Research and Development in Education
(RaDEn)

UMM

Research Article

Study on the development and implementation of an interdisciplinary solar panel project to enhance students' interest in STEM

Ahmad Suryadi [a,1,*], **Nala Lidya** [a,2], **Hulwah Habibah** [a,3], **Iwan Permana Suwarna** [a,4]

[a] Physics Education Study Program, Faculty of Educational Sciences, Universitas Islam Negeri Syarif Hidayatullah Jakarta, Jl. Ir. H. Juanda No. 95, Ciputat, South Tangerang, Banten 15412, Indonesia

[1] ahmads@uinjkt.ac.id ; [2]nala.lidya20@mhs.uinjkt.ac.id; [3]hulwah.habibah20@mhs.uinjkt.ac.id; [4]iwan.permana.suwarna@uinjkt.ac.id

Abstract: This study aimed to develop and implement a STEM education program on solar energy. This study follow Analyze, Design, Develop, Implement, and Evaluate (ADDIE) model. The study was conducted by analysing, designing, and developing a STEM education program consisting of a program guide and a solar panel STEM KIT. The program was implemented in schools involving 83 high school students. The program was implemented in two formats, namely STEM after school and regular learning. Students completed the STEM interest instrument after participating in the STEM education program. The results showed that the program was declared valid for use. In addition, the program implementation results showed no significant difference between students' technology, engineering, mathematics, and STEM career interests in STEM after school and regular STEM classes. This may be due to several things such as similar content and activities, similar engagement, and similar mentorship. This study implies that the STEM education program can increase students' interest in STEM after-school and regular learning activities.

Keywords: Solar panel project; STEM after school; STEM education; student interest

1. Introduction

STEM education has received significant attention from many people around the world. The nature of knowledge is also evolving; interdisciplinary fields are becoming increasingly important. Many have highlighted the relationship between subjects that must be made integrative to prepare a competent generation. For example, a superpower country like the United States in recent decades has made massive reforms in STEM education (Kelley & Knowles, 2016). The reforms are highly visible in the efforts to integrate engineering into the science curriculum from kindergarten to high school. Several countries have followed this reform. According to some reports, Egypt, as one of the developed countries in the African region, was also reformed by integrating science, technology, engineering, and mathematics disciplines into school learning (El Nagdi et al., 2018). They showed that STEM education reforms have allowed teachers to develop and build their identity positively (El Nagdi & Roehrig, 2020). In Indonesia, efforts to integrate STEM disciplines are also growing. Recently, the Ministry of Education of the Republic of Indonesia has provided an alternative curriculum focusing on soft skills development, essential content and flexible learning. This curriculum provides teachers with the opportunity to conduct integrative learning, such as integrated STEM. Although the Ministry of Education has provided guidebooks, many teachers still experience difficulties implementing integrated STEM learning (Muchtar & Ding, 2024; Nuragnia et al., 2021). Suryadi et al (2023) showed that efforts to develop teacher professionalism in integrated STEM teaching in Indonesia are relatively scarce. Furthermore, Sulaeman et al (2022) found that the majority of Indonesian physics teachers are familiar with the integrated

Citation: Suryadi, A., Lidya, N., Habibah, H., & Suwarna, I.P. (2024). Study on the development and implementation of an interdisciplinary solar panel project to enhance students' interest in STEM. *Research and Development in Education (RaDEn)*, 4(1), 415-427. https://doi.org/10.22219/raden.v4i1/32881

Received: 26 March 2024
Revised: 14 May 2024
Accepted: 19 May 2024
Published: 21 May 2024

STEM education approach; however, more than half have never tried to implement an integrated STEM teaching approach in the classroom.

In addition to the learning resources factor, students' lack of interest in STEM can make student engagement in STEM learning a challenge for teachers (Drymiotou et al., 2021; Wang et al., 2023). According to Will (2017), only 38% of students are naturally interested in STEM subjects, with 69% reportedly interested in technology, 42% in science, 25% in engineering, and 14% in math. In Indonesia, this is also seen in the interest in STEM majors in some universities tends to be smaller than in other fields (Kemendikbud, 2020, 2021). Students' interest in STEM fields is influenced by various factors. Lichtenberger and George-Jackson (2012) found that science course taking, standardized test performance, and college aspirations were significant predictors of STEM interest. Kızılay and Yamak (2023) further, the role of motivation was emphasized, with students who performed well in STEM subjects considering majoring in STEM fields in college. Another factor that remains less explored is gender. Previous finding, Sadler et al (2012) noted gender differences, with men showing greater interest in engineering and women in health and medicine.

One of the efforts made to develop students' interest and competence in STEM is integrated STEM learning. The majority of studies have shown that STEM learning, especially integrated learning, has a positive impact on students' knowledge and skills (Astawan et al., 2023; Indranuddin et al., 2024; Mutakinati et al., 2018; Parno et al., 2020; Yuliati et al., 2018). In STEM learning, students are challenged and motivated to design and design technology to increase their ability to solve problems (Purwaningsih et al., 2020). In addition, through STEM learning, students will be involved in various meaningful activities to develop their critical thinking and creative thinking skills (Sumarni et al., 2022).

An important aspect to consider in the design of an integrated STEM education curriculum is customizing the topics. One topic that can facilitate integrative learning is renewable energy. Among the types of renewable energy, considering the geographical location of Indonesia, the use of solar energy seems very suitable. Solar energy can be used as an applicable and real context for students to understand STEM applications (Machuve & Mkenda, 2019)\. The exploration of solar panels in STEM education allows students to engage in project-based learning, where they can design, build, and test mini solar panel systems, understand the working principles of photovoltaic, and analyze energy efficiency (Shahbazloo & Mirzaie, 2023). This approach not only improves students' conceptual understanding of physical phenomena and engineering principles but also develops their critical skills in problem-solving and innovation (Perea et al., 2021). Currently, attention to renewable energy sources, especially solar energy, is growing rapidly. However, support related to introducing solar energy at the secondary school level has so far been limited. Therefore, based on the above discussion, this research was conducted with the following objectives: 1) developing a solar panel STEM KIT; 2) exploring the extent to which the solar panel STEM program can influence students' interest in STEM fields.

2. Materials and Methods

2.1 Research Procedure

This research is a research and development (R&D) conducted following the ADDIE (Analyze, Design, Develop, Implement, and Evaluate) stages (Branch, 2009). First, a needs analysis is conducted, especially on alternative energy topic. Second, Design and Develop, the integrated STEM education program developed, consists of two parts, namely student worksheets and solar panel STEM KIT. In this research, the STEM KIT facilitates learning that is used for each meeting (four meetings) starting from introducing components to presenting the products that have been made, namely solar panel-based automatic garden lights, with the help of student worksheets. The integrated STEM education program was developed by first making a prototype and testing it. The program development then involved experts to validate the program. The validation results are used to consider making improvements to the program. Third, Implement, the STEM education program is then implemented in two forms, namely as an after-school STEM program and a regular learning program. After participating in the program, students fill out a questionnaire to evaluate students' STEM interests. The research stages are presented in Figure 1.

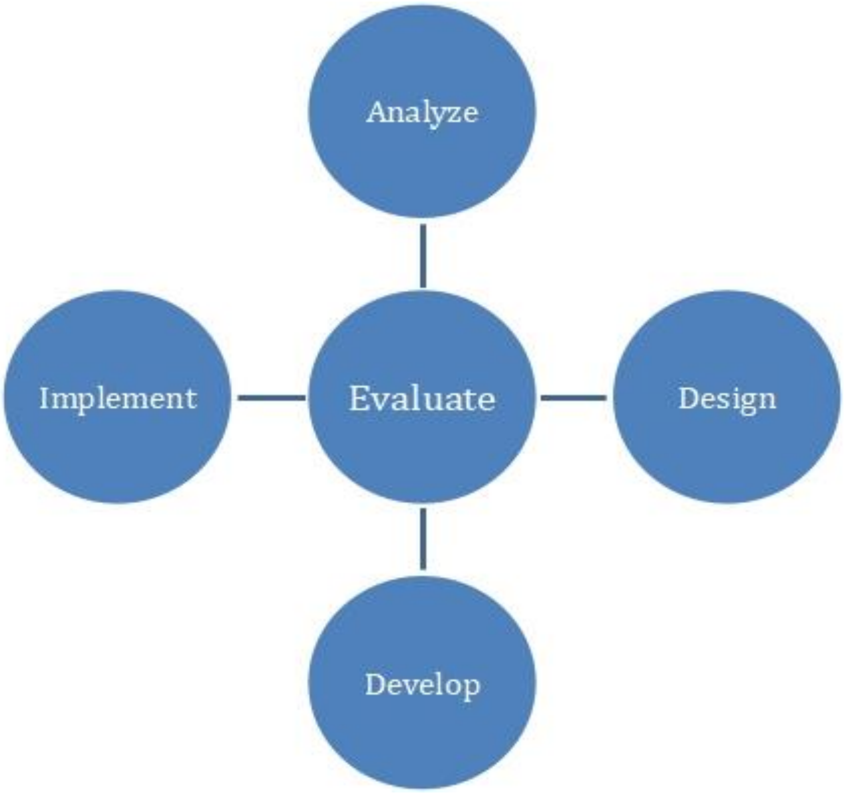

Figure 1. Stages of research and development

2.2 Participants

The first phase was conducted using a student STEM interest survey involving 339 participants, of which there were 122 male and 217 female students spread across Jakarta and East Java. The second phase of the research involved three experts who are physics education lecturers who are experienced and competent in assessing a learning product/program. In the third stage, we involved high school students as participants in the pilot test of the STEM Education program. The research was conducted by implementing the integrated STEM program in two schools. This study was conducted by implementing an integrated STEM program in two schools, namely School A located in South Tangerang and School B located in South Jakarta. Participants were involved with convenience technique, the selection of the two schools was based on the availability of the schools to participate in the research and the implementation of the program was only at the pilot stage. A total of 25 students from School A were involved in the STEM education program in the form of after-school STEM, and 58 students from School B were involved in regular STEM learning. A total of 25 students from School A were involved in the STEM education program in the form of STEM after school, and 58 students from School B were involved in regular STEM learning.

2.3 Research Instruments

The research instrument used in this study was adapted to the STEM Semantics Scale instrument developed (Tyler-Wood et al., 2010). This instrument measures students' interest in science, technology, engineering, and mathematics, as well as their interest in a career in STEM. The instrument is a 1-7 rating scale declared valid and reliable. This instrument was given to students after attending the STEM education program.

2.4 Data Analysis

Data from the validation results were analyzed with descriptive statistics. Expert assessment of STEM guide products is said to be valid if it reaches a percentage of ≥75% (Borich, 2015). Furthermore, data on students' STEM interests after participating in integrated STEM activities were analyzed with inferential statistics. Data centering parameters such as mean and median in each participant group were analyzed. Data dispersion parameters such as standard deviation and interquartile range were also presented. Furthermore, an analysis with inferential statistics was conducted to see the difference in students' interest in the two research locations. The difference test was conducted using the non-parametric Mann-Whitney U statistic.

3. Results

This section describes the solar panel STEM education program, which consists of student worksheets and the STEM KIT. It also analyzes the interest of students who participated in the STEM education program both in STEM after school and in regular STEM learning.

3.1 Analysis, Design, and Development of Solar Panel Topic STEM Education Program

The analysis was first conducted using a survey of students' STEM interests and a needs analysis with the survey. The results of first phase showed that students' interest in STEM fields was high. The data showed that more students are interested in pursuing a career in medicine, with a percentage of 17.7%, followed by engineers with a percentage of 7.7%. In third place is a career in computer programming at around 5.6%. The percentage for careers in STEM teachers is very small, at around 3.2%. Furthermore, the results showed that students' motivation for a career in STEM varies. The most chosen reason is that the career field is interesting, which is around 56.9% of students' interest, followed by the reason that the career field can help others, around 49%, and can help provide for their families, around 44.2%.

Furthermore, the analysis was also conducted by observing the implementation of renewable energy learning in two schools in Jakarta. The observation results showed that renewable energy has been taught in schools but in a limited scope. The learning is project-based but not well organized. In addition, the implementation is also still limited to certain alternative energies. The use of solar panels as an alternative energy is still rarely studied by students in a structured manner. Thus, guides and kits are needed to facilitate students' interest in STEM fields, especially in the domain of renewable energy, such as solar panels.

The solar panel KIT design was made by first designing a prototype (Figure 2). This prototyping took place iteratively with the help of experts. Furthermore, by paying attention to the stages of the engineering design process, student worksheets were designed. The worksheet contains objectives, problem identification, tools and materials, work steps, observation results, redesign, and conclusions.

The STEM worksheets and KITs developed in this study have been checked by experts and declared valid. The expert gave some notes on the improvement of the product quality. The researcher has responded carefully to the suggestions from the expert validators and made a comprehensive set of revisions. First, the learning objectives have been formulated using the ABCD format, including audience, behavior, condition, and degree. Second, we have replaced the images in the materials with more relevant ones, ensuring that each illustration supports the content effectively. Third, the issues raised in the materials are now more relevant, reflecting real situations faced in the community. Finally, to improve understanding, we have ensured that each work step is accompanied by a clear image, providing a visual guide that helps students follow the process more easily. These revisions are expected to improve the quality of the learning materials and facilitate a more effective learning process.

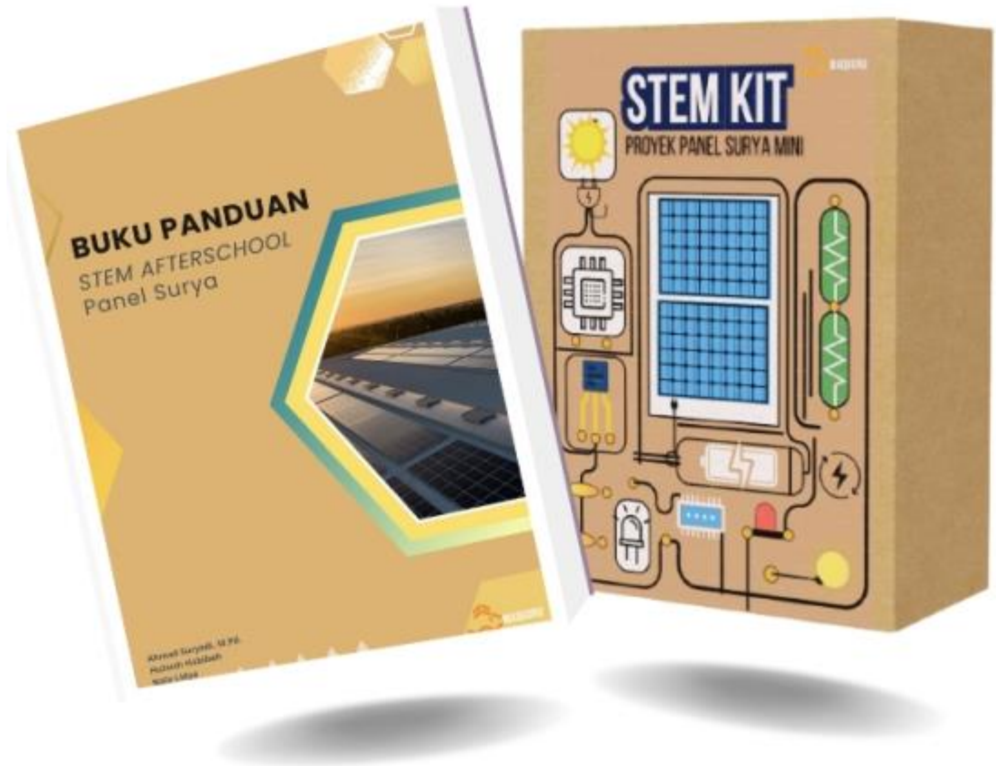

Figure 2. Social sciences teaching module

The worksheets developed to facilitate regular STEM learning activities and after-school STEM learning are basically the same. The only difference is the time allocation provided to complete the project. Furthermore, the STEM KIT provided in this version focuses on the project of making automatic lights. The KIT consists of solar panels, Li-Ion batteries, and electronic circuits that can produce automatic garden lights. Furthermore, this STEM KIT also provides facilities for students to redesign. For example, students can creatively change the automatic garden light's shape or the electrical circuit to make the light brighter. Experts also validate the STEM program regarding material content, appearance, language quantitatively (Table 1).

Table 1. STEM program validity results based on expert assessment

Aspect	Percentage (%)	Category
Content	89.50	Valid
Appearance	95.00	Valid
Language	95.00	Valid

The STEM program with solar panels is an activity shown to students at the high school level and carried out in two schools, namely through regular STEM learning and STEM after-school learning. This activity contains physics learning using the STEM approach. The activities carried out by students in this activity are presented in Table 2 and Table 3.

Table 2. Description of program implementation through STEM after-school Learning

Meeting	Activity
1	The activity began with an opening with the principal; then, students were divided into several groups and introduced to renewable energy material and STEM KIT, followed by carrying out activities in Guidebook 1 starting from identifying problems (Figure 3), conducting research, conducting activities to analyze the effect of solar panel area and light intensity, conducting discussions related to the activities that have been carried out, and finally given the task of designing an automatic garden light cover for the next meeting. All activities are carried out with the guidance of the research team.  Figure 3. Identifying problems activity
2	Activities are carried out by following guide two, which consists of core activities, namely making a solar panel automatic garden light circuit. After the circuit is successfully made, students conduct an automation test on the circuit (Figure 4). The circuit is successful when the lights turn on during dark conditions and the lights turn off during bright conditions. Based on the automatic garden lights made, students identify the quality of the product and the improvements that need to be made by answering some questions in the discussion section. At the end of the guide, students are asked to assemble the circuit with the lamp frame assigned at the previous meeting.  Figure 4. Making a solar panel circuit
3	The activity begins by giving time to finalize the work of automatic garden lights and prepare for the presentation of the work. Then, each group will make a presentation, be assessed, and be given joint input by peers and the research team. This activity ends by giving rewards to teams that make products, presenting them interestingly, and following the criteria to be achieved (Figure 5).  Figure 5. Group presentation

Table 3. Description of program implementation through regular STEM learning

Meeting	Activity
1	The activity begins by dividing students into several groups and introducing them to renewable energy materials and STEM KIT. Furthermore, students are guided to carry out activities in Guidebook 1, starting from identifying problems (Figure 6), conducting research, carrying out activities to analyze the effect of the area of solar panels, conducting discussions related to the activities that have been carried out, and finally being given the task of designing an automatic garden light cover for the next meeting. All activities are carried out with the guidance of the research team.  Figure 6. Problem identifying
2	The activity began with carrying out activities in guidebook two, starting from analyzing the effect of the area of solar panels and the effect of two solar panels if they are assembled in series or parallel, then conducting discussions related to the activities that have been carried out (Figure 7), and finally being given the task of designing an automatic garden light cover for the next meeting. All activities were carried out with the guidance of the research team.  Figure 7. Group discussions and analysis
3	Activities are carried out by following guide three, which consists of core activities, namely making a solar panel automatic garden light circuit. After the circuit is successfully made, students conduct an automation test on the circuit. The circuit is successful when the lights turn on during dark conditions and the lights turn off during bright conditions. Based on the automatic garden lights made, students identify the quality of the product and the improvements that need to be made by answering several questions in the discussion section (Figure 8). At the end of the guide, students are asked to assemble the circuit with the lamp frame assigned in the previous meeting.  Figure 8. Testing a solution

Meeting	Activity
4	The activity begins by giving time to finalize the work of automatic garden lights and prepare for the presentation of the work. Then, each group will make a presentation and be assessed and given joint input by peers and the research team. Then, each group will redesign based on the input that has been given. This activity ends by giving rewards to teams that present them attractively and follow the criteria to be achieved (Figure 9).  Figure 9. Group presentation

3.2 *Analysis of students' STEM interests after the program*

This study measured students' interest in science, technology, engineering, and mathematics and their interest in a career in STEM in students who have participated in STEM program activities. The results of the study are expressed in Table 4.

Table 4. Comparison of students' STEM career interest in two locations

	Regular Learning			After-School Program			Comparison	
	N	**Mean (SD)**	**Median (IQR)**	**N**	**Mean (SD)**	**Median (IQR)**	**U**	***sig.***
Science Interests	58	4,87 (1,04)	4,80 (1,40)	25	5,45 (1,54)	5,80 (2,00)	444,00	0,005
Technology Interests	58	5,17 (0,96)	5,00 (1,80)	25	5,36 (1,56)	5,60 (2,40)	607,00	0,240
Engineering Interests	58	4,58 (1,18)	4,40 (1,45)	25	4,62 (1,18)	4,40 (1,50)	719,00	0,952
Math Interests	58	4,36 (0,71)	4,40 (1,00)	25	4,40 (1,00)	4,20 (1,60)	703,50	0,830
STEM Career Interests	58	4,91 (1,04)	4,80 (1,85)	25	4,98 (1,31)	5,20 (1,70)	676,50	0,629

The results showed no significant difference in interest in technology, engineering, mathematics, and STEM careers between the groups of students who attended regular and after-school STEM programs ($p>0.05$). The study found a significant difference in interest in science between the group of students who participated in after-school STEM activities and those who participated in STEM activities during regular hours ($p<0.05$). The median of the group of students who participated in STEM after-school learning (Median = 5.8; IQR = 2.0) was greater than that of students who participated in the regular STEM learning program (Median = 4.8; IQR = 1.4).

4. Discussion

This study was conducted by developing a STEM program and exploring the effect of the solar panel STEM program on students' STEM interests. The study results showed that the solar panel project can be an engaging learning context for students. This finding gives us an insight that using projects closely related to contemporary global issues, such as the energy crisis, not only increases students' engagement but also deepens their understanding of the real applications of STEM concepts (Struyf et al., 2019; Suryadi et al., 2023). According to the literature, choosing interdisciplinary and challenging learning contexts can influence students' motivation (El Nagdi & Roehrig, 2020; Mayasari et al., 2019). The integrated STEM program for solar panel topic developed in this study is designed to facilitate active, creative and collaborative learning. Students first need to understand the problem of the energy crisis and renewable energy solutions. This motivates students to complete the solar panel project. According to Aldemir et al (2022), engineering process activities can increase students' interest.

This study has developed a solar panel learning KIT for secondary school students. The results of the expert validation show that the solar panel STEM program developed in this study is valid and feasible to use. One important aspect of research and development is expert involvement. In this study, expert opinion has qualitatively helped improve the quality of the product. By accommodating expert suggestions, product quality in various aspects can be improved (Pasaribu et al., 2023).

The solar panel topic STEM Learning KIT had also been implemented through afterschool activities and regular learning. The project implementation results showed that the solar panel project ideas designed by students were quite varied. Although limited to solar panel applications, the products produced by students were very creative. This result aligns with previous studies that state that integrated STEM learning can encourage students' creativity (Gök & Sürmeli, 2022; Lidya et al., 2024). Moreover, such activities can also develop students' critical thinking (Indranuddin et al., 2024).

One of the most interesting findings of this study was that there was no significant difference in students' interest in technology, engineering, mathematics, and STEM careers between students who participated in the after-school STEM program and those who studied through the regular curriculum. This result indicates that the solar panel STEM program developed can attract students' interest. This result aligns with Sulaiman et al (2023) study that showed that integrated STEM learning can develop student interest. According to Leammukda et al (2024), not only male students, projects like this are also effective in developing female students' interests.

There are several factors that may account for the lack of difference in STEM interest between the two groups of students. First, the content and activities are the same. At the secondary school level, photovoltaic materials are still rarely covered (Sulaiman et al., 2023). This may be one factor that makes students interested in participating in STEM programs. Second, both groups of students had the same opportunity to present and receive feedback. Finally, the guidance provided by the teacher to both groups was also the same. Through STEM project activities students are more active, fun, and joyful (Hiğde & Aktamış, 2022). The only difference between the two is the participants. For STEM after school, the participants are students who choose scientific extracurricular activities. Meanwhile, for the regular class student group, the participants are more heterogeneous. This is confirmed by the results of the study, which showed that the significant difference was only in science interest. In summary, in terms of program implementation, this study showed that the program can practically be applied in regular learning and after-school learning modes.

Adjustments are needed in its implementation. This is due to the difference in time allocation between these two activities. For example, in after-school activities, the time provided by schools tends to be more flexible with less rigid demands on content. Therefore, the program can focus on product completion. Although this study showed its effectiveness in STEM after-school programs as a new domain, further studies are needed.

The findings of this study offer valuable insights for future STEM curriculum development and teaching practices. Learning using this STEM KIT can be implemented in both programs. However, future research needs to be conducted in an experimental study. This study showed that active engagement of students through challenging and relevant real-world projects could be the key to unlocking their full potential in science, technology, engineering and math (Drymiotou et al., 2021; Gasiewski et al., 2012). This study can inspire the development of various other interdisciplinary programs to make integrated STEM learning easier and more effective to implement.

5. Conclusion

In this study, we explored students' STEM career interests and developed a STEM education program on solar panels. The program aims to introduce students to one form of renewable energy, namely solar energy, through integrative STEM learning. Furthermore, the effectiveness of the STEM program in this study was measured by investigating students' STEM career interests. The results showed no significant difference between students attending the STEM after-school and regular STEM programs. With a fairly high average score, it can be said that the STEM program with solar panels positively impacts students' STEM interests. Significant differences were only found in students' science interest in STEM after-school activities and regular learning. STEM education programs can be developed on more diverse topics in the future.

This study provides several important implications. First, integrated STEM education can be implemented optimally if it involves an interdisciplinary context. In this study, the issue of solar energy became quite a productive context for facilitating the learning process with an integrated STEM approach. Secondly, this study showed that the STEM KITs and worksheets developed in this study can be applied in both regular and after-school learning environments. Regular and after-school learning activities are two learning activities that contribute significantly to developing students' interests.

In addition, it is important to highlight the limitations of this study. One is the limited research sample, which may not fully reflect Indonesia's demographic and social diversity. Another limitation is the focus on a few specific aspects of STEM careers, which may not cover the full spectrum of students' interests and motivations in STEM fields. Future studies could address these limitations by including a wider sample and more diverse variables to gain a more comprehensive understanding of STEM career interests and choices in Indonesia. Considering these implications and limitations, future research could focus on developing more targeted and inclusive educational interventions that increase students' interest in STEM and support the development of students' necessary skills and knowledge. This approach could significantly contribute to human capital development in Indonesia and strengthen the overall STEM education ecosystem.

Authors Contribution: Suryadi, A: methodology, conducting the research and writing original article; Lidya, N., and Habibah, H, field data collection and data analysis. Suwarna, I.P: Field data collection data analysis, and revision.

Conflict of Interest: The authors declare no conflict of interest.

Acknowledgement: This research received funding support from PUSLITPEN UIN Syarif Hidayatullah Jakarta with contract number B-392/LP2MPUSLITPEN/TL.03/09/2023.

6. References

Aldemir, T., Davidesco, I., Kelly, S. M., Glaser, N., Kyle, A. M., Montrosse-Moorhead, B., & Lane, K. (2022). Investigating students’ learning experiences in a neural engineering integrated STEM high school curriculum. *Education Sciences*, *12*(10). https://doi.org/10.3390/educsci12100705

Astawan, I. G., Suarjana, I. M., Werang, B. R., Asaloei, S. I., Sianturi, M., & Elele, E. C. (2023). STEM-based scientific learning and its impact on students’ critical and creative thinking skills: An empirical study. *Jurnal Pendidikan IPA Indonesia*, *12*(3), 482–492. https://doi.org/10.15294/jpii.v12i3.46882

Borich, G. D. (2015). *Observation skills for effective teaching: Research-based practice*. Paradigm. https://doi.org/10.4324/9781315633206

Branch, R. M. (2009). Instructional Design: The ADDIE Approach. In *Department of Educational Psychology and Instructional Technology University of Georgia* (Vol. 53, Issue 9). https://doi.org/10.1007/978-0-387-09506-6

Drymiotou, I., Constantinou, C. P., & Avraamidou, L. (2021). Enhancing students’ interest in science and understandings of STEM careers: the role of career-based scenarios. *International Journal of Science Education*, *43*(5), 717–736. https://doi.org/10.1080 /09500693.2021.1880664

El Nagdi, M., Leammukda, F., & Roehrig, G. (2018). Developing identities of STEM teachers at emerging STEM schools. *International Journal of STEM Education*, *5*(1), 1–13. https://doi.org/10.1186/s40594-018-0136-1

El Nagdi, M., & Roehrig, G. (2020). Identity evolution of STEM teachers in Egyptian STEM schools in a time of transition: A case study. *International Journal of STEM Education*, *7*(1). https://doi.org/10.1186/s40594-020-00235-2

Gasiewski, J. A., Eagan, M. K., Garcia, G. A., Hurtado, S., & Chang, M. J. (2012). From gatekeeping to engagement: A multicontextual, mixed method study of student academic engagement in introductory STEM courses. *Research in Higher Education*, *53*(2), 229–261. https://doi.org/10.1007/s11162-011-9247-y

Gök, B., & Sürmeli, H. (2022). The effect of scientific toy design activities based on the engineering design process on secondary school students' scientific creativity. *Asian Journal of University Education*, *18*(3), 692–709. https://doi.org/10.24191/ajue.v18i 2.17987

Hiğde, E., & Aktamış, H. (2022). The effects of STEM activities on students' STEM career interests, motivation, science process skills, science achievement and views. *Thinking Skills and Creativity*, *43*(March). https://doi.org/10.1016/j.tsc.2022.101000

Indranuddin, R. D., Susetyarini, E., & Miharja, F. J. (2024). Developing STEM-PjBL worksheet to lift students' critical, creative, and computational thinking skill. *Research and Development in Education (RaDEn)*, *4*(1), 85–101. https://doi.org/10.22219/ raden.v4i1.27165

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, *3*(1). https://doi.org/10.1186 /s40594 -016-0046-z

Kemendikbud, Pdd. (2020). Higher Education Statistical Year Book 2020. In *Pangkalan Data Pendidikan Tinggi*. https://pddikti.kemdikbud.go.id/publikasi

Kemendikbud, Pdd. (2021). Higher Education Statistical Year Book 2021. In *Direktorat Jenderal Pendidikan Tinggi, Riset, dan Teknologi: Vol. Ke-6*. https://www.slideshare. net/fransmitter/statistik-pendidikan-tinggi-2021-finalpdf

Kızılay, E., & Yamak, H. (2023). Factors affecting high school students' motivation and career interest in STEM fields and their modeling. *Science Insights Education Frontiers*, *16*(1), 2409–2433. https://doi.org/10.15354/sief.23.or256

Leammukda, F., Boyd, B., & Roehrig, G. H. (2024). Fostering STEM Interest In Middle-School Girls Through Community-Embedded Integrated STEM. *Journal of Women and Minorities in Science and Engineering*, *30*(2), 59–87. https://doi.org/10.1615/JWomen MinorScienEng.2023039905

Lichtenberger, E., & George-Jackson, C. (2012). Predicting high school students' interest in majoring in a STEM field: Insight into high school students' postsecondary plans. *Journal of Career and Technical Education*, *28*(1). https://doi.org/10.21061/jcte.v28i1.571

Lidya, N., Habibah, H., & Suryadi, A. (2024). The effect of design-based STEM learning on students ' scientific creativity in solar energy topic. *Momentum: Physics Education Journal*, *8*(2), 166–180. https://doi.org/10.21067/mpej.v8i2.9767

Machuve, J., & Mkenda, E. (2019). Promoting STEM education through sustainable manufacturing: Case study of photovoltaic toys. *Procedia Manufacturing*, *33*, 740–745. https://doi.org/10.1016/j.promfg.2019.04.093

Mayasari, T., Susilowati, E., & Winarno, N. (2019). Practicing integrated STEM in renewable energy projects: Solar power. *Journal of Physics: Conference Series*, *1280*(5). https://doi.org/10.1088/1742-6596/1280/5/052033

Muchtar, A. H., & Ding, L. (2024). Integrated STEM education in Indonesia: What do science teachers know and implement? *Jurnal Pendidikan Sains Indonesia*, *12*(1), 232–246. https://doi.org/10.24815/jpsi.v12i1.35588

Mutakinati, L., Anwari, I., & Yoshisuke, K. (2018). Analysis of students' critical thinking skill of middle school through STEM education project-based learning. *Jurnal Pendidikan IPA Indonesia*, *7*(1), 54–65. https://doi.org/10.15294/jpii.v7i1.10495

Nuragnia, B., Nadiroh, N., & Usman, H. (2021). Pembelajaran STEAM di sekolah dasar: Implementasi dan tantangan. *Jurnal Pendidikan Dan Kebudayaan*, *6*(2), 187–197. https://doi.org/10.24832/jpnk.v6i2.2388

Parno, P., Yuliati, L., Hermanto, F. M., & Ali, M. (2020). A case study on comparison of high school students' scientific literacy competencies domain in physics with different methods: PBL-STEM education, PBL, and conventional learning. *Jurnal Pendidikan IPA Indonesia*, *9*(2), 159–168. https://doi.org/10.15294/jpii.v9i2.23894

Pasaribu, K., Khairuna, K., Adlini, M. N., & Abrori, F. M. (2023). Developing STEM students' worksheet to improve students' creative thinking ability. *Research and Development in Education (RaDEn)*, *3*(2), 127–136. https://doi.org/10.22219/raden.v3i2.25331

Perea, J. D., Gasca, D. C., Echeverry-Prieto, G., Quiroga-Fonseca, V., Orozco-Donneys, C., Díaz-Montealegre, L. C., Ortiz, A., Molina, G., Cruz, D., Persad, A., Redd-Kantareddy, S. N., Wachsmuth, J., Heumueller, T., Brabec, C., Rodriguez-Toro, V. A., & Salguero, C. (2021). Last generation solar cells in Outer Space: A STEM outreach project with middle and high school students in Colombia. *European Journal of STEM Education*, *6*(1), 1–7. https://doi.org/10.20897/ejsteme/11353

Purwaningsih, E., Sari, S. P., Sari, A. M., & Suryadi, A. (2020). The effect of stem-pjbl and discovery learning on improving students' problem-solving skills of the impulse and momentum topic. *Jurnal Pendidikan IPA Indonesia*, *9*(4), 465–476. https://doi.org/10.15294/jpii.v9i4.26432

Sadler, P. M., Sonnert, G., Hazari, Z., & Tai, R. (2012). Stability and volatility of STEM career interest in high school: A gender study. *Science Education*, *96*(3), 411–427. https://doi.org/10.1002/sce.21007

Shahbazloo, F., & Mirzaie, R. A. (2023). Investigating the effect of 5E-based STEM education in solar energy context on creativity and academic achievement of female junior high school students. *Thinking Skills and Creativity*, *49*(September). https://doi.org/10.1016/j.tsc.2023.101336

Struyf, A., De Loof, H., Boeve-de Pauw, J., & Van Petegem, P. (2019). Students' engagement in different STEM learning environments: integrated STEM education as promising practice? *International Journal of Science Education*, *41*(10), 1387–1407. https://doi. org/10.1080/09500693.2019.1607983

Sulaeman, N., Efwinda, S., & Putra, P. D. A. (2022). Teacher readiness in STEM Education: Voices of Indonesian physics teachers. *Journal of Technology and Science Education*, *12*(1), 68–82. https://doi.org/10.3926/jotse.1191

Sulaiman, F., Rosales, J. J., & Kyung, L. J. (2023). The effectiveness of the integrated STEM-PBL physics module on students' interest, sensemaking, and effort. *Journal of Baltic Science Education*, *22*(1), 113–129. https://doi.org/10.33225/jbse/23.22.113

Sumarni, W., Sudarmin, S., Sumarti, S. S., & Kadarwati, S. (2022). Indigenous knowledge of Indonesian traditional medicines in science teaching and learning using a science–technology–engineering–mathematics (STEM) approach. In *Cultural Studies of Science Education* (Vol. 17, Issue 2). Springer Netherlands. https://doi.org/10.1007/s11422-021-10067-3

Suryadi, A., Purwaningsih, E., Yuliati, L., & Koes-Handayanto, S. (2023). STEM teacher professional development in pre-service teacher education: A literature review. *Waikato Journal of Education*, *28*(1), 7–26. https://doi.org/10.15663/wje.v28i1.1063

Tyler-Wood, T., Knezek, G., & Christensen, R. (2010). Instruments for assessing interest in STEM content and careers. *Jl. of Technology and Teacher Education*, *18*(2), 341–363. https://www.researchgate.net/publication/267414391_Instruments_for_Assessing_Interest_in_STEM_Content_and_Careers

Wang, N., Tan, A. L., Zhou, X., Liu, K., Zeng, F., & Xiang, J. (2023). Gender differences in high school students' interest in STEM careers: A multi-group comparison based on structural equation model. *International Journal of STEM Education*, *10*(1). https://doi.org/10.1186/s40594-023-00443-6

Will, M. (2017). *Most students are not naturally interested in STEM, teachers say*. Education Week. https://www.edweek.org/teaching-learning/most-students-are-not-naturally-interested-in-stem-teachers-say/2017/06

Yuliati, L., Parno, P., Yogismawati, F., & Nisa, I. K. (2018). Building scientific literacy and concept achievement of physics through inquiry-based learning for STEM education. *Journal of Physics: Conference Series*, *1097*(1). https://doi.org/10.1088/1742-6596/1097/1/012022