Research Article

What Can Elementary Students Learn From Self-watering System Project? Evaluating Students' Achievement in Engineering Design Behaviour

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Abstract.
Developing problem-solving and design skills in elementary school students is critical in fostering innovation and scientific literacy. This study employed a pre-experimental method to assess 57 elementary students in Cimahi, Indonesia, as they engaged in the engineering design process by creating an automatic watering system. The research analyzed key stages, including understanding challenges, generating ideas, experimenting, and troubleshooting. The results showed students as "developing designers," excelling in hands-on experimentation but struggling with creative problem-solving.This highlights their proficiency in hands-on experimentation and the need for enhanced support in creative problem-solving. The findings demonstrate the potential of integrating engineering design into elementary education to improve cognitive, affective, and psychomotor skills. Through project-based learning, students gained a deeper understanding of scientific concepts such as fluid mechanics and plant biology while developing critical thinking and innovation skills. This study emphasizes engineering design as an effective approach to connect theoretical knowledge with real-world applications, preparing young learners for future challenges.

Keywords: elementary, engineering design behaviour, design process

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1. INTRODUCTION

In today's fast-changing world, equipping students with engineering design behaviors is crucial for fostering innovation and solving complex problems (1)Through this process, they learn to think systematically, generate creative ideas, and refine solutions iteratively (2), enhancing critical thinking, collaboration, and resilience. Countries like Finland and the U.S. have successfully integrated engineering design into elementary education, improving problem-solving skills. Indonesia can adopt these practices to strengthen science education, using project-based learning and hands-on experiments to boost comprehension and early innovation (3).

One practical application of engineering design in education is through hands-on projects that align with real-world challenges (4). The integration of design into education, as demonstrated through the automatic watering system project, supports the development of students' ideas, concepts, and methods in the learning process. Along with technological developments, designs are now widely adopted into education because they can support students in developing students' ideas, concepts, and methods in the learning process (5,6). The learning process in schools is expected to be able to develop 21st-century skills. The learning process is usually carried out through a project or problem base. This approach aligns with 21st-century learning goals, enabling students to plan, implement, and evaluate solutions to real-world problems.

Problems that arise in the student environment cannot always be resolved only by discussion. Sometimes, students have to do something to find the best solution or make something so that the problem is solved (7,8). Based on this, it is necessary to design something in school so that children get used to developing various ideas to solve a problem (9). Do not let school activities only be based on proving a concept and facts without knowing the application in their closest life.

This experience is very supportive in increasing student understanding in the future because the valuable expertise allows students to continue to feel motivated and raise curiosity about a concept or lesson (10). At the first level, such as elementary school, the engineering design process needs to be included in the learning process as an addition to the initial experience for students (11). In facing the future, students need to be equipped with various skills and knowledge. Therefore, we need a learning method that can support the growth of student learning outcomes in cognitive, affective, and psychomotor aspects. The Committee on K–12 Engineering Education (12) recommended that learning engineering design become a key feature of K–12 engineering education after finding that significant learning in preschool through high school classrooms was associated with the use of extended design activities that were presented in meaningful contexts.

Studies on the implementation of the engineering design process method in learning aimed at improving the engineering design behavior have not been widely carried out in Indonesia. Some research on the engineering design process is more focused on the study of the STEM approach as a whole and is still a combination of method studies. These studies include Howard, et al (13) that describes the creative design Howard process by the integration of engineering design and cognitive psychology literature.

Similarly, another study explores the impact of STEM learning through engineering design on middle-secondary students' interest in STEM disciplines(14,15).

Several studies that focus on the study of engineering process behavior have also been conducted. However, none of these studies have been conducted on elementary school students. Study of Purzer, et al (16) on An exploratory study of informed engineering design behavior associated with scientific explanations was conducted on students engaged in a project on designing energy-efficient buildings. Moreover, Song, et al(11) also conducted a study on the professional engineer, engineering seniors, and engineering freshmen about a comparison of their design behavior on problem decomposition and recomposition in engineering design.

This research investigates the impact of the engineering design process on enhancing elementary students' problem-solving, critical thinking, and creativity. Through structured design activities, students develop cognitive and collaborative skills essential for real-world challenges. The engineering design process is a structured, iterative approach used to solve problems by continuously refining solutions (18,19). Khandani (20) identifies five essential steps in this process, commonly applied to design problem-solving.

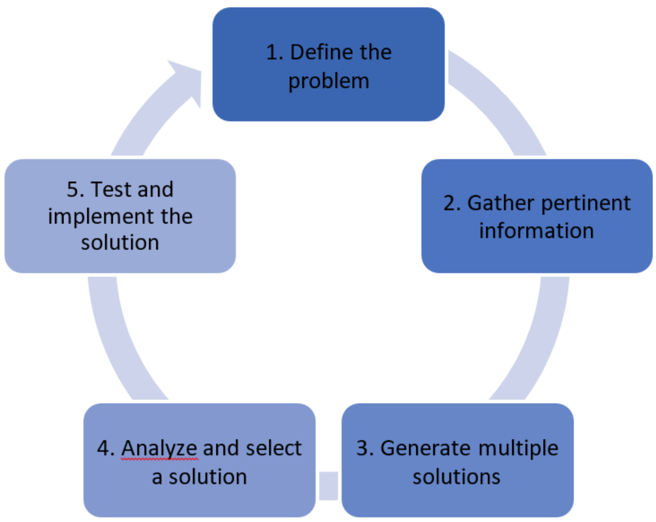

Figure 1: Engineering Design Process Steps.

The first step is the process of analyzing existing problems from the challenges given. At this initial stage, the process of scoping the problem becomes very important because it directly deals with opening up problem spaces and solution spaces so that they can be developed in solving problems (21–23). The next step is to search for information related to problems that have been previously explained. In the next step apart from seeking information on the issue, students will also find information about possible ideas that can be applied to solve the problem. After collecting various kinds of data, the next step is to sort and analyze solutions from multiple solutions to choose the best one. The last step is to test and implement it.

2. METHODOLOGY

This study employed a pre-experimental method, a quantitative approach commonly used to measure changes or outcomes before and after an intervention without a control group (24). The objective was to assess the design skills and behaviors of elementary school students as they engaged in the engineering design process through structured activities. The research focused on the development of an automatic watering system and evaluated how students applied the engineering design process in solving scientific problems.

The research process involved four stages: (1) **Planning**, where engineering design rubrics were developed and validated to assess student performance; (2) **Implementation**, during which students followed the engineering design process to create an automatic watering system through problem identification, ideation, prototyping, and testing; (3) **Observation**, where behaviors and progress were documented; and (4) **Analysis**, using descriptive coding to evaluate both the design process stages and relevant scientific competencies. This method integrated scientific experimentation with engineering principles, as students tested variables like water flow rates and soil moisture levels during prototyping, demonstrating the convergence of engineering design and scientific inquiry.

The subjects were elementary school students from Cimahi, selected using non-random sampling based on the objectives and characteristics of the study. At the implementation stage, students were guided through the engineering design process with worksheets, while their design behavior was observed using the Informed Design Rubric by Crismond & Adams (1). This process, known as engineering design behavior, is assessed using nine indicators: Understand the Challenge, Build Knowledge, Generate Ideas, Represent Ideas, Weigh Options & Make Decisions, Conduct Experiments, Troubleshoot, Revise/Iterate, and Reflect on Process, distinguishing beginner designers from informed ones.

Researchers employed descriptive qualitative analysis, using data from observations and interviews to describe findings and address the research questions. This structured approach highlights the potential of combining engineering design methods with practical scientific experimentation to develop essential problem-solving skills in elementary students.

Researchers used descriptive qualitative methods in analyzing data. Data obtained through observation and interviews. The data in this study were analyzed using descriptive analysis by describing the data as a whole to be used as material in answering research questions

3. RESULTS AND DISCUSSIONS

The results of the study are following the aim of describing the ability to design the behavior of elementary school students. each student spells out an engineering design-based worksheet. the value of engineering design behavior is generated from the average score that each student gets. The following are the results of students' engineering design behavio

TABLE 1: The Score of Engineering Design Behavior.

No	Indicator	Score
1	Understand the Challenge	2,9
2	Build Knowledge	2,5
3	Generate Ideas	2,1
4	Represent Ideas	3,4
5	Weigh Options & Make Decisions,	3,0
6	Conduct Experiments	3,7
7	Troubleshoot	3,5
8	Revise / Iterate	2,7
9	Reflect on Process	2,5
Average		2,97

The results show that elementary school students achieved an average score of 2.97, which places them at the "developing designer" level of engineering design behavior. Students demonstrated strong abilities in conducting experiments (3.7) and troubleshooting (3.5), which align with their hands-on engagement during the project.

However, they faced challenges in generating ideas (2.1) and reflecting on the process (2.5), indicating the need for further development.

Students' ability to **Understand the Challenge** averaged **2.9**, reflecting their moderate capacity to identify and scope problems presented during the design process. While many students were able to articulate key challenges, interview responses revealed that some relied heavily on teacher guidance and struggled to independently explore the problem space. This highlights the need for activities that promote independent critical thinking in the early stages of the design process.

For **Build Knowledge**, the average score of **2.5** suggests a reliance on prior knowledge rather than conducting in-depth research. Observation data showed that most students referred to their existing understanding rather than actively seeking additional information or resources. For instance, one student mentioned, *"I already know how plants absorb water, so I didn't feel the need to look it up further."* This underscores the importance of integrating structured research tasks to encourage students to expand their knowledge base (25).

The lowest-scoring indicator, **Generate Ideas (2.1)**, reveals a significant challenge in creative ideation. Observational data showed that students often struggled to propose innovative solutions, with some repeating similar ideas or copying their peers. For example, one group designed a system nearly identical to another, with minimal modifications. Students expressed difficulty in thinking beyond immediate, familiar concepts, underscoring the need for activities like brainstorming sessions or exposure to diverse problem-solving examples to stimulate creative thinking.

Conversely, students excelled in **Represent Ideas**, achieving an average score of **3.4**. They effectively communicated their concepts through detailed sketches and verbal explanations, as noted during their presentations. One student explained their design with clarity, saying, *"This pipe here controls how much water flows to the plants, and it's connected to the tank."* This strength suggests that while students may face challenges in generating ideas (26), they are capable of articulating and visualizing their solutions effectively.

In **Weigh Options & Make Decisions**, students averaged **3.0**, showing moderate ability to evaluate alternative solutions. However, their decision-making processes often prioritized immediate practicality, such as material availability, over long-term considerations. For example, when asked why they chose a specific material for their prototype, one student responded, *"Because it was easier to get and cheaper."* This indicates a need for guidance in considering broader factors, such as durability or efficiency, in their evaluations.

The highest score, **Conduct Experiments (3.7)**, reflects students' enthusiasm and competence in hands-on experimentation. Observations showed students eagerly testing variables like water flow and soil absorption, with one group testing multiple configurations to optimize their system's performance. This indicator highlights the effectiveness of hands-on activities in fostering scientific inquiry and engagement.

Students also performed well in **Troubleshoot**, with an average score of **3.5**, as they identified and resolved issues during prototyping. For example, when a group noticed uneven water distribution, they adjusted the pipe layout and retested until achieving a functional solution. This iterative approach demonstrates their ability to engage in problem-solving and refine their designs effectively.

The **Revise/Iterate** indicator, with a score of **2.7**, showed that while students engaged in revisions, their approach often lacked structure. Observations revealed that some revisions were conducted without clear evaluation of their effectiveness, with one student noting, *"We just fixed what didn't work, but we didn't think much about how to make it better."* This suggests a need for more structured feedback and iterative guidelines to enhance their revision strategies.

Lastly, the **Reflect on Process** indicator averaged **2.5**, indicating that students allocated minimal effort to evaluating their learning experiences. When asked to reflect on what they learned, many students focused on describing the tasks they completed rather than discussing what they gained from the process. For example, one student remarked, *"We made the system work, but I'm not sure what else we could have done differently."* Introducing reflective activities, such as journaling or guided group discussions, could encourage deeper engagement with the learning process.

In conclusion, the results highlight the strengths of the engineering design process in fostering hands-on experimentation and troubleshooting while identifying critical areas for growth, particularly in ideation, reflection, and iterative design. Addressing these gaps through targeted instructional strategies could further enhance students' overall engineering design behavior and better prepare them for complex problem-solving challenges in the future.

4. CONCLUSION

This study concludes that primary school students demonstrate engineering design behavior at the developing designer level. Their strong ability to conduct experiments highlights the potential of integrating engineering design processes into elementary education. The structured steps in the engineering design process provide a practical approach to problem-solving, mirroring the scientific method and enhancing students' understanding of key concepts like fluid dynamics and plant biology. By incorporating engineering design into science education, students are encouraged to think critically, solve problems creatively, and connect theoretical knowledge to real-world applications. This approach not only supports the development of 21st-century skills but also fosters a deeper engagement with science learning, making it more accessible and meaningful for young learners.

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