How engineering notebook supporting Thai elementary student practice in STEM learning

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Abstract. This paper examines the use of engineering notebooks to foster 5th grade Thai student engagement and the learning of engineering practices in STEM education. This study examines how students’ engineering notebooks support student work during design challenges. Through educational ethnography and discourse analysis, transcripts of student talk and action were created and coded around the uses of engineering notebooks at three Thai elementary schools in Bangkok, Thailand. Our coding process identified two broad categories of roles for the notebooks: scaffold student activity and support practices of engineering design. The study showed the importance of prompts was to engage students in communicating, writing, drawing, and redesigning in the small group by having an engineering notebook as a tool to support their learning.

1. Introduction

Many countries are strongly advised to support STEM education. To prepare students for the twenty-first century, educational institutions in many countries have adopted and forced in support of an increased focus on STEM education in schools [10]. In Thailand, to help students stay globally competitive in terms of innovation and technology, STEM teaching has become a priority in K-12 education [16]. However, there is a difficulty with an integrated STEM activity on respective disciplines and ensuring students develop the required learning, primarily when multiple content areas are addressed [9]. Several researchers have indicated that increasing students’ awareness of their disciplinary learning and how they are applying this in an integrated STEM activity remains a challenge for educators. There are many reports of failings in the educational system to provide suitable science and technological training for young students concerning the employment needs for the 21st and the need to improve research in engineering education [12]. Likewise, elementary teachers frequently lack the required pedagogical knowledge to implement integrated STEM activities effectively [15]. The number of enrolments in scientific courses has fallen in many countries. Students begin elementary education with a spontaneous interest in nature; however, by the end of their educational stage, they perceive science to be irrelevant, boring and too difficult to learn [11]. While students’ interest in science is high at ten years old or in grade 4, regardless of gender, by the time students are 14 years old, their interest has decreased considerably [2].

The research suggested to keep their interests in science and engineering, STEM activities should be conducted in grades 5-6 before they start in middle school [1]. In many nations, engineering design is not given attention even though the discipline draws strongly on many areas of STEM education. For
example, the application of reflection on the STEM disciplinary content during the design phases is not well defined, although it is a critical component within the role of disciplinary knowledge which develops during inquiry-based, design-based problem-solving opportunities [6], [20]. A solution to the stated problem is the use the workbooks to sketch a design that can contribute to students’ learning by helping them develop and convey meaning and understanding about a given problem as well as draw connecting details to the targeted disciplines in creating and annotating their sketches [15]. Design sketches are one of the multiple communication modes assisting problem solution with the interaction of various methods and can play a powerful role in knowledge scaffolding [13]. Nevertheless, design sketching appears to lack the recognition required, often because of claims that younger students would rather experiment with the workbook rather than sketching. Therefore, for educational aims, students’ conversations should be used to help students’ ability to scaffold knowledge by using science and engineering notebooks. We should provide classroom students with notebooks that offer opportunities to organize their collective thoughts, actions and structure their activities the same as the professional engineers who often use an engineering notebook to document and structure their work [4]. Other studies also demonstrate the engineering notebook and how it supports engineering design. Students can communicate through spoken and written discourse in engineering contexts, which has similarly been recognized in education [12].

Therefore, written communication is central to the many processes of engaging in engineering design, from negotiating, planning, communicating, presenting, evaluating, and reworking solutions. Discourse processes and practices have a dialectical relationship with disciplinary knowledge, as knowledge is shaped by, but also shapes, the patterned uses of discourses to accomplish scientific and engineering tasks [9]. In this study, we examine the roles of the engineering notebook in the part of engineering design activity which challenges 5th grade elementary school students at three Thai elementary schools. Different school sizes characterize these three public schools as a small, medium, and large school in Bangkok City, Thailand.

2. Research objectives
To find the value of the use of our engineering notebooks, we had students in elementary classrooms implement bridge design challenges. Each student was provided a notebook before they built the bridge to discuss, plan, write, sketch, and redesign their work. Everyone had a notebook to think individually first, and then as a small group; students would work cooperatively together to finalize their thinking. The questions provided in the notebook support engineering design preparation for the students. Notebooks include background knowledge, engineering problems, and planning. In this part of the research, we focus on the roles of the engineering notebook during the design challenge activity. Therefore, we pose two main questions:

1) How do notebooks structure student learning through engineering design activities?
2) What roles of the engineering notebooks support students engaging in engineering practices?

3. Methodology
The research was conducted with 175 5th grade elementary students from three volunteering Thai elementary schools. The selection was based on school size in the Bangkok service area belonging to Suan Sunandha Rajabhat University (SSRU) in Thailand and was completed after the approval from ethics in human research by the SSRU board committee. There were two females and one male willing to participate in the engineering design and STEM teaching two-day workshop. After agreeing to participate in the research, participants agreed to use bridge-building activities to teach their STEM class while using provided engineering notebooks for three weeks (12 total hours) during the second semester of the 2019 academic year. In class, students were participating in the activity as a small group of 4-5 students. The total number of groups participating was 42. The data collection was drawn from engineering notebooks based on videotape, classroom observation, and photos. The notebooks structured student investigations that informed their choice of materials for the bridge design
challenge. Guided questions and figures were provided in the notebooks, and then students were asked to sketch their thoughts, plans, and make decisions based on the bridge challenge. Students were asked to articulate the materials they would use for their engineering bridge design. Then they shared their design and sketch in class and were given recommendations from a teacher. Our analysis uses educational ethnography by using methodology consisting of a focus group among teachers, classroom observation, and interviewing students (informatively) [8]. We examined classroom videos and student engineering notebooks focusing on the understanding of how the notebook plays a role in the engineering processes and practices of student groups. The discourse processes in which students were communicating with one another during the process of working through the notebooks were recorded through texts that were inscribed and evoked in conversation. The researchers transcribed the speech of the teachers and students and their actions associated with the engineering notebooks. Analysis of the transcript led to the development of a set of codes focused on the use of the notebook in the small group conversations. Using an iterative process and reviewing the codes, categories were developed for analysis and identified patterns in the usage and roles of notebooks during the design challenges.

4. Results
The data showed the notebook held the group accountable to their plan and supported the students’ engineering design practice. It also allowed students a more accurate use of the results to test designs by sketching and discussing the information for improvement and planning. The group later referenced the plans while debating which of the materials did and did not work well. There are two ways notebooks supported students’ engagement in preparation practices of the engineering design activity. The first was the concerns with the communication of knowledge claims and secondly, those initiated by the students to reflect on such knowledge claims. Students showed the capability of evoking written texts for epistemic purposes in engineering design. Teachers also rely on the notebook to remind students what they should be doing and where they are headed within the lessons. For example, one teacher, Ms. Aoraya, started her class by showing her boat model to students and then asking how the bridge should be built to enable the boat to float underneath safely. Then, she asked students to plan and design by working through the engineering notebook. In another classroom, before improving their designs, Mr. Nattapon opened a discussion related to the value of improving their engineering designs by asking, “If you guys look at the different types of bridges in your notebook, can you see the possible engineering design on how to build it?” He also asked, “What ideas should we apply to it, and is there any force acting on the bridge?” (Nattapon.S.1). In these ways, the notebook, along with the teacher guides, can support the structured teachers’ lesson plans to help students improve engineering design in the STEM classrooms.

The data in Table 1 shows the school names, sizes, and the number of students in each school. Each school has two 5th grade classrooms.

| School            | School size | Number of students | Number of groups |
|-------------------|-------------|--------------------|------------------|
| Watkosit (Code. W) | Small       | 49                 | 10               |
| SSR demonstration (Code. S) | Medium       | 62                 | 13               |
| Rajvinit (Code. R) | Large       | 64                 | 16               |

There are codes we used for each school. W is Watkosit School, S is Suan Sunandha Rajabhat Demonstration School, and R is Rajvinit School. When the number 1 or 2 follow the code, the class number is identified. The smaller size school has lower numbers of students than the larger schools. All schools volunteered to participate in the study and were members of the university network. Each student group had 4-5 students per group and was consistent in every school. The teachers taught the classes based on our activity from the workshop and used the provided notebook. The researchers observed all classes and interviewed students informatively during the lessons. Table 2 shows an
example of a group of students’ discussions during their group work. They were asked to work individually on their notebook before they came to the class to work as a group. The teacher helped by asking encouraging questions and guiding students during their design preparation activity. At the same time, researcher roles were to observe student actions and take videos.

Table 2. Transcript example of Miss Aoraya class 1.

| Student     | Discourse                                                                 | Researcher notes                                                                 |
|-------------|---------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| W1 Anutida  | Which pictures show the technology? The Engineer created it.            | They started the discussion.                                                     |
| W1 Soravit  | All of them, I think. How are forces acting on this woman sitting on the chair? | They brainstorm on each question in the notebook.                                |
| W1 Chutta   | I think forces acting on this woman have opposite direction, and there are four forces, do you think so? | Not all of them understand the forces, but one can teach others with the help of the teacher. |
| W1Thitiputta| You miss another one from the force from the floor acting on the chair. | A few of them like drawing. They enjoy sketching, especially the girls.          |
| W1 Anutida  | I will sketch the bridge we’re going to build later in the notebook.     |                                                                                  |
| W1 Nichaput| I will do the color. I like coloring.                                    |                                                                                  |
| W1 Soravit  | Who wants to draw an engineer? What does he look like?                   | The teacher needs to help with giving students time during the activity, then they help each other and work together better as a team. |
| W1 Chutta   | I can help you; I think he should be a thin man with a lot of tools.     |                                                                                  |
| W1Thitiputta| Should he wear a safety hat?                                            | The teacher gives this question.                                                 |
| W1Anutida   | Yes!                                                                     | Then, they can ask each other within the group. The answers are different among groups. |
| W1Thitiputta| What kind of paper shape should work better?                             |                                                                                  |
| W1 Chutta   | Rolling.                                                                 |                                                                                  |
| W1 Soravit  | I think many pieces would help to support the bridge.                    | In the last 10 minutes, the teacher tried to walk around checking students’ notebooks and preparing them to give a short talk on their work after. |
| W1 Anutida  | Should we use a sticky type?                                             |                                                                                  |
| W1 Nichaput| No, that should be used with the wood sticks only. I think.              |                                                                                  |

After 45 minutes, each group was asked to show their sketches and answers from their notebooks by preparing a short talk. The teacher asked the students questions to encourage them to think more about using different materials and shapes. The teacher reminds each group to complete each section in the notebook before letting them build the bridge.

Here we see how the notebook structures the teachers’ lessons, allowing Ms. Aoraya to refer to it to organize her lesson plans and guide children’s work in the engineering design of her STEM class. The need to write an answer, a collective response across the group in their notebooks, meant the students were required to discuss what they thought and then suggest their next steps in improving their design.
Anutida, Soravit, and Chutta relied on their notebook work to provide a reference for their decision-making and preparation for the bridge design. By asking students to focus on what did and did not work well, the questions in the notebook scaffolded the group’s progress towards planning for the next step of building the bridge. The example of their design was shown in Figure 1.

![Figure 1. Example of drawing design from two groups (a) at Watkosit and (b) Suan Sunandha School](image)

The notebook played a supporting role in getting the students quickly back to their conversation after needing to break and checking their plan; it provided prompts for students and groups to refocus their engineering design process. As in Figure 1, it shows students’ sketches of their bridge design in different ways. The group in (b) estimated their load that the bridge could handle more than the group in (a). You can also see the different designs of their sketches and how they can incorporate engineering skills by comparing and redesigning across the groups. Evidence of this refocusing role on the notebook was presented across the forty-two groups studied from the three schools. For example, in one group, Thitiputta asked questions related to the best paper shape to use to build the bridge among group members. Then they went back to observe their notebook plan design and drawing. Teachers also used the notebooks to reorient students who might be side-tracked, participating in off-topic discussions, or who had failed to record their ideas, as Mr. Nattapon did by telling one group of students ‘So you need to start drawing your bridge before the time is up and please recheck with your decision made in your notebook.’

5. Discussion and conclusion

Our study found the work that students did in the notebook across the bridge design challenges supported communication of ideas to other students and teachers. The same as mentioned in practices identified to improve STEM integration in K-12 education [4][12]. Our engineering notebooks provided scaffolding opportunities for student work and supporting engagement in their practices as related to the educational goals of learning science concepts, applying the engineering design process, and developing identity as learners of engineering which provide similar results in many studies [13][15]. Even though the three schools in the study are different school sizes, the results show the roles of engineering notebooks are the same. The early research on bridge design was in 1997 [5] showed that the engineering design activity for young students should provide time for students to
prepare and gain background knowledge, plan, and solve the problems before constructing their project, in this case, the bridge. In this study, it is agreed that the more you prepare your students, the better they can work on engineering design. Furthermore, there was a more recent research study conducted early in 2017 demonstrating how notebooks can improve communication and knowledge in the engineering design activity as part of STEM education. The report was on sixth-grade students’ responses to a set of problem activities in engineering design which focused on students’ reflection and scaffolding through thought-provoking student workbooks [4]. This research showed the same results for our study. It showed that students’ notebooks helped them understand more knowledge of engineering design activity. Likewise, another research study suggested that the group work on developing materials, knowledge, and experience that build engineering knowledge for educational purposes must consider ways of integrating epistemic practices into curriculum, and teaching [1]. In this study, we would also suggest that epistemic practices in a similar circumstance, but more likely focusing on using the engineering notebook as the material for engineering or STEM classrooms. For further research, we may want to find ways to support student engagement more in epistemic practices of science and engineering through the use of spoken and written discourse practices. As engineering becomes a more common discipline in elementary classrooms, we must gain a better understanding of how to structure design activity and the use of engineering notebooks to help students solve science questions and projects.

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