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BOOSTING ENGINEERING CAPABILITIES THROUGH SCIENCE LEARNING

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ABSTRACT

This research aims to review increasing engineering capabilities through science learning using the case study method. The primary focus of the research is to understand how the integration of science concepts in the engineering curriculum can improve students' technical and analytical skills. The case study was conducted at a vocational high school that applies an interdisciplinary approach between science and engineering. Data was collected through classroom observations, interviews, and questionnaires. The research results show that students who are involved in science learning integrated with engineering can demonstrate an understanding of engineering concepts, problem-solving abilities, and critical thinking skills. In addition, teaching methods that focus on scientific projects and experiments have proven effective in building students' interest and motivation towards the field of engineering. This research concludes that science learning applied in an integrative manner can be an effective strategy in improving students' engineering capabilities.

Keywords: engineering capabilities, learning, science

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1. INTRODUCTION

In this modern era, education plays a very important role in preparing the younger generation to face increasingly complex global challenges. One crucial field in the development of human resources is engineering. Engineering skills are not only needed in the field of technology but also in various other disciplines that require innovative and creative problem-solving. Engineering activities are related to project-based learning because they focus on real-world problems and applications. Additionally, engineering activities are seen as a suitable foundation for student engagement in project-based learning. (Corbett, 2012; Wang et al., 2014; Barroso, 2016). Engineering is a discipline that plays an important role in the development of technology and society. As a foundation for learning, engineering offers an approach that combines theory and practice, encourages creative problem-solving, and applies scientific knowledge in real-world contexts. Student involvement in engineering-based learning can enhance critical and analytical skills, preparing them to face real-world challenges. Engineering-based learning can increase student motivation and engagement. This learning approach combines practical and relevant contexts that can capture students' interest and enhance their understanding of scientific concepts. Integrating engineering into the school curriculum can help students develop critical and creative thinking skills, which are highly needed in today's technological era. (Douglas et al., 2004; Feder et al., 2009). Additionally, engineering also provides students with the opportunity to learn to work in teams, manage projects, and develop innovative solutions to complex problems. Project-based learning in the field of engineering gives students hands-on experience in designing, building, and testing solutions, which enhances their understanding of the engineering design process and the importance of collaboration. (Dym et al., 2005). Through the engineering approach, students not only learn about technical concepts but also develop soft skills such as communication, time management, and adaptability. These aspects make engineering a highly suitable foundation for student engagement in learning.

Although the importance of engineering education is widely recognized, there remains a gap in the learning approach that integrates natural sciences with engineering skills. Science education in many schools often focuses on theoretical aspects without providing sufficient opportunities for students to develop practical skills and critical thinking abilities that are essential in engineering (Karpudewan, 2022; Suripto et al., 2023; Heryani, et al., 2023). Integrating science education with engineering principles can provide significant benefits for students. Through this approach, students not only gain a deeper understanding of scientific concepts but also learn to apply them in real-world situations to solve problems. This can develop critical thinking, creativity, and practical skills that are highly needed in the workplace and daily life. Various previous studies have shown that a learning approach combining science and engineering can enhance students' interest and performance in both fields. Some research has found that students engaged in engineering-based projects show significant improvements in their understanding of scientific concepts and their ability to apply that knowledge to solve problems (Sein-Echaluce et al., 2017; Admawati et al.,2018; Rusmana et al., 2021; Kim et al, 2023). However, despite its clear benefits, the implementation of science education focused on developing engineering skills still faces various challenges.

The implementation of science education focused on developing engineering skills still faces various challenges, despite its widely recognized potential benefits. Integrating engineering into the science curriculum aims to provide students with a more holistic and applicative experience, enhancing their critical and creative skills. However, several key obstacles hinder the realization of engineering development in science education. Many schools lack adequate facilities to implement project-based learning, a hallmark of the engineering approach. Limited funding and equipment often serve as major barriers to executing engineering-based education programs. Another challenge is the lack of training and professional development for teachers (Penner, 2000). Teaching engineering concepts requires a deep understanding and specialized skills that not all science teachers possess. Many teachers feel unprepared to integrate engineering concepts into science education due to insufficient training in engineering development (Daugherty, 2010). Apart from that, the curriculum is dense and focuses on achieving academic standards. Teachers are often faced with pressure to meet certain academic targets, thereby reducing their flexibility to adopt new learning methods that take longer to implement and evaluate. Pressure to meet strict educational standards can stifle innovation in teaching methods (Hynes et al., 2011). The importance of overcoming these challenges to ensure that engineering-based learning can be integrated effectively in the science curriculum is one aspect that needs to be considered in efforts to improve the quality of science learning.

This research aims to: (1) Explore how science learning can be integrated effectively with the development of engineering skills; (2) Identify learning strategies that can help students develop engineering skills through science learning. It is hoped that the results of this research will provide valuable insight for the development of more effective learning. Based on the background that has been described, the research questions are formulated as follows: RQ 1: To what extent can the application of science learning in the classroom develop engineering skills?; RQ 2: What are the challenges and obstacles faced in growing engineering skills through science learning?.

2. RESEARCH METHODS

This research is a case study which is included in qualitative research. The qualitative approach emphasizes highlighting descriptions of processes and meanings. Qualitative research is a research procedure that produces descriptive data in the form of written and spoken words from people and their observed behavior. Qualitative research is an activity to explore theories from real world facts, not to test theories or hypotheses (Bogdan et al., 1997; Delamont, 2012; Cooley, 2013).

This research was conducted at one of the Vocational High Schools (SMK) in the city of Bandung, specifically in engineering classes. Researchers used observation and in-depth interview techniques as data collection methods. The research instruments used were interview guidelines and observation sheets. Observations were carried out intensively in class to observe the learning process, with the aim of revealing whether engineering elements had been integrated into science learning or not. This observation was carried out until the researcher felt it was sufficient to provide a clear picture of the ongoing learning process. Apart from observations, researchers also conducted in-depth interviews with teachers and students. These interviews were designed to gain a deeper understanding of teacher and student perspectives on the integration of engineering in science learning. The researcher recorded these interviews to ensure that data analysis could be carried out comprehensively, and to identify whether engineering processes emerged in the learning carried out. The case study method with a qualitative approach is very suitable for understanding phenomena in their original context, especially when the boundaries between the phenomenon and its context are unclear (Yin, 209; Creswell, 2013). This is in line with the aim of this research which is to explore how engineering learning is applied in the context of science learning in vocational schools.

3. RESULTS AND DISCUSSION

The research results are shown by data from observations, interviews and documentation. Observations of science learning in one of the classes at one of the Vocational High Schools in Bandung City, West Java Province, Indonesia, were carried out from February to March 2024. Observations were carried out in a series of science lessons with material on physical changes and chemical changes. All students in the observation class are female with a total of 28 students. Each observation was carried out for 2 x 40 minutes.

The extent to which the application of science learning in the classroom can develop engineering abilities among students

The results of classroom observations in science learning, with changes in physical material and chemical changes, show several important things related to the learning process, student activities, and the role of teachers in developing students' engineering abilities.

This research aims to improve students' engineering abilities through science learning by conducting a series of experiments. The results of the first observation showed that each group of students carried out four experiments designed to integrate science concepts, namely: burning newsprint, ice cubes sticking to string after being sprinkled with salt, the reaction between vinegar and baking soda which inflates balloons, and making ice cream. . The following is a description of the observation results from each experiment. In the first experiment, the newsprint was burned completely with ash remaining, showing a complete combustion process. Students observe that combustion requires oxygen and produces energy in the form of heat and light. All groups in the first experiment got experimental results with the same results and the expected conditions, namely the paper burned completely. In the second experiment, after being sprinkled with salt, the ice cubes stuck to the thread because the salt lowered the freezing point of the air, causing a small amount of melt which then refroze and stuck the thread. Students learn about the freezing point phenomenon and the role of substance breakdown in freezing point changes. Some conditions that arise include: (1) the ice cubes do not stick to the thread because too little salt is used. Students understand the importance of proportions of substances in reactions; and (2) the stone sticks to the thread, but the process takes longer because the room temperature is higher. It teaches students about the effect of environmental temperature on the rate of physical change. In the third experiment, the reaction between the vinegar and baking soda produced carbon dioxide gas which inflated the balloon. Students study chemical reactions between acids and bases and gas production. Some conditions that arise include: (1) the balloon does not inflate optimally because the amount of vinegar or baking soda used is not balanced. Students understand the importance of stoichiometry in chemical reactions; and (2) the balloon inflates too quickly and pops due to the use of excessive material. This provides insight into reaction control and the potential dangers of uncontrolled reactions. In the fourth experiment, the mixture of ice cream ingredients froze into ice cream after being mixed with salt and ice, showing a phase change from liquid to solid. Students learn about the freezing point and the effect of salt in lowering the freezing point. Some of the conditions that arise include: (1) the ice cream does not freeze completely because the ratio of salt and ice is not right. Students understand the importance of material proportions in physical processes; and (2) ice cream becomes too hard due to excessive use of salt. It teaches students about the effect of substance concentration on phase changes. Through these experiments, students gain a deep understanding of basic science concepts and their application in engineering. Each alternative condition that arises provides an opportunity for students to learn about the variability and influence of various factors in science experiments. Thus, this research succeeded in showing that learning science through practical experiments can improve students' engineering and problem solving abilities.

The results of further observations show student activities and the role of the teacher. Students present group results in the form of a report on the results of a simple practicum that was carried out at the previous meeting. The teacher acts as a moderator during the presentation. Each group displays the results of their group work in turn. There are several important notes from this observation, including: (1) students who were not presenting seemed to be paying attention, but most were busy delivering in whispers and playing with cellphones; (2) all members of the presentation group only read the prepared text, no one explains without the text. In observations in the next session, it was seen that students were involved in playing. After each group finished their presentation, several activities were carried out to increase student involvement: 1) the group leader appointed one student to answer the questions; (2) the teacher records points for students who answer; (3) the group provides an opportunity for two students to ask questions; (4) the teacher gives points to students who ask questions; (5) the teacher asks who made the video to give extra points. In the group presentation session, there were several students who took quite a long time to answer questions about the substances contained in salt, even after being given a "clue" by their group friends. This indicates that students may not understand the material enough or are not confident enough to answer questions.

During observations, the interaction between teachers and students is also important to pay attention to. In several group presentations, the teacher provided help and guidance when students had difficulty answering questions. The teacher also provides comments that help clarify students' answers, such as the balloon experiment with vinegar and baking soda, and making ice cream. Overall, the observation results show several strengths and weaknesses in the observed learning process. The advantages found include: (1) the practical activities carried out by students are quite varied and interesting, providing opportunities for students to be directly involved in simple experiments; (2) presentation of practicum results encourages students to communicate and share their knowledge with classmates; and (3) teachers play an active role in facilitating discussions and providing constructive feedback. Meanwhile, several weaknesses emerged, including: (1) many students were not focused during presentations, indicating a lack of class discipline and attention to learning activities; (2) students' reliance on text during presentations indicates a lack of in-depth understanding or thorough preparation; (3) students often require significant assistance to answer questions, indicating that their understanding of the material may be limited.

The observation results show that the practicum-based learning carried out has led to the integration of engineering skills in science learning. However, there are several aspects that need to be improved, especially in terms of class discipline, student involvement, and in-depth understanding of the material. Further strengthening can be done through increasing teacher training, using more interactive learning methods, and developing students' skills in presentations and discussions without dependence on text.

Based on interviews with students, several important findings were revealed regarding students' understanding and experiences regarding engineering-based learning. Students' Understanding of the Term 'Engineering' in Learning. This can be seen when students are asked questions about whether they know the term "engineering", the students' answers show variations in understanding and exposure to the term 'engineering': some students mentioned that the term 'engineering' often appears in Information and Communication Technology lessons (ICT). They learn about creating simple applications and the software development process. However, there were also students who stated the answer that the term 'engineering' was rarely mentioned, but sometimes appeared in physics and chemistry lessons, related to engineering principles applied in scientific experiments and projects. There are even students who admit that they have never heard the term 'engineering' specifically, but similar concepts are often discussed in the context of mathematics and science subjects. From these answers, it is apparent that students' understanding and exposure to the term 'engineering' varies depending on the teaching approach at their school. This shows that the integration of engineering in science learning is still uneven and depends on the initiative of each teacher.

Exploration of students' experiences in learning with an engineering approach was also revealed through in-depth interviews by asking questions about students' experiences in participating in learning using the pattern of thinking-drawing/designing-creating-testing or repeating designs. Student answers show different experiences in applying learning with an engineering approach. Some students admitted that they had followed this pattern of learning in science lessons. However, several students admitted that they had never formally participated in this pattern of learning in class, but had done so in their annual science project. They must think of an experimental idea, draw an experimental plan, carry out the experiment, and then test and refine the method based on initial results. This shows that the application of engineering learning models can vary in form and frequency. Findings from interviews show several important points related to engineering learning in science learning. These include (a) students' understanding of engineering is greatly influenced by how this term is integrated in the learning process in class. Some students have a clear and structured understanding of engineering, while others get only minimal exposure through related courses; (b) students' experiences with engineering learning models also vary. Some students get hands-on, structured experience in the classroom, while others only get through annual projects. This suggests that to effectively foster engineering skills, a consistent and structured approach to the curriculum is required; (c) practical experience from interview answers with several students shows the importance of students' active involvement in the process of thinking, designing, creating and testing. This learning model can help students understand scientific concepts better and develop the necessary engineering skills. The findings of this research provide an illustration that the integration of engineering learning in science in Vocational Schools in Bandung city still faces challenges. Although some students have a good understanding and experience of engineering, there is a need for a more structured and holistic approach to ensure all students have the same opportunities to develop their engineering skills. Improving teacher training, developing clearer curricula, and using interactive learning models can help achieve this goal.

Challenges and obstacles in developing engineering abilities through science learning

This research identifies various challenges and obstacles faced in developing engineering skills through learning Natural Sciences (IPA) among secondary school students. One of the main challenges faced is the limited resources available at schools. Many schools experience a lack of laboratory equipment, practical materials, and adequate facilities to support project-based learning. These limitations hinder the conduct of experiments necessary to understand engineering concepts in a practical way. Without the right equipment, students find it difficult to carry out the exploration and innovation that is at the core of engineering skills. Engineering is defined as actions taken to improve the quality of life by changing the world in such a way using knowledge and observation (bagiati et al., 2016). In the research that has been conducted, authentic engineering is described as the process of designing and prototyping a solution to a problem (Wendell et al., 2013). A major part of engineering is the design activities used by engineers when they try to create new technologies or solve specific problems (Guzey et al., 2016). This design activity requires cognitive reasoning, mental modeling and calculations that must meet certain criteria and constraints (Schnittka et al., 2016).

Project-based science learning requires sufficient time for implementation. However, busy curricula often do not provide adequate time for these activities. As a result, teachers tend to focus on completing the syllabus and preparing for exams rather than implementing more interactive and in-depth learning methods. This limited time reduces opportunities for students to engage in critical thinking processes and complex problem solving. In science learning that integrates engineering activities, students are encouraged to use the knowledge and experience they have and communicate what they have learned at the end of the lesson (Laboy-Rush, 2010). The characteristics of engineering design are student-centered, interdisciplinary, collaborative and technology-based (Han et al., 2014). Activities carried out by students in engineering design-based learning always include the construction of physical products as a way to solve human problems (Wendell et al., 2013; Marulcu et al., 2016). Apart from that, student activities always include collaborative activities as a team, not just individual activities (Wendell et al., 2013). However, engineering design is not limited to designing a technology to solve a problem, but requires an iterative process that requires engineering thinking based on scientific laws and theories (King et al., 2016). Engineering activities are activities that are relevant to project-based learning because they both refer to problems or applications in everyday life. In addition, engineering activities are considered an ideal foundation for student activities in project-based learning (Barroso, 2016).

Teachers play a key role in developing students' engineering abilities. However, many teachers have not received special training in integrating engineering principles into science learning. This lack of training makes teachers feel less confident and less able to teach with a project-based approach. Adequate training will help teachers develop more effective and innovative teaching methods. Changing teaching methods from traditional approaches to more interactive and project-based approaches is often met with resistance. Both teachers and students may feel comfortable with conventional teaching methods and be reluctant to try new approaches. This resistance can stem from old habits, concerns about the effectiveness of new methods, or a lack of understanding about the benefits of project-based learning. Support from schools and educational policies is very important in implementing changes in teaching methods.

This research found that a lack of support from schools, including financial support and policies that encourage innovation in learning, is a significant obstacle. Rigid and inflexible education policies often leave no room for the development of more creative and project-based learning programs. To overcome these challenges and obstacles, several recommendations that can be given include: (1) Schools and the government need to increase investment in providing adequate equipment and practicum materials. This includes providing laboratories equipped with the necessary technology; (2) Adjustments need to be made in the curriculum to provide greater space for project-based learning activities. This could include more flexible time scheduling and a reduction in theoretical material loads; (3) Holding ongoing training and workshops for teachers to improve their competency in teaching using a project-based approach and engineering principles; (4) Building a culture of innovation in schools by encouraging experimentation and active learning. This can be done by providing appreciation and incentives for teachers and students who successfully implement innovative engineering projects; (5) Encourage schools and policy makers to provide greater support for engineering learning initiatives. This includes developing more flexible and adaptive policies that support innovation in learning. By implementing these recommendations, it is hoped that challenges and obstacles in developing engineering skills through science learning can be overcome, so that students can be better prepared to face future challenges with relevant and innovative skills.

4. CONCLUSION

This research found that the application of science learning in the classroom has a significant impact on the development of engineering skills among secondary school students. Through interactive and project-based learning methods, students can apply science concepts practically, which helps students understand engineering principles. Several indicators of success include increasing students' abilities in critical thinking, problem solving, and innovation. Additionally, students demonstrate improved technical skills and a deeper understanding of how science concepts can be applied in real-world contexts.

This research also identifies several challenges and obstacles faced in growing engineering skills through science learning. The main challenges include limited resources, such as a lack of adequate equipment and practicum materials as well as limited time in the curriculum for project-based learning activities. In addition, teachers often lack special training in integrating engineering principles in science learning, which results in difficulties in delivering the material effectively. Other barriers are resistance to changes in traditional teaching methods and lack of support from schools or educational policies that support the integration of engineering learning. To overcome these challenges and obstacles, this research recommends several steps: (1) Increasing investment in adequate practicum equipment and materials and extending the time allocated for project-based learning activities; (2) Holding training and workshops for teachers to improve their abilities in integrating engineering principles in science learning; (3) Encourage schools and policy makers to provide greater support for engineering learning initiatives, including the development of more flexible and adaptive curricula. By overcoming these challenges, it is hoped that science learning can be more effective in developing engineering skills among students, thereby preparing students with the skills needed to face future challenges.

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