjah & Putra, 2021), and most of Indonesia's population lives in coastal areas and works as fishermen (Nugroho & Pawestri, 2020; Taufiqurrahman & Ali, 2023). Coastal residents often use petroleum to power ships used for transportation (Darza, 2020; Gea & Sanjaya, 2022). As is known, the

How to Cite:
Yennita, Y., Zulirfan, Z., Susanto, H., Izzati, S., & Lestari, I. (2026). STEM Learning Transformation: Solar Cell–Based Robotic Ship as an Innovative Medium for Student Creativity. *Jurnal Penelitian Pendidikan IPA*, *12*(2), 270–279. https://doi.org/10.29303/jppipa.v12i2.13821

supply of petroleum is decreasing (Andersen & Gulbrandsen, 2020; Jumnahdi, 2023). For this reason, children are taught from an early age to save energy and innovate in creating products that utilize renewable energy sources (Gill & Lang, 2018; Grønhøj, 2016; Septiana, 2023). STEM-based education can prepare young people to face these challenges in a more structured and innovative way (Mantau & Talango, 2023). This means that by involving students in STEM-based projects, they not only learn theory, but also practice developing solutions that are applicable and relevant to real conditions in the field. Robotics technology is one solution that has great potential in helping create new innovations through education (Almuaythir et al., 2024). For example, creating new solar-powered innovations that can save fossil fuels (Dwisari et al., 2023; Holechek et al., 2022; Leonard et al., 2020). However, the application of this technology requires human resources who are not only skilled in technology, but also have the ability to think creatively to innovate according to ever-changing field conditions.

In recent years, robotics technology has emerged as an innovative solution (Damaševičius et al., 2023). Robotics not only helps in creating innovative products but also offers incredible educational opportunities for students. This is in accordance with Plaza et al. (2017) who state that robotics increases engaging opportunities to turn boring concepts into amazing learning processes. However, although there is great potential in the application of STEM and robotics in education, there are still many challenges to be faced, such as the lack of teacher preparation to make connections between robotics and STEM subjects and the failure to develop resources that are accessible in all educational contexts (Castro et al., 2022). Many teachers are reluctant to face this new challenge because teachers are not yet ready, coupled with limited teaching materials that are appropriate for diverse educational contexts. This exacerbates the digital divide, making robotics in education accessible only to a privileged few, while leaving most others without equal opportunities (Wallace & Poulopoulos, 2022). Research by Anugerah (2023) shows that teachers feel unprepared and lack confidence in facing ever-growing learning demands, which can hinder the implementation of effective STEM education. Therefore, it is important to develop training programs and curricula that can facilitate this learning in a way that is engaging and enjoyable for students.

The integration of STEM, robotics, and renewable energy sources can be a bridge connecting theory and practice, giving students hands-on experience in solving real problems. In this context, research by Ramadhani et al. (2024) highlights the importance of STEM-based projects involving robotics as a tool to stimulate students' creativity in designing solutions to overcome problems. This project not only improves students' technical skills but also builds their awareness of humanitarian and environmental issues.

The importance of this research lies in developing students' creative thinking skills in facing complex challenges, especially those related to product development that utilizes renewable energy sources. In situations full of uncertainty, the ability to think creatively and critically is needed to create innovative and effective solutions. By integrating robotics technology in STEM education, this research aims to improve creative thinking skills in developing STEM-based robotic solar cell ship projects.

Method

This research is a development study (Research and Development) which focuses on implementing STEM projects for students. The development model used in this research is the ADDIE model, which consists of five main stages: Analysis, Design, Development, Implementation, and Evaluation (Branch, 2010).

This study was conducted in the 2024/2025 academic year at SMK Negeri 1 Dumai. The subjects of this research were 64 tenth-grade students who participated in the learning process using the STEM robotic project. The students engaged in both the development and trial implementation of the STEM robotic project to enhance their creative thinking skills.

Figure 1. Addie model stages (Branch, 2009)

Analysis Phase

At this stage, the researcher analyzes learning activities, student characteristics, and student needs at SMK Negeri 1 Dumai in order to produce learning media that can meet student needs. In the analysis phase, questionnaires and observations were distributed.

Design Phase

At this stage, the researcher determines the components and design of the STEM KIT being developed. Researchers also prepared several required research instruments, including validation questionnaires, practicality questionnaires, and creative thinking test questions.

Development Phase

At this stage, the initial design is transformed into a tangible form of learning media. This phase is considered the most crucial stage in development research because what has been planned during the design stage does not always align with real conditions in the field. Therefore, the researcher repeatedly revised and replaced prototypes through several cycles until the desired STEM project media was obtained.

After the STEM-based media was successfully developed, it underwent an expert validation process. Three experts evaluated the media using a validation questionnaire with four response options: (1) strongly disagree, (2) disagree, (3) agree, and (4) strongly agree. The media was categorized as valid if each validator gave a minimum score of 3 on every statement item. However, if a validator assigned a score of 1 or 2, the media was required to be revised and re-evaluated.

Following the validation process, a small-scale trial was conducted to assess the practicality of the media. This trial involved students as users of the STEM media in classroom learning. The practicality instrument used a four-point scale consisting of (1) not practical, (2) less practical, (3) practical, and (4) very practical. In addition, the practicality questionnaire was also distributed to three physics teachers and twenty prospective physics teachers. This stage was essential to evaluate the feasibility, usability, and flexibility of the developed media. The data collected from both groups were used to ensure that the media had a high level of practicality and could be effectively implemented in learning activities.

Table 1. Media Validity Criteria (Widoyoko, 2016)

Validity Index	Category
$3 \leq \bar{x} \leq 4$	Valid
$\bar{x} \leq 3$	Invalid

After the validity of the developed media is determined, a practicality test is then carried out. The following are the media practicality test criteria used in this study.

Table 2. Media Practical Criteria (Widoyoko, 2016)

Validity Index	Category
$3 \leq \bar{p} \leq 4$	Valid
$\bar{p} \leq 3$	Invalid

Implementation Phase

After the learning media is declared valid and practical, the next step is to test the learning media in schools. The subjects in this research were 64 class X students at SMK Negeri 1 Dumai. Data collection was carried out in the odd semester of the 2024/2025 academic year. At this stage, the STEM robotic learning model was tested in a classroom environment. To test the effectiveness of the learning media, students were given a test which aims to measure the increase in creative thinking skills. The creative thinking test consists of 11 questions consisting of indicators of creative thinking skills. The creative thinking indicators used are flexibility, fluency, originality, and elaboration (Munandar, 2012). Data analysis techniques are conducted after data from all respondents or other data sources have been collected. The data analysis technique uses a descriptive percentage method to determine the level of students' creative thinking skills using the following formula:

$$S = \frac{R}{N} x 100\% \quad (1)$$

S : Percentage of creative thinking skills
R : The score obtained from the correct answer
N : Maximum score of the test

So the percentage of students' creative thinking skills obtained can be grouped into the following criteria:

Table 3. Percentage Categories of Creative Thinking Skills Test Achievements (Sumarwati et al., 2013)

Category	Percentage Gain
Very Creative	81-100%
Creative	61-80 %
Quite creative	41-60 %
Less creative	21-40%
Not Creative	≤ 20%

Evaluation Phase

At this stage, the researcher evaluates the validation results that have been given by material expert validators and media experts on validation questionnaires, which are then used to make improvements to the learning media in accordance with the input and suggestions from the material and media expert validators. The researcher also evaluated the practicality of the learning media obtained from the practicality questionnaire to determine the ease of operation and usefulness of the learning media for teachers and students. The researcher also evaluates the effectiveness of the learning media, which can be seen from the results of students' test work. From this series of evaluations, it can be seen that the learning media is of good quality and meets the criteria of being valid, practical, and effective.

Result and Discussion

The results of this research include learning media development procedures which outline the steps of the ADDIE development model and the results of learning media development tests which consist of validity, practicality, and effectiveness tests. Below, the researcher describes the process and test results of learning media development.

Analysis Phase

At this stage, researchers analyze learning activities, student characteristics, and student needs. At the analysis stage, it is known that the learning currently being implemented uses less varied methods, where teachers more often use the lecture method. In fact, we know that the application of the lecture method has an impact such as tending to make students less creative (Muah, 2022), the material presented only relies on the teacher's memory (Mawardah et al., 2023), the possibility of subject matter that cannot be fully accepted by students, difficulty in knowing how much material students can accept, and it tends to be verbalistic and less stimulating (Damayanti & Dikta, 2022). In fact, based on the results of the questionnaire, it is known that 66% of teachers know that project-based learning is STEM project learning. Even though teachers know specifically about STEM project learning and realize that implementing STEM projects is very important, there are still many teachers who rarely implement STEM project learning in schools. Many factors cause the lack of implementation of STEM project learning in schools. Teachers' lack of control over the pace of the curriculum and its consequences for teaching is also considered a challenge for teachers in efforts to integrate interdisciplinary subjects for authentic STEM learning (Herro & Quigley, 2017). Other barriers include administrative and financial support (Asghar et al., 2012; Hsu et al., 2011; Park et al., 2016; Park et al., 2017), or a lack of technology resources for students such as computers (Wang et al., 2011). Teachers' perceptions about STEM learning are in line with students, where 72.1% of students want science learning to be accompanied by making simple technological tools. Then, the results of the questionnaire showed that the actual robotic STEM project that students expected was 72.1%, where students preferred learning about robotic STEM projects that used simple technological tools.

Design Phase

In this phase, researchers designed a robotic-based STEM Project Kit. The kit is designed using plastic material with disassemblable components. The following is a picture of the solar cell ship circuit design and construction.

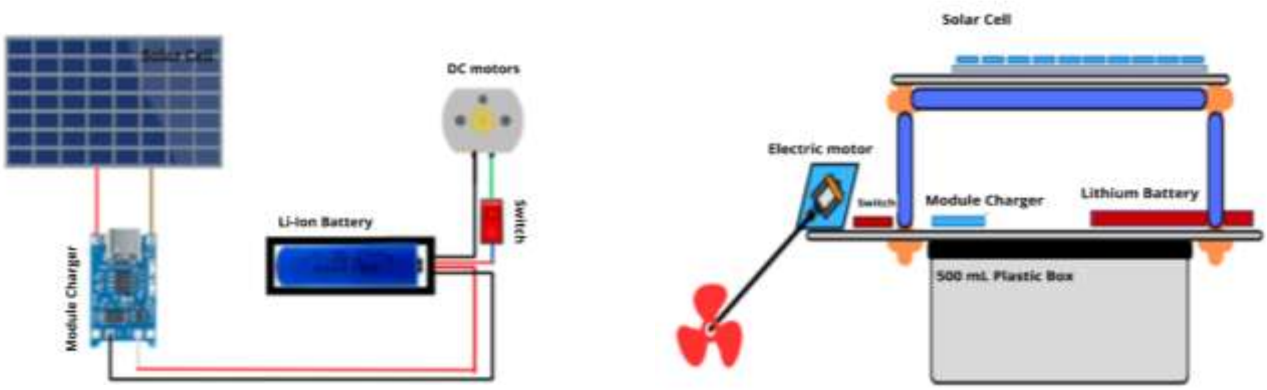

Figure 2. Solar cell ship circuit and construction

Solar cell ships are a renewable energy-based transportation technology that utilizes solar cells as the main source of power. Solar panels installed on ships capture solar energy and convert it into electricity to power the ship's motor, thereby reducing dependence on fossil fuels and reducing carbon emissions. This technology is very suitable for use in coastal areas because of the abundant availability of sunlight and the need for environmentally friendly transportation. In addition, solar cell ships have lower operational costs than conventional fuel ships, making them a sustainable solution for coastal and island communities. One study states that an alternative source of electrical energy is using sunlight. With the help of a device that can convert sunlight into electrical energy, the sun becomes the most promising alternative source of electrical energy, because sunlight is a renewable and free resource (Zamista, 2017).

Development Phase

Realizing the Solar Cell Ship Design

The following is a picture of a solar cell ship that was developed as a STEM learning medium.

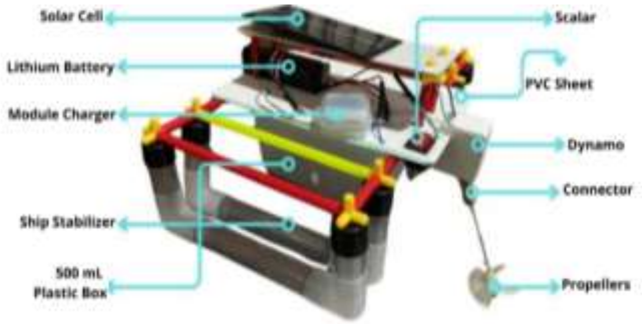

Figure 3. Solar cell ship

At the development stage, researchers realize the learning media design that has been designed. The equipment used in the process of making a solar cell ship includes a 500 mL plastic box, solar panels, a lithium battery, a charger module, a PVC (paralon) sheet**,** bolts and nuts, a dynamo and propeller shaft, and a magic straw as a support for the ship's circuit. Experiments that can be carried out on this device investigate the use of solar cells to help ships move with the help of dynamos, which is a form of utilizing renewable energy.

Solar cell ships are an innovation in the use of renewable energy that uses solar power as the main source of propulsion. This technology works by converting sunlight through solar panels into electrical energy, which is then used to drive the ship's motor. As an environmentally friendly solution, solar cell ships reduce dependence on fossil fuels and exhaust emissions, thereby contributing to environmental conservation efforts. In addition, these ships have high operational efficiency with lower maintenance costs, making them a sustainable alternative for sea transportation, especially in coastal areas and islands that are rich in solar energy sources.

Validity and Practicality Test of Solar Cell Ships

The learning media that has been developed is then validated by material and media expert validators to test the level of validity. Validation was carried out twice, where there were improvements to the tools developed. The following are the validation results of the developed Robotic STEM KIT.

The validity of the STEM Robotic project in this research is based on the assessment of three experts, including media, pedagogical, and material experts. The results of the assessment by experts on the learning support tools that have been developed are declared valid for all validation elements. Thus, STEM Robotic projects can be used in science learning at school. After a validity test has been carried out by an expert, a practicality test is then carried out as input for the project being developed. Practicality testing is the first step in the process of evaluating or testing a learning product. The function of this practicality test is to identify errors, deficiencies, or aspects that need to be improved in the product before it is tested on a larger group. The results of the practicality test for teachers, prospective Physics/Science teachers, and students are in Figure 5.

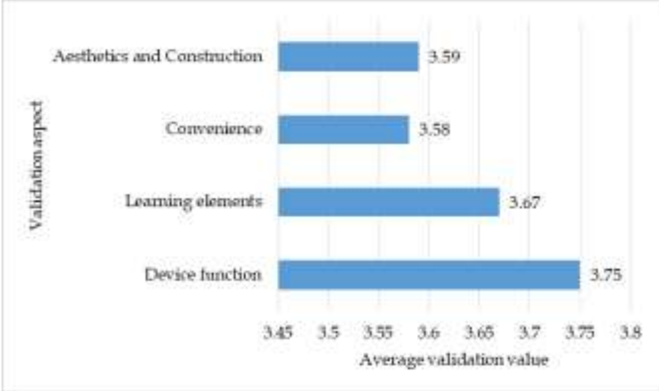

Figure 4. Solar cell ship validation results

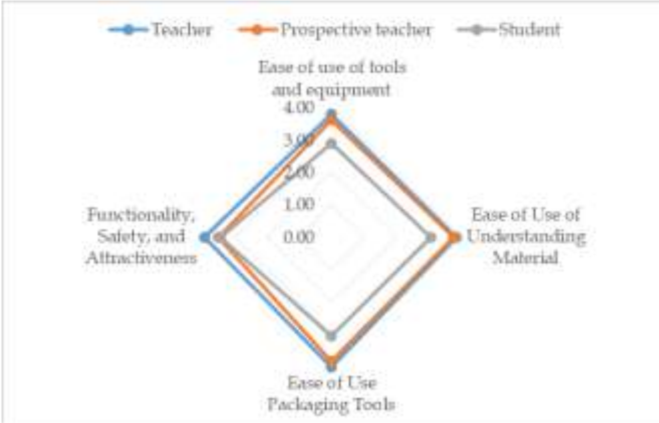

Figure 5. Practicality test results for teachers, prospective teachers and students

From the results of the teacher practicality test, the four aspects asked in the practicality form were superior to the others. This shows that the solar cell ship prototype is considered quite easy for teachers to use and understand, and has a good level of safety and attractiveness. This advantage reflects success in media design, especially in meeting the needs of professional users such as teachers, who have certain standards regarding ease and safety in operating the equipment.

Based on the picture, it can be explained that the trial value of the STEM Robotic solar cell ship project, which was tested on prospective teachers was stated to be practical with the type of good practice in terms of ease of use of tools and materials, ease of understanding the material, ease of packaging the tools, and usefulness, safety, and attractiveness. The use of robotic STEM projects offers a very effective and engaging learning approach, especially for students who have an interest in science, technology, engineering, and mathematics, and by combining theory with practice, these projects provide many benefits. By implementing robotic STEM projects in learning, students will not only gain knowledge but also develop skills that are very valuable for their future.

The practicality test results from students show a slightly different picture, with a lower average score than the practicality test results from teachers and prospective teachers. These differences reveal challenges in ensuring that prototypes are accessible and optimally utilized by students. In particular, lower scores on ease of use and packaging aspects indicate the need for further improvements, both in design aspects and in providing simpler and easier-to-understand guides.

Comparison of the results between teachers, prospective students, and students shows that although the prototype was rated as quite good by the teacher, students experienced more difficulties in understanding and using it. These findings emphasize the importance of considering the perspective of students as end users, especially in STEM learning. Therefore, robotics-based learning materials must be designed to be not only interesting, but also educative and easy to understand for students with various levels of technological understanding.

Implementation Phase

Learning media that is valid and practical is then tested for effectiveness. The media KIT STEM Robotic solar cell ships are used in learning. After the learning was completed, a test was carried out on the students to determine their level of creative thinking after implementing the learning using the solar cell ship Robotic STEM KIT. The following are the results of students' creative thinking skills.

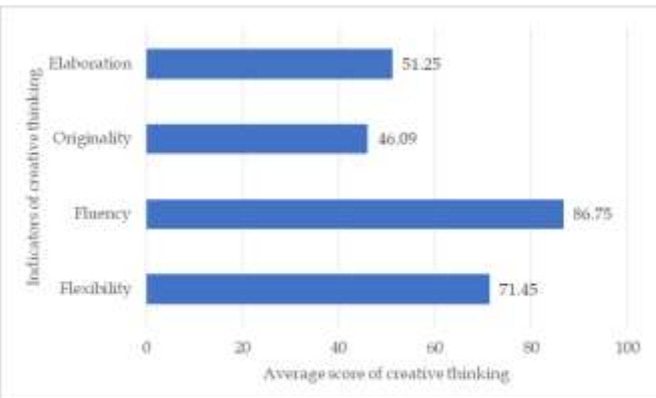

Figure 6. Results of students' creative thinking skills elaboration

The elaboration indicator obtained a score of 51.25% which is included in the quite creative category. Elaboration refers to a person's ability to develop ideas with richer and deeper details (Lestari, 2024; Agusta & Noorhapizah, 2020; Joklitschke et al., 2022). This score shows that students are able to add additional information to the ideas developed, but still need reinforcement in deepening existing concepts. According to Wallach et al. (1968) good elaboration allows someone to be more creative in connecting various aspects of an idea into a more complex and mature solution. Lack of practice in idea exploration can limit students' elaboration abilities (Furqon, 2022).

Originality

The originality indicator scored 46.09%, which is also in the quite creative category. Originality refers to the ability to generate unique and unusual ideas (Agustina et al., 2021; Mursid et al., 2022). This score shows that students have the potential for original thinking, but still need encouragement to create truly innovative ideas. Amabile (1996) in her theory of creativity emphasizes that an environment that supports free exploration can increase originality. However, Cropley (2011) states that a learning system that is too structured can hinder students from developing unique ideas, because they are more likely to follow existing thinking patterns rather than creating something new.

Fluency

The fluency indicator obtained the highest score, namely 86.75%, which is included in the very creative category. Fluency refers to the ability to generate many ideas in a short period of time. This score shows that students are able to think divergently well and can produce various possible solutions to a problem. Fluency is one of the main indicators of creativity because the more ideas generated, the greater the possibility of finding innovative solutions (Mufarrohah & Setyawan, 2024). In addition, research by also shows that students who often practice solving project-based problems tend to have a higher level of fluency (Rohana & Wahyudin, 2017; Sandy et al., 2024).

Flexibility

The flexibility indicator has a score of 71.45% which is categorized as creative. Flexibility of thinking refers to the ability to move from one idea to another and see a problem from various points of view. This score shows that students are quite capable of developing ideas with a variety of approaches and can adapt their way of thinking according to the context of the problems they face. Flexibility is very important in creative thinking because it allows a person to be more adaptive to changes and new challenges (Khoerudin et al., 2023). Meanwhile, research finds that individuals who have a high level of motivation tend to be successful in finding innovative creative solutions (Rasulong et al., 2024).

Overall, the results in the graph show that students have an excellent level of fluency, indicating that they are able to generate many ideas quickly. However, the originality and elaboration scores were still in the quite creative category, indicating that although many ideas were generated, these ideas still needed to be developed further to make them more unique and in-depth. Flexibility is in the creative category, indicating that students have a fairly good ability to adapt their thinking patterns to various challenges. Therefore, more innovative learning strategies are needed to increase originality and elaboration, such as a project-based approach and exploration of new ideas through creative discussions and more intensive divergent thinking exercises.

Evaluation Phase

In the evaluation stage, researchers evaluated the STEM Robotic Solar Cell KIT that had been developed based on the assessment of validity, practicality, and effectiveness. The following are the results of the validity, practicality, and effectiveness assessments.

The KIT STEM Robotic Solar Cell learning media is classified into the valid category from the aspects of device function, learning elements, convenience, aesthetics, and construction as assessed by experts, with the overall validity score being 3.65, which falls into the valid category.

The KIT STEM Robotic Solar Cell learning media has met the practical criteria with a practicality score obtained by teachers of 3.89, prospective teachers of 3.68, and students of 3.10.

The STEM Robotic Solar Cell KIT learning media has met the effective criteria because the creative thinking test results for each indicator show that elaboration is 51.25% (quite creative), originality is 46.09% (quite creative), fluency is 86.75% (Very Creative), and flexibility is 71.45% (creative).

Conclusion

This study shows that STEM learning through the use of solar cell ship robotics is a valid, practical, and effective learning medium for improving students' creative thinking skills. The developed media was considered feasible by experts and well received by teachers, prospective teachers, and students, indicating that it can be implemented in classroom learning. The learning activities successfully encouraged students to generate ideas, think flexibly, and explore solutions related to renewable energy and technology, although students still need support to develop more original and detailed ideas. These findings suggest that integrating robotics and renewable energy projects into STEM learning can create a more meaningful, engaging, and creative learning experience for students, while also supporting environmental awareness and sustainable education.

Acknowledgments

Thank you to the students on the Dumai coast who participated in this research.

Author Contributions

Conceptualization, Y.Y. and Z.Z.; methodology, Y.Y.; software, H.S.; validation, Y.Y. and Z.Z.; formal analysis, I.L. and S.I.; investigation, H.S. and S.I.; resources, Y.Y.; data curation, Y.Y.; writing—original draft preparation, Y.Y. and I.L.; writing—review and editing, Y.Y., Z.Z. and I.L.; visualization, Y.Y. and H.S.; supervision, Y.Y.; project administration, Y.Y.

Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflict of interest.

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