Engineering design behavior elementary student’s through the STEM approach

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Abstract. This study aims to obtain an overview of the engineering design behavior students at the elementary school level. This research was carried out using the Pre-Experiment method with Pretest-posttest One-Group design. The lesson is implemented using learning based on Science, Technology, Engineering and Mathematics (STEM) where the learning method refers to the Engineering Design Process. The stages consist of problem scoping, idea generation, design and construct, design evaluation and re-design. Data analysis uses quantitative descriptive analysis. Observations of the engineering design behavior students revealed that in the first phase, students who learned through STEM were categorized as beginner designers and in the second phase as emerging designers. The conclusion of this study is that STEM-based learning can improve the engineering design behavior of elementary students.

1. Introduction
The development of technology has changed various things related to human life. How people help each other or how to solve problems now certainly requires the role of technology. Therefore, technology becomes something that needs to be learned in educational programs and primary schools as the first formal place to get education need to facilitate this in order to provide understanding for students when graduating later[1].

In this era, education is expected to produce students who are ready to face the 21st century. In the implementation, students must have skills such as life skills (dexterity, flexibility, and adaptability), work skills (collaboration, leadership initiatives and responsibilities) Skills to apply (access and analyze information, effective communication and determine alternative problems) resolution), personal skills (curiosity, imagination, critical thinking, and problem-solving), interpersonal skills (teamwork and teamwork) and non-cognitive skills (feelings) [2]. Although previous skills have existed for decades, there are now more incentives to educate students to have these skills at all stages of education because success in this modern era demands skills [3]–[5].

The necessary skills are not the exclusive property of the students. The interests, talents, and opportunities to develop these skills also determine the existence of these skills in students. Schools should give students the opportunity to learn the latest technological developments, this has implications for the renewal of student knowledge.

The problems in everyday life that arise cannot always be solved simply by discussion. Sometimes, students have to do something to overcome the solution of the problem or even do something that can help solve the problem. For that, skills are needed to design something that can be used as a solution to
a problem. This is related to the student's behavior when designing tools or so-called technical design behavior[6][7].

The National Academy of Engineering and the National Research Council [8] explain that Engineering is a process of designing man-made. Engineering design behavior (EDB) can be interpreted as student behavior in doing design when designing something or a tool. This designing behavior makes students more aware of their role and presence in society and is able to apply science to find solutions to problems in real life.

In solving problems in real life, in addition to engineering design behavior of students, also requires another ability, namely the cognitive abilities of students. This is because in the engineering process when developing design ideas, they must apply the scientific knowledge they learned earlier. Engineering design behavior and cognitive are two important capabilities and there should be on the students. When students encounter a problem, students not only need engineering design behavior in the process of overcoming it but also need other knowledge where it can help develop solutions to be made.

The US National Science Foundation (NFS) in the 1990s launched STEM as the theme of the educational reform movement in all four disciplines to foster the labor force of the STEM fields, as well as develop STEM-literate citizens, and enhance the global competitiveness of the United States in Innovation of science and technology [9].

This STEM trend has echoed to various countries including Indonesia. In Indonesia the theme of STEM learning appears in each of the activities of the PPPPTK IPA or Qitep of Science, this shows that STEM is developing in Indonesia because Indonesia as a country with a large number of human resources and natural resources cannot avoid its development. To become a better country, Indonesia also needs to improve the quality of education to be able to compete with other countries.

To optimize the talents and abilities of learners, a learning approach is needed to explore various aspects such as real-world challenges, high-order thinking skills, problem-solving skills, cross-disciplinary learning, self-learning, information-sharing skills, teamwork, ability to communicate[10]. The emergence of STEM in the educational world is expected to respond to these challenges as STEM is designed to improve the skills needed to deal with the 21st century [11].

The process of implementing an integrated STEM approach is in line with the learning percentage in the applicable curriculum in Indonesia. In the 2013 curriculum, it is stated that learning in elementary schools is applied in a thematic way. This allows STEM to be applied in elementary schools. STEM-based learning is expected to facilitate students in developing soft skills and hard skills because this learning will emphasize active learning in the learning process. STEM is an integration of interdisciplinary science, technology, engineering and mathematics into a single science. STEM education provides a shift in the plural of conventional learning paradigms to being integrated into a single knowledge [12]. This makes STEM education patterns considered more interesting to study because of awareness of the important role of Technology and Engineering in the 21st century in improving students' soft skills and hard skills [13].

STEM-based learning is a subject matter of science that integrates into the design of system designs, the use of technology and mathematics for solving real problems. With STEM-based learning, students are challenged to think creatively and innovatively in solving real problems by involving group (team) activities in collaboration.

2. Methods

2.1. Type of Research

This research is quantitative research. The research subject was one of the elementary students in Cimahi with the students who would be included in the sample in this study who were fourth-grade students. The sampling technique used is non-random sampling. This is because it is not possible to change the composition of class members that have been determined by the school, which means that
researchers prefer research topics based on the composition of available class members and are easier and more comfortable with the objectives and characteristics of the study.

2.2. Procedure
This research is pre-experiment research with One Group Pretest-Posttest Group design with two variables that is STEM-based learning (X) as the independent variable (Independent Variable) and Engineering Design Behavior (Y) as dependent variable (Dependent Variable). This study was designed in one group (pre-test and post-test).

2.3. Instrument
The non-test instrument of engineering design behavior is an observation sheet given to the experimental class at the end of the lesson. This observation is assessed by looking at the instrument of the Informed Design rubric.

Teachers use Informed Design Rubric to see students' ability to do practical work. This rubric gives different values when students practice. Striking differences between beginner designers and skilled/informed designers can be judged based on these rubrics

Table 1. Assessment Instrument Engineering Behavior Design

| Pattern-1 | Beginning Designer | Informed Designer |
|-----------|--------------------|-------------------|
| Understand the Challenge: Problem Solving vs Problem Framing | Do not grasp the basics of design task, or treat it as a well-defined, straightforward problem that they prematurely attempt to solve. | Understand basics of design problem, and then delay making design decisions in order to explore, comprehend and frame the problem better. |
| Build Knowledge: Skipping Vs. Doing Research | Skip doing research and instead pose or build solutions immediately. | Do investigations and research to learn about the problem, relevant cases and how the system works. |
| Generate Ideas: Idea Scarcity Vs. Idea Fluency | Work with few or just one idea, which they can get fixated or stuck on, and may not want to discard, add to, or revise. | Practice idea fluency in order to work with lots of ideas by doing divergent thinking, brainstorming, etc. |
| Represent Ideas: Surface Vs. Deep Drawing & Modeling | Propose superficial ideas that do not support deep inquiry of a system, and that would not work if built. | Use multiple representations to explore and investigate design ideas & support deeper inquiry into how system works. |
| Weigh Options & Make Decisions: Ignore Vs. Balance Benefits & Tradeoffs | Make design decisions without weighing all options, or attend only to pros of favored ideas, and cons of lesser approaches. | Use words and graphics to display and weigh both benefits and tradeoffs of all ideas before picking a design. |
| Conduct Experiments: Confounded Vs. Valid Tests & Experiment | Do few or no experiments on prototypes, or run confounded tests by changing multiple variables in a single test. | Conduct valid experiments to learn about materials, key design variables and the system work. |
| Troubleshoot: Unfocused Vs. Diagnostic Troubleshooting | Use an unfocused, non-analytical way of viewing prototypes during testing and troubleshooting ideas. | Focus attention on problematic areas and subsystems when troubleshooting devices and proposing ways to fix them. |
| Revise/Itearate: Haphazard or Linear Vs. Managed & Iterative Designing | Design in haphazard ways where little learning gets done, or do design steps once in linear order. | Do design in a managed way, where ideas are improved iteratively via feedback. Strategies get used as many times as needed, in any order. |
| Reflect on Process: Tacit Vs. Reflective Design Thinking | Do tacit designing with little self-monitoring while working or reflecting on process. | Practice reflective thinking by keeping tabs on design strategies and thinking. |
2.4. Data Analysis Technique
Students’ engineering design behavior was analyzed descriptively based on the data that were collected through observation during the engineering design process. Engineering design behavior of each group was observed twice (first phase and second phase) during engineering design process activity to see which category of engineering design behavior that students possess in each phase and whether each group made progress from the first phase until the second phase. The results of the assessment are used as the material in describing students.

3. Research and Discussion
The engineering design behavior of students was analyzed based on observations made during the learning process using the stages of engineering design consisting of problem scoping, idea generation, design and construction, design evaluation, redesign. There are nine indicators of engineering design behavior that serve as a benchmark of assessment during the experimental process. the assessment process is carried out in groups, where students are divided into six groups in one class.

3.1. Understand the Challenge
The first indicator is understanding the challenges. The indicator assesses students in defining the problem to be solved, knowing the needs needed in solving problems and setting targets for the level of success. it becomes a benchmark for students in making designs that are solutive in their opinion.

Most students are in the beginner category when carrying out the first phase of the experimental process. because the process is the first experience in making the design process, most students do not think about what problem is actually being faced. they are more interested in going directly to the next stage and find this first stage less attractive. This behavior states that when designing problems, especially younger children, it can be revealed that some team members quickly grab some material and try to solve problems with little talk and thought, or immediately draw up plans to solve problems. Improvement appears when the second phase, where students before starting their experiments have a discussion about things that must be considered, looking for possible problems that arise and not in a hurry in determining the problems faced.

3.2. Build Knowledge
The second indicator shows the strategy of building knowledge through research where learners gather pertinent information about product functions and features among other things.
The data shows in this indicator almost all groups are in the category of novice designers. most of them did not do prior research, looking for similar research results which may be due to existing limitations. in the second phase, all groups fall into the emerging designer category. they just come up with some ideas from students in conducting small research or just a discussion about matters relating to the problem to be solved.

3.3. Generate Ideas
The third indicator shows the strategy of generating ideas through research where learners may solve the problem and analyze solutions and then decide which solution is best suited for implementation.

For this indicator, in the first phase, the groups fall into various categories. most enter the category of emerging designers where students have at least 1 idea to solve a problem but do not have the initiative to improve or revise the idea of solving it. there is only 1 group that has several ideas before starting the engineering process, the group falls into the category of developing designer.

In the second stage, a development occurs where all groups are categorized in developing designers. all groups have more than one idea in solving problems. they have alternative ideas when the first idea doesn't go well.

3.4. Represent Ideas
The fourth indicator shows the strategy of representing ideas where learners communicating early design ideas.
Most groups in this phase are categorized as emerging designers. Most ideas generated by the group allow walking or can solve problems. There is only one group where if the idea is implemented it doesn't work. In the second phase there was not much change, only one group made a rather significant change.

3.5. *Weigh Options & Make Decisions*

The fifth indicator shows the strategy of weighing options and making decisions where learners perform several types of analysis on each design.

In the first phase, all groups fall into the beginner design category. This is because all groups do not take into consideration what positive or negative things will emerge during the engineering process. In addition, each group did not have an additional discussion when engineering. They only focus on the first idea agreed.

In the second phase, there was an increase in this category. All groups appear to be in the process of weighing their ideas and seem worried that their designs have failed.

3.6. *Conduct Experiments*

The sixth indicator shows the strategy of conducting tests and experiments where learners prepare tools and materials, determine the procedures, and build a prototype of the product.
In this indicator, students are categorized into two groups. In the beginner designer group, students did not do any experimental tests on prototypes. Most of them just focus on the building without thinking about the success rate of the prototype can work or not. Indeed there are some students who do small tests but do not show the test is related to the prototype. They mostly just seemed to play with existing tools and materials.

In the second phase, students use the results of the previous phase as a reflection of how the tool works, most students are categorized as emerging designers because many of the group members start trying how the tool works. Considering the success variable of the specified tool also begins to emerge in the second phase.

3.7. Troubleshoot
The seventh indicator shows the strategy of troubleshooting where learners conducted testing and verification of the prototype extensively under real conditions in order to identify the part that would have to be redesigned until a satisfactory solution was reached.

In the first phase, the data shows that most groups are classified as novice designers who do not focus on carrying out the engineering process. In addition, they did not make a prototype performance analysis that was built and was not active in the search for suspicious things during the process. The rest of the group is classified as a new design that appears where the group begins to observe or see a prototype that is being made. Try to find out if there are possible errors and try to fix it.

In the second phase, the entire group is classified as developing designers. This improvement occurs in all groups wherein the second phase all groups have begun to focus on the problem areas of the prototype and try to solve them. Not only to observe but to pay more attention to the problem area.
3.8. **Revise/Iterate**

The eight indicator shows the strategy of revising and iterating where learners identify the part that would have to be redesigned and the process completed until a satisfactory solution was reached.

![Figure 8. Score Revise/Iterate Students](image)

In the first phase, the entire group is classified as a beginner designer in which the group performs the process carelessly. In addition to this, the group carries out a once linear engineering process. Whatever the result of the process, the group will consider it the final result of the process.

The improvement occurred in the second phase, where half of the entire group began to carry out a well-managed process and there were efforts to improve the prototype based on the comments received. All groups are classified as developing designers. The other half is classified as emerging designers where they only make improvements no more than twice.

3.9. **Reflect on Process**

The ninth indicator shows the strategy of reflecting on the process.

![Figure 9. Score Reflect on Process Students](image)

In the first phase, all students are classified as beginner designers in which each group keeps track of their own actions or those of others and makes silent designs when they think and act with a little self-reflection.

In the second phase, there is an increase in which the entire group is classified as a developing designer in which all groups begin to think reflexively when supervising their own designs and those of others.

4. **Conclusion**

Based on research data obtained shows that engineering design behavior of students develops when STEM-based learning is applied. Behavior in a variety of indicators displays values that increase from the first phase to the second phase.
The average value of students in the first phase are in the beginner designer category, many of the students are not familiar with designing things and developing in the second phase to become an emerging designer. The biggest change is in the revise/iterate indicator while the least developing indicator is in the represent idea and weigh options & make decisions indicator.

The STEM learning process can provide direct activity in solving a problem. STEM learning becomes important to be taught early on in order to prepare students to improve the various soft skills and hard skills required in the future.

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