Embedding STEM in the mathematics classroom: A case study of vocational high school teacher's practice

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Abstract. Mathematics teachers often question the practice of Science, Technology, Engineering, and Mathematics (STEM) education without diminishing mathematics's potential as a conceptual tool to solve problems. This qualitative case study research explores the STEM teaching practices carried out by two mathematics vocational high school teachers. Further exploration seeks to investigate how is mathematics playing a role in the STEM project they are carrying. Data were collected through documents and media analysis (lesson plans, students' work, photos, and video) and interview with teachers. The findings showed that both teachers chose to implement the embedded-STEM approach in their first time STEM teaching experience. They used mathematics to facilitate students' problem-solving, mathematics modelling, and reasoning in the STEM project. The teachers had different practices and perspectives in designing, implementing, and assessing embedded-STEM mathematics classrooms. The contribution of this research is to provide practical cases of embedded-STEM mathematics teaching, which may be relevant as a solution for countries that do not offer a specific STEM curriculum.

1. Introduction

Many countries have made efforts to develop science, technology, engineering, and mathematics (STEM) literacy for students through STEM education. Many research shows the positive impact of STEM education on the development of students. "Modern STEM education imparts not only skills such as critical thinking, problem-solving, higher-order thinking, design, and inference, but also behavioural competencies such as perseverance, adaptability, cooperation, organization, and responsibility" [1]. This positive impact turned out to be side by side with questions about integrating the four STEM components in teaching practices [2].

Efforts to disseminate STEM education are also on the agenda for the vocational education system in Indonesia. Indonesia's curriculum system distinguishes secondary school into regular high school or Sekolah Menengah Atas (SMA) and vocational high school or Sekolah Menengah Kejuruan (SMK). The SMK curriculum structure distinguishes between national content, local content, and vocational content corresponding to each field of expertise [3]. Mathematics is a compulsory subject in the national content, while science, technology, and engineering are in the vocational content. After all, SMK has many resources for the practice of STEM education.

However, our preliminary survey involving 50 SMK mathematics teachers who had not yet received STEM training showed that they were not confident in other STEM fields outside of their discipline [4,5]. Moreover, they questioned the mathematics curriculum's target, which is their professional task
as mathematics teachers. From a mathematical perspective, integrating four STEM components without neglecting mathematics learning objectives still becomes a big question for mathematics educators [6,7].

Sokolowski [8] wrote that the biggest challenge in presenting STEM activities in high schools is connecting science, technology, engineering, and mathematics because students learn STEM subjects separately. The connection between the four STEM components in instructional designs is essential in STEM education [2,6,9]. Many pieces of literature discuss the connection between the four STEM components [10,11]. However, we are more interested in using the approach taken by Roberts and Cantu [12], which differentiates the type of STEM integration based on the teacher's learning process.

According to Roberts and Cantu [12], there were silo, embedded-STEM, and integrated-STEM. The silo approach concentrates on science, technology, engineering, and mathematics separately. This approach has been widely practised in various countries' curricula, although it is not explicitly documented as STEM instructional learning. Embedded-STEM is about combining other disciplines into one primary subject to strengthen understanding and implementation of the concept, so teachers do not need to assess the embedded subjects [12]. Thus, embedded-STEM maintains the primary discipline characteristics by providing real-world problems and broad context related to embedded subjects. In contrast to embedded-STEM, integrated-STEM is about removing the boundaries between STEM components to deliver STEM topics as one subject [12,13]. Sanders explains in [12] that integrated-STEM is different from embedded-STEM in assessing student competencies for all disciplines.

We studied relevant literature describing the success of STEM implementation by mathematics educators in SMK. Ni'mah, Mariani, and Prabowo's [14] study showed that SMK Tunas Harapan Pati students who get STEM integrated project-based learning have better mathematical connection skills than students who get expository mathematics learning. Another study by Ismayani [15] applied STEM project-based learning at SMK Cianjur, West Java. The results showed a significant mean difference related to students' creative thinking abilities before and after treatment. However, those studies have not dealt with the practice and real experience of STEM implementation from the mathematics teacher's perspective, the challenges, and their solutions. We believe that understanding and analyzing teachers' practices are critical to gain perspective about STEM education. We intend to investigate this fact as our research problem. Therefore, this case study research aims to 1) explore STEM teaching practices carried out by mathematics vocational high school teachers and 2) teachers' perspectives about how mathematics plays a role in the STEM project they were delivering.

2. Methods
The research paradigm is Teacher Research [16] to emphasize individual teachers' perspectives, knowledge, and instructional practice. This qualitative research design is a case study, and the cases to be studied are the STEM teaching practices carried out by two mathematics vocational high school teachers. Both teachers participated in a STEM professional development program for SMK mathematics teachers held by the Indonesian government through PPPPTK Matematika from July 29th – August 5th, 2019.

2.1. STEM Professional Development Program
The professional development program invited 50 mathematics SMK teachers from all over Indonesia who have never been involved in STEM education training and never practiced STEM in their classroom. The program aimed to equip SMK mathematics teachers better to understand STEM education and design STEM learning instructional to be practiced in their classroom. The training began with recognizing STEM education, including identifying the characteristics of science, technology, engineering, and mathematics as disciplines. The program invited experts from each STEM discipline to deliver the training material. Other materials are the integration of STEM components and the STEM instructional design. The program's focus was that mathematics teachers could promote students' mathematical thinking based on the SMK mathematics curriculum content through STEM education. We are involved in this program as one of the facilitators.
2.2. Participants
The case selection uses an information-oriented selection strategy [17]. We chose two teacher participants, Mrs. Ain (Pontianak, West Kalimantan) and Mr Sar (Jakarta). We chose their practice as our case because they used embedded-STEM and provided complete information to us. Another reason was that their practice fully describes the potential and risks of embedded-STEM compared to other participants. The practice of Mrs. Ain is unique because it is constrained by forest fires disaster in Kalimantan. Meanwhile, Mr. Sar’s practice is interesting because of the assessment results, as we will reveal later. The use of pseudonyms instead of teachers' names is at the request of teacher participants. Both teachers have a bachelor's degree in mathematics education. Mrs Ain has 14 years of experience teaching mathematics SMK. She is currently in charge of teaching mathematics in the Computer and Network Engineering department. Mr Sar has taught mathematics in SMK for 26 years. However, he mastered computer programming because he was self-taught. When the SMK opened the Software Engineering department for the first time, Mr Sar was the only teacher qualified to teach object-oriented programming. In 2018, he received dual certification as a mathematics teacher and as a vocational subject teacher.

2.3. Data Collection and Data Analysis
We asked both teachers to turn in their full unit document and media, which they used in teaching practice. Then we did document and media analysis (lesson plans, students' work, photos, and learning videos) to understand and look for evidence of their practice. We analyzed their teaching resources based on three stages, which, in our opinion, best describe the practices of both teachers: planning, implementation, and assessment. We triangulated the data with a semi-structured interview with both teachers. The questions focused on their practice and their perspective on the role of mathematics in STEM education. Data analysis was performed by interpretational analysis [18]. We read all the documents and the transcripts interview repeatedly. Then we used the key findings and categorized them as planning, implementing, assessing, and mathematics roles. We interpreted our findings by analyzing every category. All data sources for this study came from teachers. We also view this as a limitation of this study. We also conducted a reflective analysis to avoid bias in interpretational analysis results [18,19]. We emphasize that the two cases are exploratory, so even though we compare the two teachers' cases in some points, the comparison is not for measuring which case is better, but rather to compare the situations that occur.

3. Results and Discussion

3.1. Results

3.1.1. Case 1: Mrs. Ain. There were 36 students in Mrs. Ain's class. She struggled to find the STEM project idea that connected both mathematics curriculum and vocational skill. She was consulting vocational teachers, fellow mathematics teachers at school, and searching for resources on the Internet. Later, she decided to focus only on mathematics and STEM with the project "Prototype of Hydraulic Jack (PHJ)" to deliver the topic of Absolute Value Inequality in 10th grade. She said, "I want to start with the simplest and the cheapest material for my first time (practising STEM). I want to motivate my students to study mathematics first ...".

The implementation takes 3×90 class minutes. Mrs. Ain realized that this time allocation was lacking, but she had to adjust to the academic calendar and targets for that semester. Therefore, before class, she had already assigned students to search for information on the Internet about tools, materials, and how to make PHJ and asked students to bring these materials to the first meeting.

She begins the first meeting with the motivation to observe the jack pictures and discuss their benefits. During the first meeting, the teacher creates learning situations in group work to discover the concept of absolute value inequality using Worksheet I. One of Worksheet I's problems is shown in figure 1, and the capture of students' answers is shown in figure 2. After discussing and concluding the
concept of absolute value inequality on Worksheet 1, Mrs. Ain asked the students to start making a hydraulic jack prototype. In Mrs. Ain, students have no trouble making simple hydraulic jacks because the tools and materials are easily available. Due to insufficient time, the process of making the jack was continued to the second meeting.

![Figure 1. Problem in Mrs. Ain Worksheet 1](image)

At the second meeting, Mrs. Ain gives time for students to accomplish the jack and perform testing. Then Mrs. Ain distributed Worksheet II. She asked the students to use their jacks to answer the maximum weight the jack can lift if the hose's length is twice the original length or the jack height is half of its original height. In the report, Mrs. Ain wrote that several groups experienced failures in developing prototypes. So, Mrs. Ain asked them to repair their jack at home.

![Figure 2. Mrs. Ain students' answer](image)

In her lesson plan, Mrs. Ain scheduled a complete project presentation at the third meeting. Nevertheless, there was only one group presentation due to time constraints. Mrs. Ain wanted to add more lesson hours to complete the presentation, but due to the forest fire haze disaster at the end of 2019, school activities in West Kalimantan were closed. So Mrs. Ain took the initiative to assign students using video presentation and asked them to upload the video via Google Classroom. Mrs. Ain stated that she found a connection with vocational subjects through this video task. "...I accidentally explored their abilities related to the vocational. I did not think the video was even better, more creative, beyond my expectations. Though still in 10th grade...'.

Mrs. Ain's assessment includes the assessment of attitudes, knowledge, and skills. Mrs. Ain focused on assessing student activeness and cooperation. Meanwhile, the assessment of knowledge is carried out by observing the learning process and working on worksheets. Mrs. Ain reported that 92% of students completed the understanding of the absolute value inequality concept. For assessment of skills, the technique used by Mrs. Ain is product assessment with indicators were the quality of design,
implementation, function, innovation, solving absolute value inequality problems, and solving problems related to products.

When we interviewed Mrs. Ain about the role of mathematics in STEM projects, she mentioned mathematics modelling and problem-solving. She said, "I hope by using jack problem (PHJ) students can develop mathematical models using absolute values inequality. I made the problem in the worksheet by myself, so the question is not in the students' textbooks. They even used Google to search for answers. My first thought is to motivate students; the absolute value is a bit difficult content. I also assessed students' problem-solving abilities. Problem-solving is not only in mathematics problems but also in solving STEM problems because it is needed as a vocational high school graduate."

3.1.2. Case 2: Mr. Sar. Mr. Sar's class consists of 35 students. Mr. Sar admitted that he had no difficulty planning STEM projects because he mastered mathematics and vocational subjects. He connected mathematics with programming and saw mathematical logic is very important to master programming. He stated, "Programming involved much mathematical logic, the algorithm, in making decisions. I begin with the idea of programming an earthquake detector first and then looked for related mathematical content ..." Mr. Sar designed the project "Prototype of Quarke Warning Alarm (PQW)" to deliver the topic "Mathematical Logic" in 11th grade. He planned a time allocation of $2 \times 135$ minutes.

Mr. Sar started the first meeting by showing the tsunami video to gain student empathy. He said, "I saw their reaction to foster empathy, so they came up with the idea of an earthquake warning alarm. Students are motivated because of empathy. they are involved, the video is involved, the audio is involved, and the mind is involved." After explaining the project to students, Mr. Sar distributes Worksheet I, aiming to help students determine the true value and conclusion of a premise. This worksheet contains routine problems on mathematical logic, and one question was using an earthquakes context. After the teacher's presentation and reinforcement, Mr. Sar asked students to find information about QWA on the Internet then asked students to draw their design in Worksheet II. Mr. Sar ended the first meeting with each group's design presentation and assigned students to make Arduino programming to be used in the next meeting.

Mr. Sar conducted an assessment of attitude using journal notes. Meanwhile, the assessment of knowledge used observational techniques and tests on mathematical logic. The assessment result showed that quite many students did not pass the criteria of understanding mathematical logic. Still, Mr. Sar argued that this was because the children's interest in learning mathematics was low. He looked more at the enthusiasm and success of students in completing prototypes than in completing worksheets. Mr. Sar also conducts project assessments with indicators, including solving mathematical logic problems and the ability to argue based on mathematical logic.

Regarding the role of mathematics in his STEM project, Mr. Sar's comment is very dominant in reasoning and problem-solving. He said, "Frankly, about 25% of my students are not complete understanding mathematical logic. However, in my expectation, understanding mathematical logic is constructive in the reasoning and problem solving of the projects I provide. Students managed to assemble the PQW successfully. Nevertheless, I can tell the difference between a student who applies mathematical logic and those who do not. More effective one who understands mathematical logic."

3.2. Discussion
Both teachers chose to implement the embedded-STEM approach in their first time STEM teaching experience instead of integrated-STEM [12]. We see that they focus on delivering the mathematics curriculum's objectives and using the contexts of science, technology, and engineering as real-world problems. Using embedded-STEM, both teachers did not assess the aspects of science, technology, and engineering [12]. We reflect on our own experience as a mathematics educator when we first design STEM learning. Giving mathematics a dominant role makes it easier for us to design STEM projects. Furthermore, it reduced teachers' anxieties [4,5], which will lead to delays in STEM benefits offered to students.
On planning, Mr. Sar benefits more because he also had a background as a programming teacher. Mr. Sar focused on the STEM project, then tried to map the mathematics content accordingly. Meanwhile, Mrs. Ain had difficulty finding the project because she believed that learning mathematics with STEM had to be relevant to its vocational context. The triangle of connection between mathematics, vocational, and STEM curricula motivates Mrs. Ain to consult vocational teachers, fellow mathematics teachers in schools and search various sources on the Internet. The difficulty faced by Mrs. Ain is in line with the findings of Maas et al. [4] that finding project ideas is a challenge for teachers. The effort made by Mrs. Ain pointed out that the practice of embedded-STEM does not mean that mathematics teachers are free from understanding the topics of science, technology, and engineering. Teachers still have to prepare and master the project, one of which is by studying from various sources.

Using embedded-STEM, both teachers had facilitated students into a mathematics learning environment that fosters a cooperative attitude, engages students with an investigation, and is student-centred. Both of them faced time constraints in their practice. Even Mr. Sar specifically stated that material cost is a practical constraint. As indicated in previous research, teachers often perceived time and material as constraints in preparing and implementing STEM learning [20,21]. However, both teachers had different solutions to overcome time constraints. Mrs. Ain turned the group presentation strategy into a video task, and Mr. Sar added lesson hours. In Mrs. Ain's case, the time constraint appears because of the forest fire disaster situation in West Kalimantan. Mrs. Ain's effort to move the assignment to Google Classroom showed that she was very tactical in overcoming instructional learning problems. What Mrs. Ain experienced is very close to the current COVID-19 pandemic situation.

Mr. Sar's embedded-STEM practice may represent "functional mathematics" where mathematics teaching and learning process was relevant to the vocational context [22,23]. Ironically, Mr Sar assessed that some students did not finish understanding mathematics content as Robert and Cantu [12] wrote that embedded-STEM has the risk of students failing to relate embedded content to the mathematics concept. On the other hand, functional mathematics is not very apparent in Mrs. Ain's practice. However, the video task that emerged due to the forest fire disaster was very close to its vocational context. Her situation indicates that SMK mathematics teachers' training needs to strengthen functional mathematics content knowledge related to the vocational context.

The initial idea of STEM education in the 1950s was to support science learning in the United States [24], so it is natural if science education perspectives dominate research on STEM education. In their meta-analyses, Becker and Park [6] conclude that mathematics has the least benefit related to concept development in an integrated-STEM approach, especially at the high school and college levels. Mathematics is often considered as a calculation tool and numeric in STEM education [6,7]. Mathematics education researchers and practitioners naturally expect the role of mathematics to be more explicit and in line with the epistemological roots of mathematics in the practice of STEM education.

Sokolowski [8] stated that mathematics reasoning plays a role when students learn scientific phenomena. English [2] revealed that mathematical literacy plays an essential role in STEM education because it relates to data interpretation and decision making. Another research shows that mathematical modelling plays an essential role in the problem-solving of STEM task. "The interdisciplinary nature of mathematical modelling provides clear opportunities to connect mathematics to the goal of STEM education—learning how to solve problems in the real world through the application of knowledge from science, technology, engineering, and mathematics." [4]

The study's findings show that both teachers see the role of STEM context in embedded-STEM is to facilitate students' problem solving, mathematical modelling, and reasoning. These results are similar to those reported by Maas et al. [4] that the critical role of mathematics in STEM education is a bridge modelling real-world problems into mathematical solutions. Mathematical modelling skills require students' reasoning skills and problem-solving. These results also indicate that the teacher plays a role in strengthening mathematics concepts in the STEM context. So, mathematics does not only act as a calculation and measurement tool in STEM practice [6,7]. The positive findings of embedded-STEM practices carried out by both teachers also show the role of mathematics learning in fostering students' 21st century skills. Students' problem-solving in STEM projects solve mathematical problems and solve
project problems close to the real-life context. So mathematics plays a role in fostering creativity, collaboration, communication, and students' critical thinking skills in embedded STEM [4,25].

However, both teachers argued that the most significant benefit they felt from this practice was that students became more enthusiastic and motivated to learn mathematics and solve problems mathematically. Mathematics is a compulsory subject in the SMK curriculum in Indonesia. Still, most vocational students do not show interest in learning mathematics [26]. We see this phenomenon as a challenge for vocational mathematics teachers to foster students' interest in mathematics [27] because one of the positive effects of STEM education is motivating students to learn mathematics [9].

4. Conclusion
The practice of embedding STEM in mathematics classroom from both cases use STEM as a context for delivering mathematical concepts. An important role that attaches mathematics to other STEM components is problem-solving, mathematics modelling, and reasoning. Furthermore, both teachers agree that mathematics fosters students' creativity, collaboration, communication, and critical thinking skills. The contribution of this research is to provide practical cases embedded-STEM mathematics teaching, more specifically in vocational high school. Although these practices may still be improved, embedded-STEM might be relevant as a solution for countries that do not offer a particular STEM curriculum. Professional development programs should address teachers' difficulties in practicing STEM. Further research is needed to evaluate STEM practices by the curriculum system, the role of disciplines, school environment, teachers, and students.

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