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Research article

Impacts of integrating engineering design process into STEM makerspace on renewable energy unit to foster students' system thinking skills

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A R T I C L E I N F O

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A B S T R A C T

Currently, science education systems around the world are faced with global challenges, especially in anticipating environmental changes related to sustainable development programs. Complex system problems related to climate change, reduced fossil-based energy reserves, and social environmental problems that have an impact on the economy have made stakeholders aware of the Education for Sustainability Development (ESD) program. This study aims to examine the effectiveness of STEM-PBL integrated Engineering Design Process (EDP) in renewable energy learning units to improve students' system thinking skills. The quantitative experimental research with a non-equivalent control group design was conducted on 67 high school students in XI grades. The results showed that the performance of students who were taught with STEM-EDP was better than students who studied with traditional STEM learning approach. In addition, this learning strategy also encourages students to be actively involved in every EDP process so that they show good performance in mind-on and hands-on activities which have an impact on increasing students' system thinking abilities. Furthermore, the STEM-EDP learning is implemented to develop students' ability to design through applied technology and engineered activities, paying special attention to design-based theory. It does not require students and teachers to prepare super-sophisticated technology, because the integration of technology in this learning design used cheap, simple and 'easy to find' equipments, to create more meaningful learning packages. In the critical pedagogy, STEM-PBL integrated EDP can be used to systematically foster students' STEM literacy and thinking skills through the engineering design thinking process, thus expanding students' cognitive building and perspectives in reducing the routine in conventional pedagogy.

1. Introduction

The Program of Education for Sustainable Development (ESD) has been released by the United Nations from 2019 to 2030 in order

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to prepare a global platform to ensure sustainability issues [1]. Many schools and even universities around the world have actively participated in the transformation and have included the United Nations Sustainable Development Goals (SDGs) in the Education curriculum to foster the involvement of the younger generation in taking an active role in caring for the issues of everyday life phenomena related to the context of the world order. Based on sustainable principles [2–4]. Including Indonesia, in the national curriculum, especially science education, has included sustainability issues, including renewable energy and climate change materials, starting from Elementary Education to Higher Education with the main aim of growing knowledge, skills, attitudes, and sustainable values designed to shape a more promising and better future for students and the younger generation [5–7].

However, how a strategy to teach sustainability issues in schools has become a challenge for many countries, including Indonesia [5,8–10]. Particularly in Indonesia, the preliminary research conducted showed that teachers still have difficulties in designing ESD-oriented learning units to achieve sustainable education. The learning process that guides students to face real world problems in everyday life and builds student's knowledge about science has not been optimally implemented. One of the facts found is there has not been much development of problem-based Science-Physics learning on the topic of renewable energy. Even though the importance of the availability of clean and sustainable energy as well as the problems of current environmental conditions are important to discuss. Therefore, it is necessary to implement and study the impact of ESD-oriented problem-based learning on students' 21st century skills. The results of the theoretical study led researchers to the conclusion that PBL is a learning model that applies problems to everyday life so that students can be motivated to solve problems with their abilities. Along with this, several developed countries have combined the concept of Science, Technology, Engineering, and Mathematics (STEM) education with interdisciplinary learning, and applied it to ESD, especially in science subjects [4,11,12]. The STEM approach is not only a trend in the issue of the need for learning innovation but also has the opportunity to provide various possibilities of creative space (makerspace) for students so that they have the power of reasoning and creativity (minds-on and hands-on) that stimulate their higher-order thinking skills [13–16].

One of the higher-order thinking skills that future generations need about future challenges that are very complex is Complex Problem-Solving (CPS) [17–19]. Complex problem-solving abilities can be identified and stimulated through the cultivation of systems thinking skills [20–22]. Systems thinking is one of the most important skills in the 21st century. Systems thinking helps students organize their thoughts in meaningful ways and make connections between seemingly unrelated problems intertwined [23]. Systems thinking according to Nuraeni (2020) [24] is one type of complex thinking. The complexity and interconnectedness of systems thinking with other aspects. The process of system thinking will influence action or behavior [25]. Meanwhile, system thinking has an impact on a series of thoughts that form a person's thinking habits (Mindset) or a person's perspective as an implication of understanding an object of thought in responding to a problem [26]. So, mindset is a belief, a set of beliefs or ways of thinking that affect a person's behavior and attitudes that will ultimately determine the level of success in his life [27]. In this study, the system thinking indicator used adopted Meilinda's [28], namely being able to recognize the structure and role of components in the system, analyze the interaction of components in the system, analyze patterns/modeling in the system and predict/retrospective system behavior due to interaction in the system. The results of Nagahi et al. (2021) [29] have produced a Perceived Complex Problem Solving (PCPS) instrument model capable of finding and measuring the level of perception an individual holds in dealing with complex problems and can be used in different settings and environments. Further research on the relationship between Systems Thinking and CPS revealed individuals with a high level of systems thinking had a better understanding of the complex characteristics of the problem and a better perception of CPS.

Complex problems related to living systems faced by future generations, one of them is related to sustainability issues such as climate change, availability of renewable energy due to reduced fossil energy reserves, natural disasters, etc. [30,31]. Thus, the ability to think systems needs to be instilled in students, not only to prepare them to have the knowledge and skills to solve problems related to sustainability issues in their lives, but also more to instill sustainability attitudes that are expected to motivate and build positive character about their role in development. Sustainable in the context of ESD [32–34].

However, there is still little research devoted to the development of STEM curriculum development in ESD-oriented schools [35–37]. On the other hand, based on the results of research on STEM Education, the application of the Engineering Design Process (EDP) is still rarely carried out at the secondary school level [38,39]. EDP has the potential to be developed in an ESD-oriented STEM curriculum to stimulate student involvement both in exploring and developing thinking skills (habit of mind), as well as in physical activities such as designing and making projects (hands-on activities), so that learning can be more meaningful [4,40–42].

One of the main characteristics of Indonesia's National Curriculum Reform is to ensure that secondary school students have basic competencies in designing products or prototypes in the context of project-based learning [43]. This research carried out to address the objectives of the curriculum reform. Accordingly, We try to develop an innovative physics learning program model oriented to Education for Sustainable Development integrated STEM-EDP on Renewable Energy material by providing creative and innovative space (makerspace) for physics teachers in developing systems thinking skills and students' concern for the world in the future according to the principles of sustainable development. This study can provide an overview for teachers and as input in developing learning activities in the classroom towards sustainable education by using STEM-oriented integrated PBL to improve students' systems thinking abilities based on engineering design process framework in overcoming routine in conventional pedagogy. Therefore, this study aims to examine the effectiveness of STEM-PBL integrated Engineering Design Process (EDP) in renewable energy learning units to improve students' system thinking skills.

2. Literature review

2.1. Education for Sustainable Development and sustainability attitude

Education for Sustainable Development, abbreviated as ESD, is education that is oriented toward maintaining and improving the natural and social environment in a sustainable manner [40,44]. In contrast to education in general, which is only understood to educate people to be able to solve problems, gain prosperity, and social status in the community. ESD aims to build capacity and commitment to create a sustainable society, which in the acquisition process has an impact on individual decisions. The sustainable society considers the ecological balance of nature so that the quality improvement of human life is followed by the eco-friendly and comfortable environment [45–47]. This ESD has an important role in building awareness and attitudes about the importance of friendly, caring, and environmental empowerment activities that cannot be grown in a short time but must go through an education and learning process that can stimulate students' reasoning power and spirit of sustainability [34,48,49].

In addition, ESD is an appropriate educational program to educate the public from an early age to reduce dependence on nature and the social environment, the community is directed to always try to find innovations to reduce excessive natural exploitation, so that they actively participate and have knowledge about the importance of maintaining the balance of nature and maintaining social-economic harmonization in a more civilized society [33,50]. Thus, it is hoped that ESD will be able to make people aware at all levels, especially the younger generation and students, of how complex environmental problems and the universe are with the reality of depleting natural resources, the threat of climate change impacts, ecosystem damage, natural and non-natural disasters, and natural resources. Energy sources come from fossils, which are starting to decrease. Therefore, ESD is expected to encourage students as successful learning citizens, confident in being responsible, and upholding the values of welfare and harmony in the context of sustainability [47,51].

2.2. STEM education and ESD

The acronym 'STEM' stands for Science, Technology, Engineering, and Mathematics. In practice in classrooms STEM as a learning approach is defined as any activity that involves science, technology, engineering, or mathematics as a STEM activity [16,40]. STEM-based learning content and methods are important to be planned optimally to generate interest, engagement, and student learning outcomes. It doesn't matter whether teachers and students use simple materials or sophisticated kits in their activities, what matters is that they are designed in a way that can build students' enthusias, curiosity, and good intentions toward learning and careers in the STEM field. Thus, structuring the learning process by optimizing the quality of content and pedagogical abilities possessed can be a task that requires teacher integrity and so can stimulate students to solve real-life problems [52].

Education is the road to sustainability, creating the appropriate environment for learners to socialize and acquire knowledge and skills for the 21st century. In the past last 10 years, STEM education has gained attention, and little is known about how researchers designed and implemented learning activities [53]. STEM is a learning approach that is currently increasing in popularity because the STEM implementation can provide greater relevance in science learning. The positive impact of this issue is shown by the growing interest in the field of STEM research, and the interest of stakeholders to integrate STEM education into curriculum development [52,54,55]. Particularly related to sustainability issues, STEM is also recommended by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) as an approach to the teaching and learning process of STEM subjects in an effort to achieve sustainable development goals in the field of education [56].

2.3. STEM education and Complex Problem-Solving

The skills acquired by students in the 21st century can be enhanced through inquiry, project, and problem-based learning in the STEM education context [13,57,58]. In addition, even students' skills in problem solving, knowledge, creative abilities, including complex problem solving skills in increasingly complex global problems can also be improved and developed through the application of the STEM approach in learning. The complex global problems will always be a trending issue that is juxtaposed with government efforts even in every country to achieve sustainable development goals, therefore the context of STEM education is certainly very related to this because it can play a role in the intended efforts and goals. The integration between the context of STEM and sustainable education can certainly be measured by mapping the implementation of education emphasizes the development of critical thinking, knowledge from local to global perspectives, and problem-solving skills [59,60]. Furthermore, even the readiness of a country in the future can be measured by the extent to which the skills are successfully possessed and mastered by the next generation through the STEM approach [54]. Skills development is one of the main goals of education. Studies on the design and implementation of ESD-oriented STEM learning activities have the potential to be able to contribute to STEM education thoughts that have been discussed in previous studies to build Indonesian students' Complex Problem-Solving abilities.

As an interdisciplinary learning system approach, STEM education has received special attention almost across the board, long before Bybee [61] emphasized that integrated STEM education should address issues of global importance (e.g., climate change & scarcity of energy sources). STEM education is also designed to develop students' ability to design through applied technology and engineering activities, paying particular attention to theory-based design. In this context, Physics theories, particularly the concept of renewable energy and learning theories that underlie the interdisciplinary learning approach become the foundation of student activities. The advantages of this interdisciplinary learning approach shift the responsibility of learning from teachers to students, so that students are managed to create their own learning experiences according to the principles of Connectivism learning theory.

Connectivism learning theory places educators as facilitators in creating learning ecosystems, forming, and activating learning communities, and engaging learners into the real environment [62]. Therefore, EDP-based STEM-PBL can be used to systematically foster students' STEM literacy and thinking skills through the engineering design thinking process, thus expanding students' cognitive building and perspectives and reducing the lack of routine in conventional pedagogy.

2.4. Research methods

2.4.1. Research design

The design of this research is experimental quantitative research with a non-equivalent control group design. The design was chosen because it is suitable to be applied in this study. The independent variable in this study is STEM learning integrated EDP and the dependent variable of this study is systems thinking skills. For both groups, a problem-based learning model (PBL) was used to introduce and stimulate the acquisition of the required knowledge to students about the concept of renewable energy. In this study, the experimental group ($n = 31$) were students who studied with EDP-integrated STEM-PBL learning; where teaching materials, worksheets, hands outs, and quizzes are oriented to EDP activities. While the control group students ($n = 36$) studied with the steps of the conventional STEM-PBL learning approach with the scientific approach. The scientific approach is one the learning approach applied in Indonesia that contains activities of *Mengamati* (observe), *Menanya* (ask), *Mencoba* (try), *Mengasosiasi* (associate), *Mengomunikasikan* (communicate). The scientific learning approach focuses on the application of the scientific method in teaching and learning activities. This approach guides students to think scientifically, logically, critically, and objectively according to the facts. They learn with the STEM-PBL model with a learning tradition that is usually carried out by the same teacher. The treatment in the experimental and control classes is visualized in Fig. 1.

The EDP stages used in this study are represented in Fig. 2 and described in the following points.

- ASK- ask students to identify the real daily problem regarding the need for renewable energy.
- IMAGINE - Invite students to look for solutions to solve the problem.
- PLAN – Allow students to choose the solution that makes the most sense, and let them plan/design the solution, including listing what materials they need
- CREATE - Give students time to execute their plans/designs regarding to sustainability matter.
- TEST - Let students test what has been made and evaluate the strengths and weaknesses of the solution/prototype.
- IMPROVE - Ask students to make improvements, then retest the solution/prototype.

Meanwhile, each scientific approach activity mentioned in the previous paragraph is not hierarchical. In detail, several scientific approach activities are described in the following points.

- Observe - Ask students to collect relevant facts related to renewable energy.
- Ask - Allow students to ask about what, how, and why.
- Try - Invite students to do the experiment or demonstration.
- Associate - Give students time to analyze the findings by applying the concept.
- Communicate - Let students prepare and deliver reports systematically

Learning stages that integrate EDP into PBL STEM learning in the experimental class and STEM-PBL learning stages with a scientific approach are presented in Table 1.

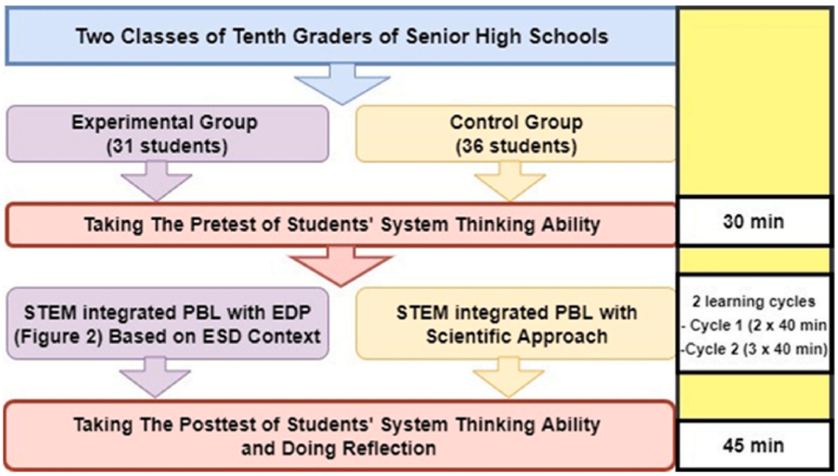


Fig. 1. Research procedure and treatment.

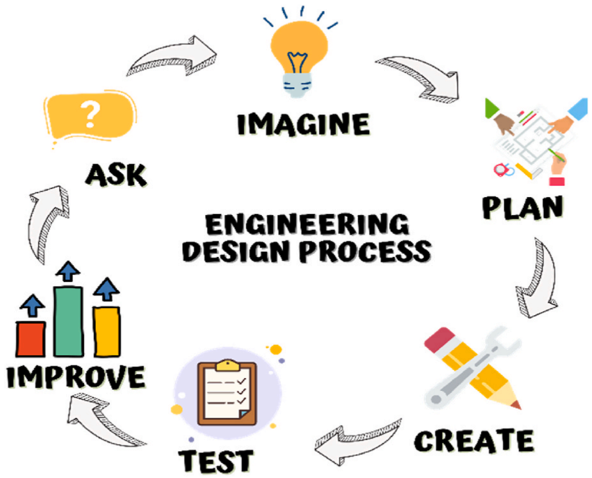


Fig. 2. Engineering design process (EDP) (adapted from long, Yen, & Van Hanh [42]).

Table 1
Learning stages in the experimental and control classes.

PBL Phase	STEM Integration	The EDP Activities (Experimental Class)	The scientific approach Activities (Control Class)
Provide orientation about the problem to student	Science Technology (STEM 2.0)	Ask, Imagine	*Ask, Observe*
Organize students to study	Science Technology (STEM 2.0)	Plan	*Ask*
Assist in conducting individual and group investigations	Science Technology Engineering Mathematics (STEM 4.0)	Plan, Create	*Ask, Try*
Develop and present the work	Science Technology Mathematics (STEM 3.0)	Test	*Associate*
Analyze and evaluate problems	TM (STEM 2.0)	Improve	*Ask, Communicate*

2.5. Participant

This study involved 67 students in class X consisting of 31 students from X MIPA 2 as the experimental class and X MIPA 3 with 36 students as the control class at SMA Al-Kautsar Bandar Lampung, Lampung Province, Sumatra Island, Indonesia. The purposive sampling technique was conducted in determining the school as the research location, with the consideration that the school applies the 2013 National Curriculum in the learning process. This school was chosen because of its location around the highway where students are faced with dust entering the classroom every day. The topic of renewable energy that introduces the concept of sustainability to students will be taught with PBL, which begins by posing real-life problems to students, how to utilize used goods and electrical energy from batteries to design and make a simple vacuum cleaner to deal with dust that interferes with the learning process. And health in their schools.

2.6. Data collection and research instrument

The pre-test and post-test data were collected by using a test technique. The pre-test was given before the learning process and the post-test was given after the treatment. The research instrument used in this study is for measuring students' system thinking skills in the form of a test sheet. This instrument used at the pretest and posttest is the System Thinking Inventory (STI) which was developed by researchers in the form of multiple-choice questions to measure student learning outcomes as many as 20 item questions that represent all indicators of system thinking. The items in the pretest and post-test refer to the indicators of systems thinking skills adapted from Meilinda (2018). The results of the validity test of the system thinking ability instrument on Renewable Energy material show that all 20 items are valid with a Pearson Correlation value > 0.349. The reliability of the question instrument in this study was processed using the KR-20 method. Based on the results of the reliability test on the KR-20 calculation, it shows that the instrument for systems thinking skills on work and energy materials is 0.903, which means it is very reliable.

2.7. Data analysis

The data obtained in this study were from the pretest and post-test results of systems thinking skills, then the data were analyzed using inferential statistics to determine the difference between the pretest and post-test in the experimental class and control class.

Each correct answer to a question is worth five marks in the objective test. However, an incorrect answer will be 0 marks. To further investigate how the implementation of STEM-PBL with ESD-oriented FC design has significant results on students' system thinking ability, a statistical approach has been used to measure the data derived from the pretest and posttest of students. Statistical analysis was used in this analysis using the SPSS version 25.0 program. The summary of the results of the descriptive statistical analysis is presented in Table 2. Furthermore, the results of the analysis of the normality test and the homogeneity test of the data are presented in Tables 3 and 4.

The normality test results are shown in Table 3, on the value of the system thinking test because of the value of sig. (P) Is more significant than 0.05; the significance value obtained is 0.200 for the pretest and posttest data. It can be assumed that the data is normally distributed. From the results of the homogeneity test shown in Table 4, the pretest and post-test data for the experimental and control classes have a significance value of more than = 0.05, which is 0.043, so the variance data is homogeneous.

2.8. *Ethic statement*

This research is aligned with a set of ethical principles and scientific integrity, human rights and dignity that have been validated by Faculty of Teacher Training and Education the University of Lampung collaborated with Lampung Province Educational Agency, Ministry Of Education, Culture, Research, and Technology. The participants stated their support in writing as research volunteers and actively contributed during the research process.

3. Results

Descriptive statistics have been carried out to identify the size and distribution of the data which can be seen in Table 2. The data from the Independent Sample T-Test test was carried out on the pre-test score to find out if there was a difference in the average system thinking ability of students using STEM-integrated PBL with EDP, which can be seen in Table 5.

The results of the independent sample *t*-test on the pre-test scores in Table 5 above show the value of Sig. (2-tailed) > 0.05, thus there is no significant difference in the average value of system thinking ability between the experimental class and the control class. Consequently, it is concluded that the two groups has equivalent prior knowledge before the learning activity. Then the independent sample *t*-test was conducted on the post-test score, it was found that Sig. (2-tailed) < 0.05, thus there is a significant difference in post-test scores between the experimental class and the control class (see Table 6).

Then, an analysis of covariance (ANCOVA) was also carried out to examine the effect of implementing STEM-integrated PBL with EDP on the system thinking ability of these learning activities. After the learning activity, analysis of covariance (ANCOVA) was used to test the difference between the two groups using the pre-test score as the covariate and the post-test score as the dependent variable, as shown in Table 7. According to the results of the F test ($F = 12{,}545$, $p < 0.05$), there was a significant difference between the two groups. That is, students taught with EDP-based STEM-PBL in the context of ESD showed higher learning outcomes in systems thinking skills compared to students taught with traditional STEM-PBL with a scientific approach. In addition, Cohen's d parameter is 1,085, which means that the effect size of the *t*-test is categorized as high [63], implying that STEM-PBL learning with EDP is more helpful for students in improving students' systems thinking skills on renewable energy topics than conventional STEM learning with scientific approach.

Furthermore, the results of the analysis of each aspect of systems thinking skills in Fig. 3 show that there is an increase in system thinking skills in both the control class and the experimental class. Likewise, there is a similarity in the highest performance of all groups in the ability to analyze patterns/modeling in the system.

4. Discussion

In this study, Physics learning with STEM-PBL integrated EDP in the context of EDS has been shown to be effective in improving the systems thinking ability of high school students in renewable energy units. One of the supporters of this achievement is that the active involvement of students in each phase of EDP in the learning process can provide a stimulus to significantly increase students' system thinking skills. This is in line with several research results, such as those Hutamarn et al. [64] and Hafiz & Ayop [65] which explain that student involvement in each phase of EDP helps them in the acquisition of their knowledge and skills, both in content and in the context of the learning unit they learn. In addition, STEM-PBL has also long been the choice of physics teachers to stimulate students to begin to recognize real problems in their lives and then creatively solve problems in the form of works or product prototype designs for

Table 2
Summary of student's system thinking objective test.

Statistics Parameter	Experiment Class		Control Class	
	Pretest	Posttest	Pretest	Posttest
Number of samples	31	31	36	36
Highest score	25	70	20	60
Lowest score	65	90	60	85
Maximum score	100	100	100	100
Mean	47.74	82.41	44.03	75.27

Table 3
Results of normality test on students' system thinking.

Class	*Kolmogorov Smirnov*		
	Statistic	Df	Sig.
Experiment	0.106	31	0.200
Control	0.093	36	0.200

Table 4
Homogeneity test of student's system thinking.

Levene's Statistic	df1	df2	Sig.
0.018	1	65	0.203

Table 5
Different test results in the two sample groups on pre-test scores.

Class	N	Mean	S.D	t	Sig. (2-tailed)	Interpretation
Experimental	31	47,74	9384	1587	0,117	No significant difference
Control	36	44,03	9697	1591	0,117	

Table 6
Different test results in the two sample groups on post-test scores.

Class	N	Mean	S.D	t	Sig. (2-tailed)	Interpretation
Experimental	31	82.42	5.608	2288	0.000	significant difference
Control	36	75.28	7.741	2.297		

Table 7
Descriptive data and ANCOVA of the post-test results.

Group	N	Adjusted mean	SD	Std. Error	F
Experimental group	31	65.0806	19.08763	2.42413	12.545
Control group	36	59.6528	17.98525	2.11958	

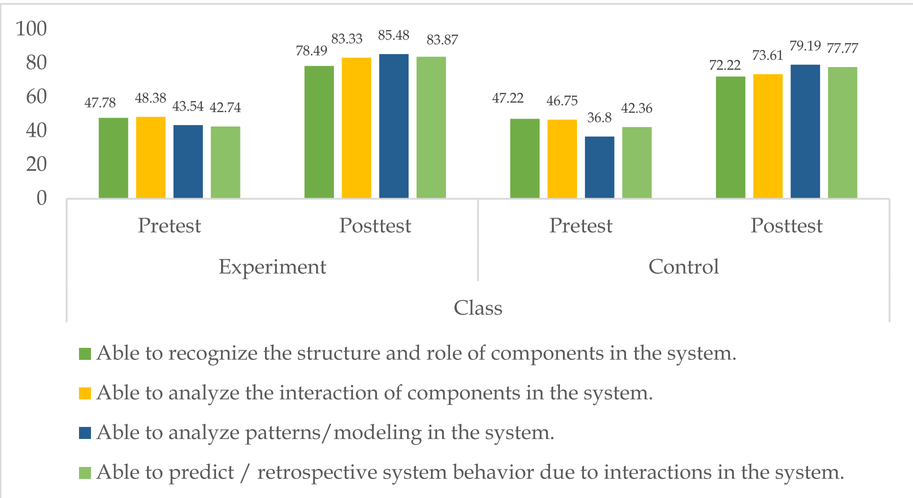


Fig. 3. Students' system thinking performance.

problem-solving [61,66].

The EDP cycle in the learning of renewable energy units guides students to carry out individual and group investigations. Then each group can analyze the pattern/modeling in the system by designing the Vacuum Cleaner product that they want to make. The following is one of the Vacuum Cleaner product designs shown in Fig. 4.

In this study, the problem of the condition of the school environment adjacent to the Sumatran highway is presented. This condition results in a lot of dust around the school which makes learning uncomfortable. Based on these problems students are led to be able to create a product that can overcome these problems. The researcher led the students to connect the scientific knowledge that had been obtained into a simple product, namely a vacuum cleaner. In this process, students can recognize the structure and role of components in the system. At this stage, students can analyze the problem and find the solution shown in Fig. 5.

In addition, student worksheets as teaching materials in this study direct students to be able to analyze by solving problems presented by the teacher, explain the application of energy conversion in everyday life, write mathematical formulas about energy equations, and describe the principles and workings of a vacuum cleaner. Outcome in this phase, students are trained to execute the design made in the previous phase which is shown in Fig. 6.

Based on students' discourse during the learning process of process design, it was found that students in the experimental group tended to pay more attention to developing alternative problem-solving designs preceded by information processing and a number of investigations, while those in the control group spent more time discussing how to complete observation tasks and scientific findings. These findings are also in line with the findings of various experimental studies showed that the use of a series of tasks in developing the work in EDP activities is very effective for growing knowledge construction, intrinsic motivation, and the level of enthusiasm of students [42,67,68]. An important finding that emerged from this study was that STEM-PBL with EDP was able to foster students' systems thinking ability to a better level than students who learned non-EDP PBL-STEM. This result supports previous findings indicating that STEM PBL improves students' thinking skills [69,70].

This study provides an overview of the implementation of EDP within the scope of integrated STEM as a strategy for using technology to support student learning. The authors hope to raise awareness of the intersection of technology-supported learning and STEM-EDP learning. Currently, the community's need for technology is very rapid, but both the integrated STEM learning environment and technology have not been fully utilized. The anxiety of teachers and students about how technology can be applied optimally in learning is also found by researchers. In fact, the use of technology in learning can actually facilitate interaction and achievement of learning objectives, it's just how the teacher can work around this [71,72]. The limited research currently available on technology use strategies and integrated STEM learning environments further suggests that linking the two is necessary and important.

The use of technology in STEM-EDP learning can extend effective teaching and learning beyond what is possible with traditional teaching and learning approaches. Categorizing strategies for using technology (for example, providing authentic contexts, offering web-based inquiry environments, using interactive and immersive technologies, and creating content) can help educators adopt effective strategies to support and guide student learning in STEM-EDP learning. It is important to note that the strategies described in the selected studies are supported through research and theoretical frameworks, which also reflect the effective use of technology [72,73].

The technology in STEM-EDP learning identified in this study support student learning and enhance student experiences in meaningful ways. The technology used in STEM-EDP learning only utilizes simple equipment that is around students. In fact, in relation to the topic of ESD, STEM-EDP learning becomes very integrated. The author hopes to provide insight that the use of technology in STEM-EDP learning does not have to be sophisticated, but right on target. STEM-EDP learning can provide 'real-world' (i.e., similar to that of professionals) experiences for students and encourage engagement [74,75]. By incorporating technology into complex STEM learning environments, we are able to expose students to authentic contexts and provide opportunities to develop the technical skills that highlight learning of STEM disciplines.

5. Limitations and future work

Despite the findings from this study, there are limitations worthy of attention. The first is that we cannot control for variations in teachers' implementation of STEM-PBL especially in each variation of the EDP phase. Secondly, the sample size involved in this study was minimal, thus the involvement of a larger sample would provide a more challenging positive impact on the best outcome for the implementation of this learning model. Nevertheless, despite these limitations, the results showed clear differences between the STEM PBL with EDP and non-EDP STEM-PBL learning models in terms of students' engagement with thinking processes and skills. Further,

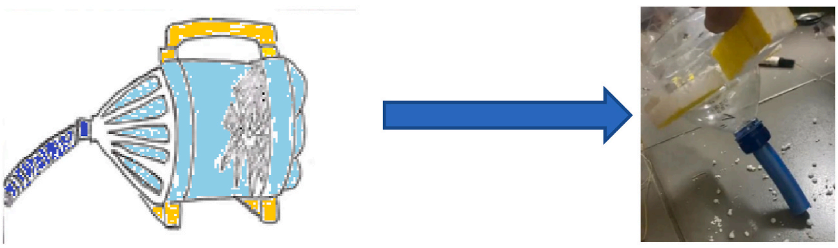
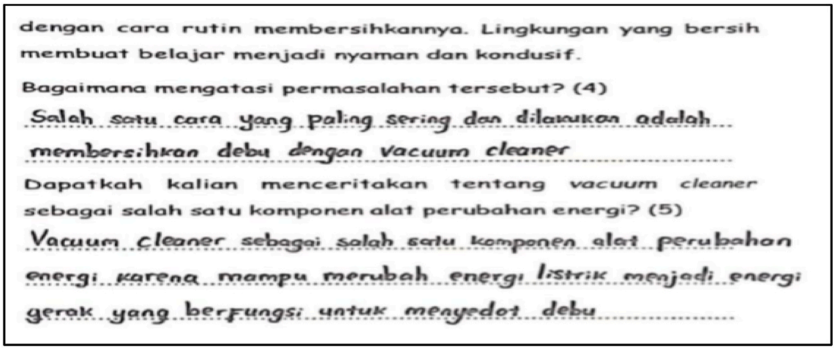


Fig. 4. Vacuum cleaner prototype design.


dengan cara rutin membersihkannya. Lingkungan yang bersih membuat belajar menjadi nyaman dan kondusif.

Bagaimana mengatasi permasalahan tersebut? (4)

Salah satu cara yang paling sering dan dilakukan adalah membersihkan debu dengan vacuum cleaner

Dapatkah kalian menceritakan tentang vacuum cleaner sebagai salah satu komponen alat perubahan energi? (5)

Vacuum cleaner sebagai salah satu komponen alat perubahan energi karena mampu merubah energi listrik menjadi energi gerak yang berfungsi untuk menyedot debu

Fig. 5. Student's Ideas about the problem.

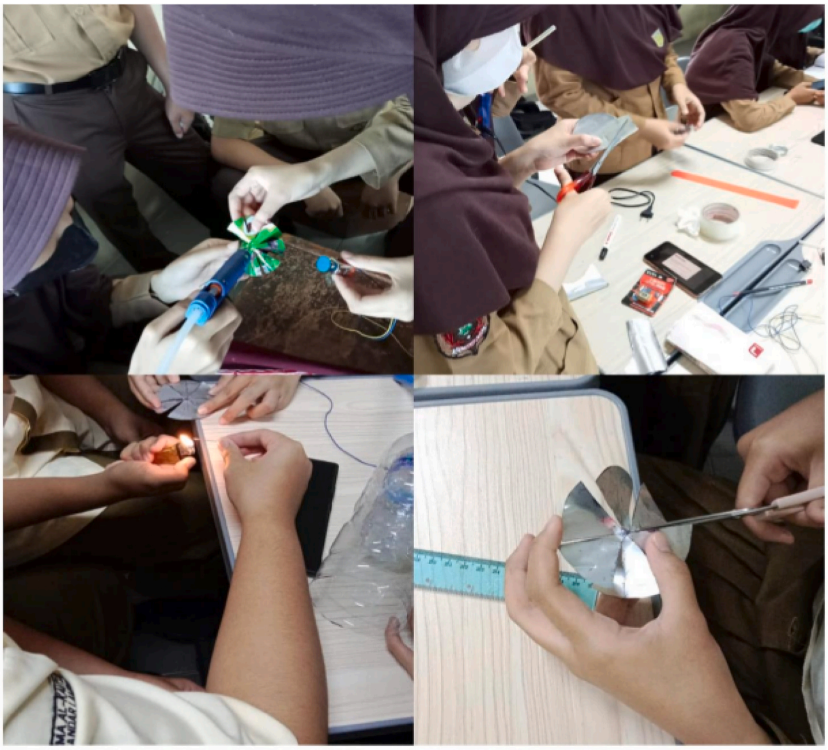


Fig. 6. Students' engineering design process activities.

future studies need to be designed to examine in more depth a number of phenomena and innovations presenting renewable energy by considering the breadth and depth of the lesson content and aspects of teachers' pedagogical skills.

6. Pedagogical implication

The STEM learning approach has the potential to engage students in solving real-world problems by guiding students' mindsets like engineers and scientists think. The results in this study showed that integrating STEM-EDP learning with simple technology can develop students' systems thinking skills. STEM-EDP learning is very relevant to be implemented in line with the current developments in science and technology in this recent times. However, to avoid the burden or stress of excessive use of technology on students and schools, the use of simple equipment packed with simple technology can be an alternative in its implementation. The most important thing is how students can gain learning experience to form essential concepts from their minds and thoughts.

In relation to the context of sustainable education, ESD-oriented STEM-EDP is very relevant for a learning today, because it can lead students to become problem solvers, inventors, innovators, build independence, think logically, be technologically literate, and be able to connect STEM education with the context of problems in the environment. The implementation of ESD-oriented STEM-EDP can optimally direct students to problem-solving-based learning that deliberately places scientific investigations and the application of mathematics in the context of designing technology as a form of solving real problems found in everyday life. Through ESD-oriented learning, students will be equipped with a sensitivity to environmental problems in their daily lives, so that design and scientific investigations are routinely applied simultaneously as technical solutions to real-world problems.

STEM-EDP provides a flexible process that leads students to identify problems to create and develop solutions through solutive design. Our research highlights the potential of STEM-EDP for the development of continuing education, which is still under-utilized in learning design in Indonesia and provides some suggestions on how to use STEM-EDP effectively to improve students' systems thinking abilities in implementing it. Compared to the number of studies on ESD, STEM EDP does seem to be a useful tool for developing learners' competencies. Responding to the implications of this research, creativity and innovation by teachers are also very important in optimizing STEM-EDP implementation, especially those oriented towards sustainable education topics. Learning using the STEM EDP approach needs to be carried out in an integrated manner so that it can provide training for students to be able to integrate each aspect at once. The learning process that involves the four aspects of STEM will form knowledge about the subject being studied to be better understood, as is the theory of constructivism learning which emphasizes lots of experience to construct knowledge. As in learning physics or science, STEM-EDP can help students to use technology and construct an experiment that can prove a law or scientific concept. The learning process can develop higher students' thinking skills if it is carried out continuously.

7. Conclusion

The STEM-PBL-based learning approach with the Engineering Design Process (EDP) offers an effective environment where students can better explore the knowledge and context of renewable energy. Through EDP activities they tend to be more confident in designing the prototype of a project. In addition, the fulfillment of students' collaborative and communicative performance in designing and making projects is a prerequisite for the successful application of EDP in physics learning with the STEM-PBL approach. On the other hand, there are some limitations in this study where the STEM approach with EDP only focused on one project, namely designing, and manufacturing a vacuum cleaner from unused items; the findings may not represent the effectiveness of the EDP activity-assisted STEM-PBL approach. For future research, it would be useful to investigate the impact of the EDP-assisted STEM-PBL approach with several more diverse projects on other ESD-oriented topics, for example, climate change materials. It would also be interesting to investigate students' sustainability behavior.

This study provides empirical support that brief interventions can produce positive changes in how young people interact with STEM activities. Young people can contribute their thoughts and engineering processes especially on renewable energy supply issues, so they have the potential to be involved in revitalizing the education curriculum that triggers youth confidence and creativity that enables them to be interested in a career in STEM. Furthermore, in the critical pedagogy, STEM-PBL integrated EDP can be used to systematically foster students' STEM literacy and thinking skills through the engineering design thinking process, thus expanding students' cognitive building and perspectives in reducing the routine in conventional pedagogy. Finally, further investigation of the role of EDP in science-physics learning based on STEM Education can provide a holistic picture of the pedagogic development in aspects of teacher professional development program.

Author contribution statement

Abdurrahman: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper. Novinta Nurulsari; Hervin Maulina; Ismu Sukamto: Performed the experiments; Analyzed and interpreted the data; Wrote the paper. Ahmad Naufal Umam: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data. Karlina Maya Mulyana: Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data associated with this study has been deposited at http://repository.lppm.unila.ac.id/

Declaration of interest's statement

The authors declare no competing interests.

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