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Exploring Students' Engineering Design Thinking in The Renewable Energy Topic: A Case of Problem Identification and Developing Ideas and Plans

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Abstract

Science learning provides an opportunity to prepare students with 21st-century Engineering Design Thinking skills (EDT). EDT is a means of looking at and addressing daily real-world problems that greatly need solutions. This study aims to explore students' EDT skills on alternative energy issues, specifically problem identification and developing ideas and plans. This research is a qualitative exploratory study in a senior high school in the Jember district. The learning design in this study uses the Science Learning through Engineering Design (SLED) models. Research data was gathered through observation and students' worksheet documents. Content analysis is used as an approach to analyzing data. The results indicated that EDT trains students' thinking processes to become more critical through problem identification and creativity in developing new ideas and imagination. EDT provides opportunities for students to combine their creativity and critical thinking to produce innovative design solutions. It improves students' epistemic comprehension while studying and helps them acquire relevant knowledge. This research is expected to be supplementary information for teachers to integrate EDT into their learning so that students can achieve meaningfulness and epistemic understanding.

Keywords: EDT, problem identification, renewable energy

INTRODUCTION

In the 21st era, students must have the skills, knowledge, and ability to solve complex and open problems. Complex problems are not enough to rely on one solution but are more open to various solutions. Engineering Design Thinking (EDT) is an essential element based on exposed issues related to engineering problems (Taleyarhan, Dasgupta, Garcia, & Magana, 2018).

Chizek, VanMeeteren, McDermott, & Uhlenberg (2018) define EDT as a complex and open cognitive process that involves multiple interrelated levels of abstraction, decomposition, and interaction in a system. Also, Chang and Yen (2023) described design thinking as at the center of engineering competency that involves generating various answers initiated with problem identification, suggesting multiple probable solutions, prototyping and testing to determine the best solution, and improving or revising it repeatedly. EDT is used to discover, explore, and deeply solve math and science problems. It helps students develop critical thinking skills that are applied in all aspects of life (Kennedy & Odell, 2014). EDT directs students to find, explore, and solve problems through creative and unique solutions (Lin, Wu, Hsu, & Williams, 2021). Also, it allows students to construct their own experiences and provides opportunities to understand science mathematically by analyzing scientific inquiry designs (Long, Yen, & Van Hanh, 2020).

The concept of energy and the sustainability of energy resources has become one of the most critical global issues. Since the industrial revolution, the unconscious and continuous use of fossil energy resources such as coal, oil, and natural gas has decreased energy resource reserves and raised environmental pollution problems (Onbaşılı, 2020). In addition, the rapid population growth in the world, technological developments, and increasing usage and energy needs have become international problems (Subahi, 2020). Therefore, alternative energy is needed to counter the dwindling fossil energy. Renewable energy sources are presented as an alternative to replacing fossil fuel energy, which is diminishing and is predicted to decrease environmental pollution and reduce the number of greenhouse gases, which are also increasing due to the use of fossil fuels (Hiğde, 2022). Renewable energy is frequently present in the natural environment and can be used continually (Çelik, 2021). Individuals aware of renewable energy sources will be sensitive to the correct and effective use of energy (Yenice & Alpak Tunç, 2018). In short, by raising awareness of this issue, it will be feasible to increase people's orientation toward renewable energy.

Learning at school provides an opportunity to equip students with problem-solving skills related to energy and environmental issues, especially renewable energy. In schools, renewable energy materials are taught only limited to basic knowledge without emphasizing the higher-order thinking skills of EDT. In the classroom, EDT is rarely implemented and seems challenging to teach and learn because the nature of engineering problems results in a multi-level of cognition and solutions (Taleyarkhan, Dasgupta, Garcia, & Magana., 2018). EDT is one of the efforts to improve competitiveness and strengthen students' thinking skills and responsiveness to renewable energy issues. The main factor in establishing preferences by recognizing the energy issues is improving students' understanding of renewable energy. That is why this study aims to explore students' engineering design thinking on renewable energy material, explicitly on the skills of problem identification and developing ideas and planning.

METHOD

This research is exploratory qualitative research. The research subjects were selected using a purposive sampling method. The participants are 30 students in tenth grade, aged 15-16 years. The reason for choosing these participants is because they had a solid understanding of the concept of energy.

Furthermore, participants in this study were divided into eight small groups of 3-4 students. Each group is given a symbol (Gr) followed by a group number; for example, Group 1 is given the code Gr_1. Also, the learning design in this study uses the Science Learning through Engineering Design (SLED) model adopted from Capobianco et al. (2013). SLED is a learning model focusing on students' engineering design skills with five successive stages: problem identification, developing ideas and plans, creating and testing, communicating results and gathering feedback, and revising and retesting (Sung & Kelley, 2023). The SLED model was chosen because the stages are simple and easy to implement in schools that are unfamiliar with EDT.

In stage 1, students are given a case and asked to identify the problem through several questions: what is the problem? What is the setting? What is the constraint? Furthermore, in the second step, students are asked to reveal ideas and develop plans to solve the problems. In stage 3, students are tasked with designing, creating a prototype or model of a solution to the problem, and testing their design. In the sharing results and gathering feedback phase, students are asked to communicate and present the results of the solution in classroom discussions to receive feedback from other groups. Finally, in the fifth phase, students are asked to improve the design and retest the revised prototype for the best solution to address the problem. Figure 1 below illustrates the scheme of the SLED model.

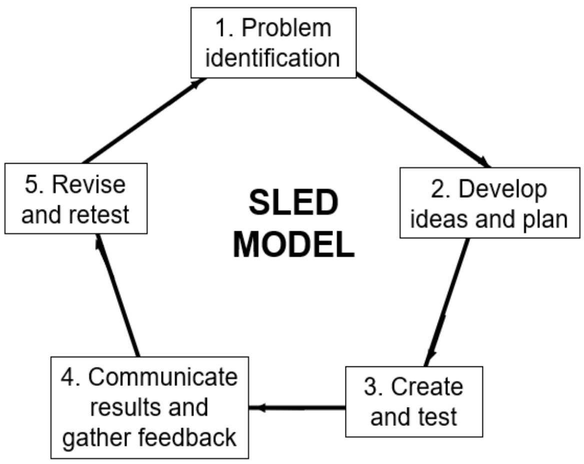

Figure 1. The SLED models

Research data was gathered through observation and student worksheet documents. Observation is the most significant data collection method in qualitative research (Silverman, 2015). Observations were made during the research process, where researchers were assisted by eight observers who recorded all student activities. The observers were members of the researchers and were assisted by several physics teachers. Before conducting the observation, the researchers coordinated with the observers regarding the partitioning of tasks, observation positions, and aspects to be observed. Coordination aims to ensure that observers have a similar understanding and uniformity when observed. One observer approached one group with a position close to the group being observed. Observers use a checklist to document all student activities relevant to the SLED stages, including problem identification, formulating ideas and plans, creating and testing, sharing results and gathering feedback, and modifying and retesting. Every indicator in SLED was discussed in Focus Group Discussions with lecturers and practitioners and declared valid.

Meanwhile, worksheets are written documents that contain students' activities and thoughts in practical form (Utariadi, Gunamantha, Suastika, 2021). Documents are an excellent and essential source for more precise text data that is ready for analysis (Balmer & Richards, 2022). This study analyzes the research data using a content analysis approach. Content analysis is a systematic and objective method that emphasizes written text, verbal, and visual communication analysis in the research context of use to make reliability (Krippendorff, 2019). The content analysis method allows for filtering words and data into aspects of engineering design thinking. First, all group students' worksheets and observation data are composed into a folder. We read the data repeatedly to look for essential findings related to problem identification, student ideas, and development plans. Significant information obtained is then collected to look for patterns so that it becomes a finding. The findings obtained are then validated by methodological triangulation and authorized with other research related to engineering design thinking.

RESULT AND DISCUSSION

Science learning is a learning activity about nature that is carried out through a series of scientific methods expected to increase students' knowledge and higher-order thinking skills. The topic of energy and the sustainability of energy supplies has become one of the most critical concerns that are widely discussed. In the most recent curriculum, the Indonesian government has begun integrating energy-related topics into primary and secondary schools. This topic covers improving students' engineering design thinking.

Engineering design thinking is a systematic and intelligent process for solving complex problems involving many variables in knowledge and skills. The primary goal of engineering design is to prepare learners to think like experienced designers (Mentzer, Becker, & Sutton, 2015). SLED was developed in science learning to improve students' design thinking skills (Sung & Kelley, 2023). Integration of science and engineering design of SLED improves student participation in class, learning outcomes, and thinking skills (Dankenbring & Capobianco, 2016). The skills of identifying, presenting evidence, expressing ideas, designing solutions, and designing prototypes provide great opportunities to make science learning more meaningful for students (Purzer et al., 2015).

EDT must be implemented using real-world problems. Real problems employ realistic data, which provides detailed information about the specified situation and can be solved in various methods. In this study, EDT focused on problem identification and developing ideas and plans for renewable energy, particularly wind energy topics. The results of this research on learners' thinking processes may impact future teaching strategies. The results and discussions are as follows.

Problem identification

Problem identification is recognizing situations, looking for problem gaps, and formulating problems. It is a multi-step process that identifies and resolves challenging problems. Also, it allows students to identify the root cause of an issue, create a detailed problem description, and apply an ideal solution. Problem identification aims to define the issue and make a quantifiable explanation and solution.

The worksheet and observation results show that all group students identify problems carefully. Students in groups discuss the issues in the text and look for essential and correct information and data about energy problems. Three discussion points for students are discussed: what problems occur, the users/clients, and the constraints. Students read and inspect the problem's line-by-line text, highlighting significant words and sentences to capture the roots of the problem. Additionally, students create a more thorough problem description once they identify the source of the energy issue.

The following are examples of problem identification carried out by students in their worksheets.

> "Conventional energy reserves in Indonesia which are based on fossil fuel are predicted to decrease in the next few decades significantly" (Gr_1)
>
> The rapid Indonesian growth and a population of more than 270 million and energy reserves that are almost depleted are massive problems for the Indonesia government" (Gr_3)
>
> "Fossil-based energy reserves in Indonesia are expected to run out in the following few years, so alternative energy is needed" (Gr_6)
>
> "A large population caused greater energy consumption, while fossil fuel energy capital in Indonesia is not enough to cover the next few decades" (Gr_7)

Identification is the first step to solving problems and making decisions related to appropriate and practical solutions. The research results show that identifying issues in this study trains students to develop critical thinking skills carefully to find and respond to the root of problems. Students exhibited high engagement, persistence, and motivation in discussing the problem. They are taught to seek critical information concerning energy problems and alternative energy proactively. Identifying problems makes them sensitive and able to select and sort information related to energy issues correctly and accurately. Stannard (2021) states that problem identification linkage allows students to understand the relationship between problems and solutions. Exploring issues from a particular perspective can stimulate empathetic processes, creative ideas, and innovation (Kim, Yi, & Ko, 2023). Meyer (2018) also states that identifying problems is an integral part of the design process of experienced professionals, where the information significantly obtained influences the solution and client satisfaction. It enables students to look deeply into the challenges at hand, encouraging them to develop a solution that directly addresses the problem at its core (Vale, Barbosa, Peixoto, & Fernandes, 2023). In simple terms, it can be understood that problem identification skills in engineering design assist students in thinking more deeply and critically, focusing, and being sensitive to fundamental problems and the roots of the issues.

Develop ideas and plans.

Developing ideas and planning are the most significant aspects of EDT. Creating ideas and plans requires conceptualizing solutions to identified challenges. Developing ideas and planning in this study focused on students' ability to convey ideas and design alternative energy solutions for windmills. The observation shows that most students (75%) express ideas to their group about the shape of the propeller, size, and number of propellers. They believed an effective propeller could spin when exposed to the wind and generate a large amount of electrical voltage. The propeller's rotational speed generates a significant amount of electrical energy. In groups, students convey ideas, exchange opinions, criticize, and assess the feasibility of energy alternatives. They brainstorm and measure the advantages and disadvantages of each idea so they can find the best solution.

Furthermore, the students' worksheet analysis also showed that the whole group wrote that a good and robust windmill is a wheel with three blades. One group of students argues that a 3-pointed blade is more efficient in generating electricity because the wheel can rotate fast when exposed to wind. The following are examples of students' statements in worksheets.

> "Using a windmill with a propeller or 3-bladed design will be more efficient in generating electricity all the time" (Gr_5)

> "Making the blades thin and light would make it easier to push the propeller. The wind will easily accelerate three propeller blades" (Gr_8)

> "The lightweight propeller will easily rotate so that electrical energy will be easily generated" (Gr_2)

> "A good wind turbine is a turbine that uses a 3-pointed propeller design" (Gr_4)

Based on the results, students have good brainstorming skills. Brainstorming is the most significant method for fostering creativity and problem-solving. Brainstorming is using thought to solve problems and find the best solutions. The solutions can be identified by connecting and expanding the scopes of knowledge by discussing from every perspective. This is all to discover the options for making decisions and produce the best ideas that can be used in planning as much effectiveness as feasible. Aldalalah (2022) posits that developing ideas or brainstorming is proven to direct students to higher thinking skills, such as exploring solutions more broadly and deeply. When students discuss and share ideas and thoughts, it will increase students' cognitive abilities significantly so that many new ideas emerge. Taleyarkhan et al. (2018) posit that evolving thoughts in EDT increase the number of ideas generated about design assignments for beginners. Also, it provides opportunities for all students to develop new and more creative ideas (Chang, Chien, Yu, Chu, & Chen, 2016). The skill of developing ideas is related to not only cognitive but also mental students. This is because criticism, objection, or rejection of the ideas raised will help and train students to be more prepared to accept all the consequences when their ideas are conveyed. Chien, Liu, Chan, and Chang (2023) state that engineering design is a form of mental iteration through a series of cognitive activities such as analyzing, communicating, designing, interpreting, predicting, and questioning.

There are four variations of the resulting propeller with a striking difference in the shape of the blades and rotating axis. The four propeller designs in Figure 2 are similar to those with 3-blade points. Even though all the students' ideas about the 3-blade point were the same, the propeller design drawings results by students varied widely. Design (a) has pointed blades with one center; designs (b) and (c) are similar designs with three sides centered on a circular axis but a difference in the direction of rotation, clockwise for design (b) and counterclockwise for design (c); design (d) centered on a circular axis with pointed blades.

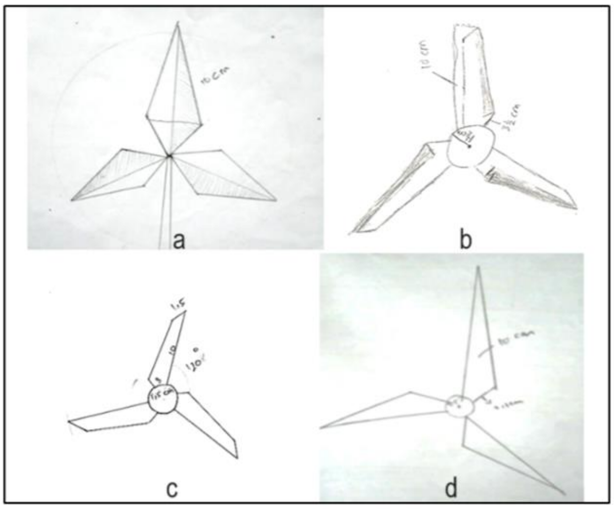

Figure 2. An example of a propeller design scratched by students

The resulting design differences show that students' imaginations are different. Students can construct representations of their ideas, such as drawings, or develop a prototype focused on a solution for windmills. Variations in the development of alternative solutions could be linked to differences in problem identification. Students' ability to develop alternative solutions is crucial in the engineering design process and a path to innovation (Zhan, Sun, Song, Yang, & Zhan, 2023). In this study, imagination embodies the idea of producing a modeling product for the best solution.

The study shows that designing activities trains students' creative thinking. The reason is that designing involves a process of imagination and synchronization between ideas and realization. Imagination is the foundation of creativity, and constructive thinking can broaden knowledge and assist pupils in effectively addressing complex issues (Hsu, Chiang, & Liang, 2014). In other words, designing activities trains students with skills, knowledge, imagination, creativity, and imaginative thinking. Tipmontiane and Williams (2022) state that design activities train students' engineering design skills and positively impact student creativity. In short, students indicated considerable progress in their assessed engineering design thinking.

Designing and making prototypes is a form of externalizing ideas and students' thinking processes (Waters, Yang, Finet, Verhees, & Bosmans, 2022). In this study, engineering design combines creativity and critical thinking to produce innovative design solutions by implementing new ideas in actual practice, such as modeling or making prototypes. Modeling is fundamental in design thinking and serves as a critical distinguisher between engineering ways of thinking and knowing and other problem-solving approaches (Mentzer et al., 2015). It helps learners gain meaningful knowledge and increases their epistemic understanding when studying.

For creating and testing, students create prototypes of varying sizes and shapes. They work together in groups to complete tasks in the manufacturing process. They develop details of the windmill by adapting surrounding objects such as fans. They test the prototypes that have been made to prove whether the plans that have been created are in accordance with expectations. The suitability of the design and product can be measured by considering how much voltage is produced. The process of developing prototypes and testing makes students explore certain concepts in more depth and build their own experiences of science mathematically (Kelley & Knowles, 2016)

Furthermore, the results of the created propeller are presented and discussed with the class. All students actively participate in conveying the results of their group work. Students present the prototype product systematically and smoothly, from the manufacturing design of the material used to the resulting propeller product. Students are mentioned to have understood the concept if they have explained the material systematically and in their own words (Ningkaula, Laliyo, Iyabu, & Abdullah, 2021). During this process, students get feedback from other groups about the blade project or product that has been made. The resulting feedback is then used as a basis for making improvements to the product to be better.

In addition, implementing the SLED model can train students in engineering design thinking. Engineering design incorporates numerous approaches and perspectives, such as analytical and critical thinking, in-depth and comprehensive understanding, planning and creativity, and procedural and conceptual knowledge to develop solutions. Students practiced these skills and gained the trust required to complete their projects. They are taught to identify problems, generate ideas, and design windmills as a source of renewable energy. This is under Cross (2021), who considers engineering thinking skills to play a crucial role in determining solutions.

This study has limitations; it cannot be generalized due to the partial research sample, and the review only focuses on two aspects of engineering design thinking: problem identification and developing ideas and planning. The finding of this research is expected to be the fundamental information for teachers to integrate engineering design into their learning for meaningfulness and epistemic understanding in learning.

CONCLUSION

Learning at school provides an opportunity to equip students with the skills to identify problems and develop ideas about energy issues through engineering design. Engineering design thinking can train students' thinking processes to become more focused and critical through problem-identification activities. Identifying problems helps students to be more careful and accurate in sorting essential and unimportant data and information. Engineering design allows students to develop new, more creative ideas through their imaginations. Students are skilled in developing many ideas and expressing their creativity in design drawings to gain more accurate solutions. It advances students' epistemic understanding while studying and aids in acquiring relevant knowledge.

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