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Exploring teachers' epistemological framing through classroom discourse in 6E-STEM classes: From perception to practice

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Abstract

This study investigated teachers' enactments in 6E-STEM implementation with technology integration. Teachers' professional development utilized coaching and examining teaching and learning as strategies. Coaches trained three Vietnamese teachers for content, pedagogical content, and technological pedagogical knowledge through intensive STEM curriculum examples. Basic electrical engineering and application of technology for science learning curriculum was designed in 6E instructional model. In addition, CloudClassRoom was integrated with the curriculum to record students' performance. After coaching, three teachers had practical teaching with 107 students in junior high schools. Each class was implemented in three classes. Examining teaching and learning was conducted to investigate teachers' epistemological framing in teaching 6E-STEM. Classroom videotapes, and teachers' responses to interviews were analyzed by NVivo. The key results show that *delivering an artifact* was a function of teachers' framings in STEM teaching. However, teachers desired students to provide engineering knowledge, socialize scientific explanations, or develop students' creativities depending on the individual.

Keywords: discourse, 6E model, teachers' epistemological framing

INTRODUCTION

STEM education was defined as an instructional approach that impressed teacher-student (T-S) interaction, context-based learning, and encompasses engineering design challenges (Moore et al., 2014). The appearance of both design and inquiry was advocated as a solution for more integrative STEM education (Burke, 2014; Lin et al., 2020; Sanders, 2009). Many researchers advocated effective teaching strategies for STEM implementation successfully, such as problem-based learning (PBL), project-based learning (PjBL), and engineering design process (EDP) (Chung et al., 2018; Guzey et al., 2016; Lin et al., 2020; Wahono et al., 2020). Burke (2014) proposed the 6E (engage, explore, explain, engineering, enrich, & evaluate) instructional model to make STEM implementation more integrative with "T" and "E" apparent. Many studies recently proved the effectiveness of 6E-oriented STEM implementation such as facilitating students to deepen integrative knowledge, attitudes, confidence, and design and inquiry abilities (Chung et al., 2018; Lin et al., 2020).

However, a few studies focus on teaching practices of 6E-STEM implementation. Once the engineering is typical and dynamic in the 6E instructional model, researchers should research how teachers respect engineering design and integrate content (Wendell et al., 2019). Therefore, this current study aims to understand how teachers' enactments of the 6E-STEM curriculum, specifically on teachers' epistemology framing for

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Contribution to the literature

- This study explores how teachers implement the 6E-STEM curriculum, focusing on their epistemological framing for teaching by analyzing discourse practices, perceptions, and the reciprocal relationship between these factors.
- Delivering an artifact has been identified as a key strategy that reveals teachers' instructional approaches, with varying desires for students to gain engineering knowledge, articulate scientific explanations, or enhance creativity.
- In addition, the results indicate a significant alignment between teachers' perceptions and their practices in STEM education, emphasizing their commitment to promoting collaboration and problem-solving skills.

teaching. We investigated teachers' epistemology framing for teaching by indicators in discourse practices, perceptions and the bi-direct relationships between practices and perceptions. For such purpose, this current study addressed research questions below:

1. How do teachers structure 6E-STEM classroom discourse?
2. What are teachers' perceptions regarding the implementation of the 6E-STEM curriculum?

The 6E Instructional Model in STEM Education

There have been ample effective STEM instructional practices to help students achieve valuable STEM competencies, for example, the 6E instructional model, PjBL, PBL, and EDP (Burke, 2014; Guzey et al., 2016; Han et al., 2015; Thibaut et al., 2018; Vossen et al., 2019; Wahono et al., 2020). Teachers dynamically choose any instructional model to implement STEM education successfully. Although STEM instructional practices might differ in teaching sequences or characteristics, such instructional models are based on STEM teaching principles. STEM instructional practices are rooted in student-centered pedagogies (Thibaut et al., 2018). Thibaut et al. (2018) synthesized five STEM teaching principles by reviewing 23 STEM interventional papers in terms of instructional practices:

(1) STEM content integration,

(2) problem-centered learning,

(3) inquiry-based learning,

(4) design-based learning, and

(5) collaborative learning.

STEM teaching is primarily based on student-centered pedagogies and STEM education characteristics.

The 6E instructional model is an effective teaching strategy for STEM implementation. Burke (2014) modified the 5E learning cycle of Bybee (1997) into the 6E learning ByDesign™ model. The 6E instructional model could make STEM lessons more integrative content and context (Burke, 2014). While the design has not fully represented in the STEM lesson, the 6E model differs from 5E in the "engineer" phase. The 6E instructional model is promising for integration of design and inquiry with the maximizing of "T" and "E" in STEM education (Burke, 2014; Lin et al., 2020). The 6E instructional model's effectiveness positively enhanced students' attitudes and competencies from secondary school to higher education in STEM implementation (Chung et al., 2018; Lin et al., 2020). The 6E instructional model's adaptation needs to be broadened in ample learning environments and contexts for validation.

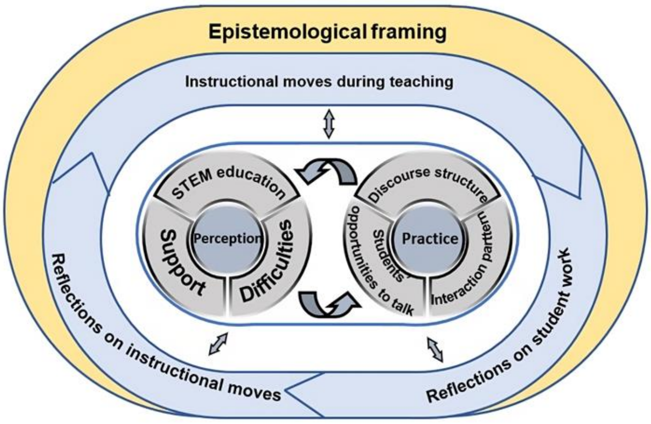

Figure 1. Theoretical framework of teachers' enactments of 6E-STEM classroom (Source: Authors' own elaboration)

This current study aims to understand how teachers' enactments in 6E-STEM implementation. Firstly, we reviewed the literature on epistemological framing to show related dimensions and relationships with teachers' perceptions and practices. Then, teaching practices were reviewed by the literature on discourse practices. Finally, teachers' perceptions were reviewed with the bi-direct relationship of practices and related components of perceptions. We create the conceptual framework (**Figure 1**) for the Theoretical framework of teachers' enactments of 6E-STEM classroom.

Epistemological Framing for STEM Teaching

Epistemological framing in teaching involves teachers' underlying expectations for teaching behavior to enhance students' learning outcomes. Teachers decide how to teach based on their previous experiences and understanding of knowledge and reasoning. However, they may place students in different epistemological frames depending on their intentions for what students should learn. Even when teachers share similar backgrounds, their framing can differ based on these intentions (Wendell et al., 2019). While many studies investigated students' epistemological framing for decades in science education (Elby & Hammer, 2001; Hammer & Elby, 2003), a few studies focus on researching epistemological framing for teaching, notably in STEM education. This current study aims to investigate teachers' epistemological framing via 6E-STEM implementation.

Recently, Wendell et al. (2019) explored teachers' epistemological framing of teaching engineering design when teachers are in two roles, as students and as teachers. Wendell et al. (2019) drew on the correlations of teachers' epistemological framing and teachers' enactments in the classroom. In the context of lacking studies and the call for teacher educators in strengthening teachers' epistemology framing, this current study investigated teachers' epistemological framing for 6E-STEM implementation through the correlation with perception practice. We adapted and generated the conceptual framework of Wendell et al. (2019) for teachers' epistemological framing for teaching in four contexts. We attended in investigating on instructional moves during students' learning activities in 6E phases, post-teaching reflections on students' work and instructional moves.

Social Aspects: How Has 6E-STEM Been Taught in a Classroom?

Valuable 6E-STEM education benefits students through the learning process rather than summative learning outcomes. The 6E instructional model provides students opportunities to engage, explore, explain, engineer, enrich, and evaluate. STEM education underlying expects students to achieve in-depth knowledge, high-order thinking skills, STEM practices. Teachers need to scaffold students in the cognitive process, reasoning, and skills through verbal interaction (Jin et al., 2016; Krystyniak & Heikkinen, 2007; Windschitl et al., 2012). Interactions between teachers and students in the learning process become important indicators for successful STEM education (NRC, 2012). From social aspects, successful 6E-STEM requires the effectiveness of sufficient discourse practices.

However, discourse practices pedagogically challenge teachers, especially in integrative STEM curricula. Teachers could elicit and adapt students' ideas in instruction through discourse practices in each phase of the learning cycle, such as engagement or engineering (Windschitl et al., 2012). Capobianco and colleagues found that teachers could struggle or succeed in instructional moves in integrating concepts and engineering activities (Capobianco & Rupp, 2014; Capobianco et al., 2017). This current study investigates teachers' discourse practices in 6E-STEM implementation.

Relevant literature on classroom discourse suggests three dimensions of classroom discourse in integrative 6E-STEM: discourse structure, students' opportunities to talk, and interaction patterns. In each E phase, I investigate how teachers' enactments help students engage, explore, explain, engineer, enrich, and evaluate, such as problem scoping, planning, or analyzing (Capobianco et al., 2017). Once 6E-STEM education is innovative, encouraging students' talk with other students and teachers is critical. I investigated interactions in the class following students' opportunities to talk, such as teacher-student-student and student-student (S-S) (Jin et al., 2016). Additionally, we aim to identify interaction patterns in the 6E-STEM classroom to examine the quality of verbal interactions.

Teachers' Perceptions of Difficulties and Supports in 6E-STEM Implementation

Teachers' effective elements of STEM education were popularly measured for decades. Researchers investigated teachers' perceptions of STEM education for implications in STEM implementation or teacher professional development (Kim & Keyhani, 2019; Knowles et al., 2018; Nguyen et al., 2020; Wahono & Chang, 2019). The bi-direct relationship between teachers' perceptions and practices was shown when researchers explored teaching practices to indicate teachers' perception of STEM education (Kim & Keyhani, 2019; Smith et al., 2018). However, a few studies have shown a slight relationship between perceptions and practices (Wang et al., 2011). Teachers' perceptions of STEM education were varied in the research literature. The term "perception" is implicitly examined as self-efficacy, attitude, or beliefs (Margot & Kettler, 2019). In the call of more studies on relationships between teachers' perceptions and practices, this current study investigates teachers' perceptions of STEM education for strengthening evidence of teaching behaviors in the classroom, including perceptions of STEM education per se, difficulties in and supports for successful STEM teaching.

METHOD

Research Context: The 6E-STEM Curriculum

We developed the STEM curriculum, namely BEATS (basic electrical engineering and application of technology for science learning). This STEM module was designed based on the authentic problem related to LED light. The BEATS provides opportunities for students to create mixed-light tools through engineering activities. In addition, the technology, namely CloudClassRoom (CCR), was embedded to enable students to monitor, revise, and improve their learning over time (Chien &

Table 1. The description of the task assigned in 6E phases

E phase	Description of tasks
Engage	Students observe devices or equipment used LED in the real world. Then students realize LED can emit different color lights.
Explore	Students observe the delicate structures of colors on the screen by dropping small water droplets on an iPad or a smartphone. Students realize the changes of colors on the screen to the water droplets.
Explain	Students explain changes of colors on the screen because of the fine structures of the screen and the effect from water droplets.
Engineer	Students create, operate LED mixed lighting model and test the functions of those models. Student practice techniques of welding and cleaning with electrical resistors, USB connector, IC, capacitor, the LED.
Enrich	Students understand the relation of RGB and color-changing through LED mixed lighting model. Students explain the reason for color by RGB overlaps.
Evaluate	Students understand how people see the colors.

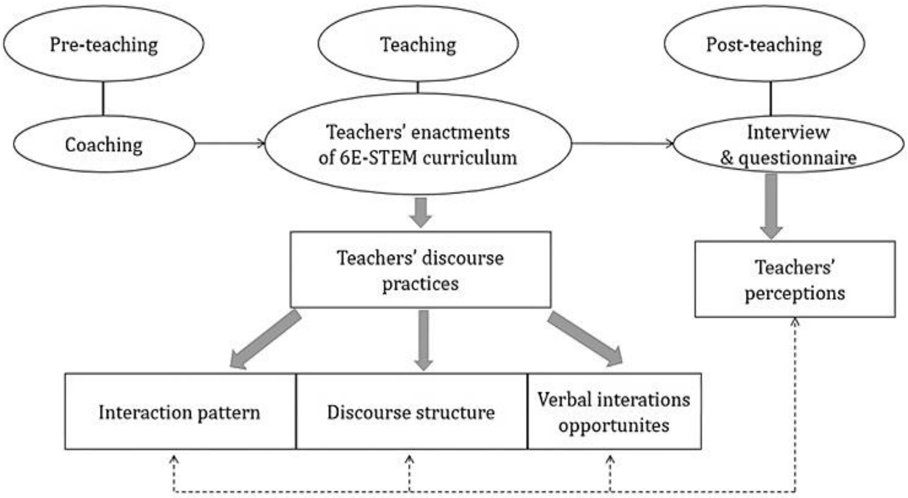

Figure 2. Research design of understanding of teachers' enactments of 6E-STEM (Source: Authors' own elaboration)

Chang, 2015). We developed the BEATS-CCR as a STEM curriculum addressing key features of the instructional model.

The development of the BEATS-CCR curriculum included two phases. In phase 1, the BEATS-CCR was translated into Vietnamese and pilot deployed for 30 students in Vietnam in May 2018. Also, at that time, we utilized the BEATS-CCR as workshop materials for 27 in-service teachers. Based on classroom observations and expert interviews, we revised the BEATS-CCR curriculum following the 6E instructional model (Lin et al., 2019). In phase 2, we translated and implemented the revised 6E-STEM curriculum in three countries Taiwan, Thailand, and Vietnam. This current study focused on implementing BEATS-CCR revising as 6E instructional model in Vietnam. **Table 1** illustrated the description of the task assigned in 6E phases.

CCR was developed to transform smartphone devices into powerful interactive tools for classroom learning. The beneficial CCR supports teachers in giving students assignments or guidelines and is a formative assessment tool. The students' responses in the course were recorded automatically on systems that enable teachers to get for assessing students' achievements. CCR played such roles in the BEATS curriculum. Students were asked before and after the course as well as each E phase related to BEATS curriculum content.

Research Design and Procedure

Figure 2 illustrates the procedure of this current study. We utilized the coach as a teacher professional development strategy (Loucks-Horsley et al., 2003, 2010). Vietnamese teachers implemented the 6E-STEM curriculum for junior high school students with 6E-STEM BEATS CCR lesson plan. Each class was implemented in three classes (about 2 to 2.5 hours). We examined epistemological framing for teaching and verbal interactions based on teachers' enactments in classrooms. After implementation, we interviewed and questioned teachers to get insight into teachers' perceptions of STEM education interview protocol.

Participants

Three Vietnamese teachers and 107 grade 8 students from two junior high schools (school A and school B) participated in this current study. Three teachers had a degree in science education. The male teacher, David, had nine years of teaching. The other two female teachers, Hana and Qiana, had teaching experience in five years and seven years, respectively. Schools' names and teachers' names are pseudonyms to assure

Table 2. The demographic data of four classes

	Class 1	Class 2	Class 3	Class 4
School information	School A	School B	School B	School A
Students' information				
Grade	8	8	8	8
Number of students	19	39	31	18
Male students[a]	7	13	11	5
Female students	10	22	15	10
Teachers' information				
Teacher's name	David	Hana		Qiana
Educational background	Science education	Science education		Science education
Gender	Male	Female		Female
Teaching experiences	9 years	5 years		7 years

Note. [a]The rest of the number of students are missing data related to students' genders

anonymity. **Table 2** shows the demographic data of four classes.

Data Source

Classroom observation

We recorded all videos of classrooms to analyze discourse and teachers' and students' behaviors. All videos were transcribed for discourse practice analysis. Segments from each E phase were chosen with a focus on teachers' instructional movements.

Interviews and questionnaires

Besides, teachers were interviewed by the first and the third author with interview protocol related to reflections of post-teaching, and teachers' perceptions of STEM education, including general understanding, difficulties in STEM implementation, and support. Teachers were semi-structured interviewed after the class to share

(1) their feelings about the class,

(2) the differences between lesson plans and real-time classes,

(3) which new learning experiences for students are,

(4) the perceptions of STEM education,

(5) STEM education supports, and

(6) improvement BEATS STEM-6E-CCR curriculum.

The sample question is "How can your class do to help develop the students to think and act as STEM professionals?" In total, there were 102 minutes for interviewing.

We utilized the survey to measure teachers' perceptions of STEM education (Nguyen et al., 2020). Besides, the questionnaire has one open-ended question (OQ) to explore which STEM competency teachers advocated as the most important.

Analytical Strategies

For classroom observation, we firstly transcribed the whole class. While transcribing, we segmented these episodes into sequences. Each sequence included a chain of discourse exchanges that teachers build to complete a task or a discussion topic (Jin et al., 2016). The segmentations resulted in 187 exchanges which are the smallest unit for analyzing conversational interactions among people (Jin et al., 2016). Qualitative analysis was employed to analyze teachers' discourse practices in classes.

Similarly, all teachers' interviews were first transcribed and then qualitatively analyzed. We utilized NVivo for qualitative analysis.

Coding Scheme Developments

We used the codes to examine how teachers' enactments in classrooms and teachers' perceptions of STEM education. Coding were developed through the constant comparisons method for qualitative analysis (Glaser & Strauss, 1967) by NVivo. We randomly selected exchanges to establish preliminary coding, which were from reviewing literature related. More codes were found for different categories to establish the final codes (Krystyniak & Heikkinen, 2007).

Table 3 illustrated the final coding for discourse practices. Each conversation exchange was located in the three codes regarding students' opportunities to talk (Jin et al., 2016), including teachers' talks (T), T-S interactions, and S-S interactions. I clarified the interaction patterns into three types depending on how students use verbal responses to teachers. Teachers asked close-ended questions (CQ) or OQ, students then provided responses (R), and teachers might or might not evaluate (Jin et al., 2016). In addition, another pattern, namely assigning (A), appeared during preliminary coding. "Assigning task" was coded when teachers assigned students to do learning tasks. Teachers used imperatives rather than questions. Teachers preferred students in assigning rather than solicit students' verbal responses. For example, students were asked to read or repeat steps to design products. Another example is that teachers required students to work in groups to match the electric component with the correct name based on the document information. The first two authors agreed

Table 3. The coding scheme of discourse practice

Codes		Describe
Teachers' talks	T	No verbal response was from students, and teachers did not solicit students' verbal responses as well.
Teacher-student interactions	T-S	Teachers solicited students' verbal responses through questioning/asking. Notably, no student-student interactions in this category. The conversation exchanges between teacher and students could be TS, TST, TSTT, & TSTS.
Student-student interactions	S-S	The conversations were mainly student interactions (SS). Still, there could have minor involvement from teachers, for example, TSS, TSSS, and TSTSS.
Assigning	A	Teachers assigned students to do tasks, for example, repeat or read the steps from documents, do experiments for learning activities.
Close-ended questions	CQ	Closed-ended questions began conversation exchanges. Then students responded.
Opened-ended questions	OQ	Closed-ended questions began conversation exchanges. Then students responded.

on transcribed segments in the segments and then independently coded. The agreement percentage between the two authors was 84%. The rest of the disagreement coding was discussed to explicit the coding list.

Table 4 illustrated the final coding for teachers' perceptions of STEM implementations, including reflections on the BEATS STEM-6E implementation, perceptions of STEM education, STEM difficulties, and supports. Open coding was utilized for analyzing every unit of text in line-byline (Cohen et al., 2018).

Table 4. The coding scheme of teachers' perceptions

Theme	Category	Code
Reflections of 6E-STEM CCR class	Reflections on implementing	CCR Content
	Reflections on students work	Feelings Impressive moments
Comparations between lesson plan and implementation	Adjustment	Learning materials Teaching sequences
	Expectation level	As expected Better-than-expected Unexpected or lower-than-expected
New experiences for students	Hands-on experiments	Electric components Experiments Making productions Target skills
	Technology	Technology-based learning Technology platform Using smartphone
The next of 6E-BEATS-CCR	Teaching adjustment	Teaching sequences Teaching strategies
STEM teaching	STEM education values	Active learning Creativity Interest
	STEM lessons	Explore authentic problems Explore new knowledge Mathematics tool supports
	STEM teaching forms	Hands-on activity Learning at home Project Survey
STEM education supports	Collaboration	Mental supports School supports
	Teaching ability	Assessment Knowledge Lesson plan Skills Teaching materials Teaching strategies

Table 4 (Continued). The coding scheme of teachers' perceptions

Theme	Category	Code
STEM education supports	Collaboration	Mental supports School supports
	Teaching ability	Assessment Knowledge Lesson plan Skills Teaching materials Teaching strategies
STEM education difficulties	Difficulties	Arranging time Collaboration Target learner Teaching materials Technology integrated

RESULTS

There were mainly three parts under this title: teachers' discourse practices, teachers' perceptions of STEM education, and the connections between perceptions and practices in deploying the 6E-STEM curriculum after professional development.

Teacher's Discourse Practices in 6E-STEM Class

Teachers' discourse practices were divided into three main parts. The first part involves analyzing students' opportunities to speak in class, including interactions where communication is predominantly one-way. For example, this includes interactions where students primarily engage with each other to perform practical tasks or instances where teachers focus on evaluating or delivering knowledge without expecting reciprocal interaction. The second part focuses on analyzing exchanges that clearly demonstrate interactions between students and teachers. These exchanges will be examined according to their conversational patterns. Finally, a cross-matrix is constructed to capture the comprehensive correlation between students' opportunities to speak and interaction patterns. From this analysis, we identified emerging trends in discourse practices in 6E-STEM classes.

Students' opportunities to talk

Teachers used all three types of conversation: T, T-S, and S-S in the 6E-STEM classroom. However, S-S conversations accounted for the lowest percentage of all four classes, about 20% only. S-S occurred when students groups discussed to answer teachers' questions or perform practical tasks. T and T-S are more common in the classroom. While class 1 and class 2 mainly use the interaction between T-S, class 1 and class 4 stand out for teachers' talks in the class (**Figure 3**).

Some teachers' talks aim to collect student learning results or deliver knowledge rather than interact with students in class, as two examples below. The first example was teachers' talks about delivering

Figure 3. Students' opportunities to talk (Source: Authors' own elaboration, using NVIVO)

engineering knowledge to students. Teachers only give presentations and expect students to listen and absorb. The second example occurs when the teacher asks the students to answer the questions in the CCR. The teacher will tell students what to do and ensure the number and speed of completing questions on CCR.

Example 1:

> T: Here … I introduce to you ... this is a tool for us to solder ... I will introduce you to ... this is a soldering tin. Let open a soldering tool cover with me to be able to solder. There is a wire ... you can connect this soldering tin so you can plugin power. Next ... You see the plugin for power. Then we give electricity to the torch. OK? ... Next, I introduce to you this is tin so that you can solder to connect the components. And next, this is the tripod. When soldering, be sure to open this head [*the cover*].

Example 2:

> T: Please log in to CCR, using CCR ... [*to*] complete part 1E ... question 1. Please complete question 1 only...you should follow your own opinion ... 23 students have completed it already. Do not answer question number 2, only question 1. I got

26 responses ... 29 already ... 2 more people left. 30 ... I received 31 responses.

Patterns of conversation exchanges

Teachers used CQ and OQ which could facilitate students to express ideas. CQ required students to recall knowledge from a textbook, supplied documents such as 'yes-no questions or definition questions (Jin et al., 2016). In contrast, OQ allow students to respond actively. Teachers could probe deeply into students' responses (R) to elicit students' thinking. Teachers might or might not evaluate (E) students' responses. An example for the OQ exchange below.

T: Why the white screen [*of smartphone*] becomes a colorful grid through tiny water droplets? Please (OQ).

S1: Broken. The old version of the smartphone could not be adapt to too many colors and become lag (R).

T: Oh. Broken? Next.

S2: I think …the colorful grid because the water droplet on the screen split the smartphone's light (R).

T: Oh. With screen was split. Thanks. Next.

S3: When going through the water droplet, the light become curve at the different color points (R).

T: Thanks ... the water droplet works as the convex lens. When going through [*the convex len*], the screen light refracts many times to different colors (E).

Teachers asked OQ to students and received all students' responses. Teachers summarized and evaluated students' responses by giving scientific phenomena with the convex lens. However, teachers did not elicit or scaffold students' ideas with probing questions. Meanwhile, probing questions were advocated as the highest level of student engagement in classroom interactions (Jin et al., 2016). In total, there were no worth probing questions found in four classes.

Besides, teachers' discourse aimed to assign students to learning activities such as repetition, notices, asking for doing the experiments. An example exchange of "assigning tasks" was below. Teachers used imperatives clauses then students respond. In the conversation below, teachers asked students to read or repeat steps to do experiments in the document. Students responded individually to teachers' imperatives.

T: We will experiment for deeply understanding. One student read the instruction, please (A).

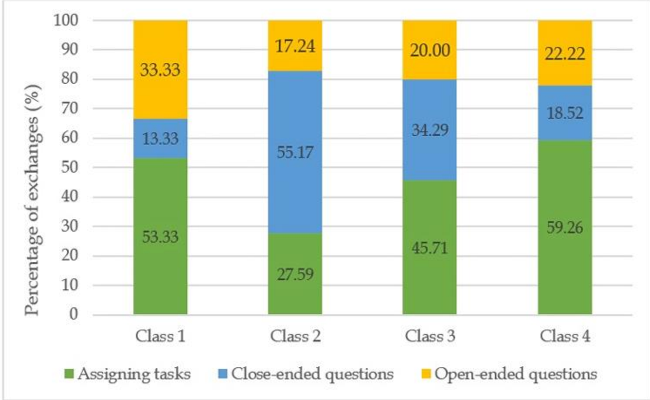

Figure 4. Interaction pattern (Source: Authors' own elaboration, using NVIVO)

S1: (read) Experiment ... each student drops one water droplet on the screen. Observe the phenomenon (R).

T: Thank you. Another repeat, please.

S2: (read) Each student drops one water droplet on the screen. Observe the fine structure of the LED screen through the water droplet. Complete the 2E questions (R).

Teachers frequently used the "assigning tasks" pattern interaction in the class, specific in about 46% of exchanges. CQ and OQ were less frequently used, approximately 30% and 24% of exchanges. Still, there were differences in interaction patterns among the four classes. **Figure 4** illustrated the ratio of three interaction patterns in each class.

"Assigning tasks" were the most frequent interaction pattern in almost all classes, except class 2. Teachers frequently used the "assigning tasks" pattern in hands-on activities, which teachers need to clarify and assure students' steps in doing experiments and design the mix-colored LED chips. There were essential steps or notices that teachers would like to remind students when assigning students to learning tasks. The 6E-STEM curriculum was designed on the engineering-based, so there were many hands-on activities. That could be the reason why "assigning tasks" became the main interaction pattern in classroom implementation.

An example below was the exchange when David assign students to solder resistors in the learning product. David presented the video to the whole class and have the whole-class talk as below. David assigned students to solder three resistors on the LED chip's printed circuit board (PCB). While students were watching the video, David frequently noticed students facilitate for the well-soldering process.

David: Now … watch the video (with the projector for the whole class). You will attach the resistor on PCB … Come on … look at the display… the way to do it is as follows ... (A).

David: You can only watch it once. If you do not pay attention, you cannot do it. Welding the resistor is as follows (Students watched a video on how to solder a resistor). Then ... Notice, please. Here are the positions of the resistors [*on PCB*]. So now, the first step for you is to posit resistors... as the same with this [point out to the display]. [Firstly] We fold the two legs of the resistor back ... remember to put it in the correct positions of 68 Ω, 120 Ω, and 100 Ω [*on the PCB*] … OK ... we look at the PCB [*that attached*] 100 Ω … [*See*] … 100 Ω … do you see? ... that ... 68 Ω need to be located at the right 68 Ω position. 120 Ω needs to be found at the right 120Ω position. Have you seen [*clearly*]?

David: After soldered three resistors. You will overturn [*PCB*]. And now is the part [*there were still other steps for soldering resistors*] for soldering resistors … watch [*video*] the welding operation again, please. So we could finish part of the resistance soldering.

CQ were the most popular in class 2. The main reason could be Hana used a different strategy in class 2. She used extra handouts for students, not CCR only. Then, she encouraged students to answer the close-questions, which implicit the answers in the documents. In other words, the handout was similar to students' textbooks. Meanwhile, other classes need to notice much information to students, Hana tried to transform it into a close-question, as the example exchange below.

Hana: Please tell me, what is the operating temperature of the soldering iron? [*the related information in handout*] (CQ).

S1: The temperature of the soldering iron will be equal to or greater than the melting point of tin (R).

Hana: OK. Thank you.

Hana: Question number 2 … Please … How long does it take to keep soldering an electric component? (CQ).

S2: 5 seconds (R).

Hana: thank you, only soldering in 5 seconds. If too long, the component will be easily broken (E).

OQ were advocates at the higher level in engaging students (Jin et al., 2016). However, the percentage of "OQ" was the lowest in almost all classes. Besides, teachers did not use the following questions to elicit students. Generally, the exchange in the "OQ" pattern was simply ended by teachers' evaluation of students' responses. The conversation below was one example in Qiana's class.

Qiana: In your opinion, what is the scientific principle behind electric welding? In physics, you have learned already (OQ).

S: Thermology (R).

Qiana: Well, the principle of thermology ... Be more specific ... Ever seen electric welding in real life?

Qiana: ... Its principle will be based on the melting and solidification of the tin wire (E).

The teacher raised OQ to the whole class to ask about the scientific principle in the electric soldering process. After the students' response, she did not raise any following questions. For example, teachers could specifically ask about the changing state of the tin wire, and the student then might describe that there were the melting and solidification of the tin wire.

Summarily, all teachers' discourse practices were in three interaction patterns:

(1) assigning task,

(2) CQ, and

(3) OQ.

While "assigning task" pattern was the most frequent interaction pattern, "OQ" pattern was the least used in the class. There was a similarity between class 1 and 4, which is mainly using the "assigning task" pattern, specific more than a half of each class's exchanges. Class 2 emerged in using CQ with innovative teaching strategies. Only class 1 had the percentage of "OQ" higher than the mean of all classes. However, all teachers used OQ without following questions to probe students' thinking.

The trends of teacher discourse practice

These findings aimed to show the corresponding interaction patterns and students' opportunities to talk. For example, the last results showed about 46% of exchanges seeking to assign tasks for students. The current finding part pointed out which teachers could appear in the class to give students learning tasks. Firstly, I investigated the trends of teacher discourse practices in all classes (**Figure 5**). Then, the analysis in each class was shown to find the similarities and differences among teachers (**Figure 6**).

As the findings aforementioned, the "assigning task" pattern was the most popular interaction pattern, nearly a half of exchanges. The "assigning task" pattern mainly appeared in teachers' talks in the class. Still, the rest of the "assigning tasks" pattern, being about 13% of exchanges, could be in T-S interactions.

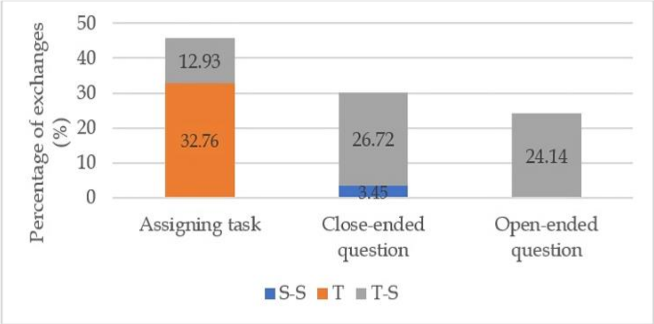

Figure 5. The corresponding interaction patterns and students' opportunities to talk in all classes (Source: Authors' own elaboration, using NVIVO)

CQ were mainly in T-S interactions. There were 3.45% of exchanges being CQ but required S-S interactions. Teachers raised the close-questions and required students to discuss in the group to address the questions. In contrast, OQ were in T-S interactions only.

Three trends could emerge in the teachers' discourse practices in 6E-STEM implementation:

(1) assigning tasks was the most popular interaction pattern but mainly authoritative from teachers without any questions,

(2) T-S interactions were powerful which facilitate teachers to assign students in learning tasks and solicit students' expression through questions, and

(3) S-S interactions were seldom organized in all three interaction patterns.

S-S interactions in four classes were mostly hands-on activities that required students to do experiments or engineering acts.

Figure 6 illustrated how each teacher used discourse in the class. There was a similarity between class 1 and class 4; and class 2 and class 3. Teachers in class 1 and class 4 are David and Qiana, who teaches in the same school. They mentioned they worked and discussed together for the lesson plan, so most teaching sequences and teaching strategies were similar. That was reasonable why David and Qiana had similar discourse practices in the classes. Hana implemented twice in class 2 and class 3. Hana seems to be kept their teaching style in both class 2 and class 3. However, there were still minor differences between class 1 and class 4; and class 2 and class 3.

The most apparent difference between David, Qiana, and Hana was the percentage of exchanges in the teacher's talk. While David and Qiana were more authoritative, Hana was more interactive with the students. Notable, only Hana's classes had the "assigning task" interaction pattern locating in T-S interactions. Hana asked students to repeat or read tasks instead of teachers' talks. In addition, Hana frequently used closed-ended questions in the class to engage students in learning activities. In the first E phases, Hana often raised questions related to scientific knowledge

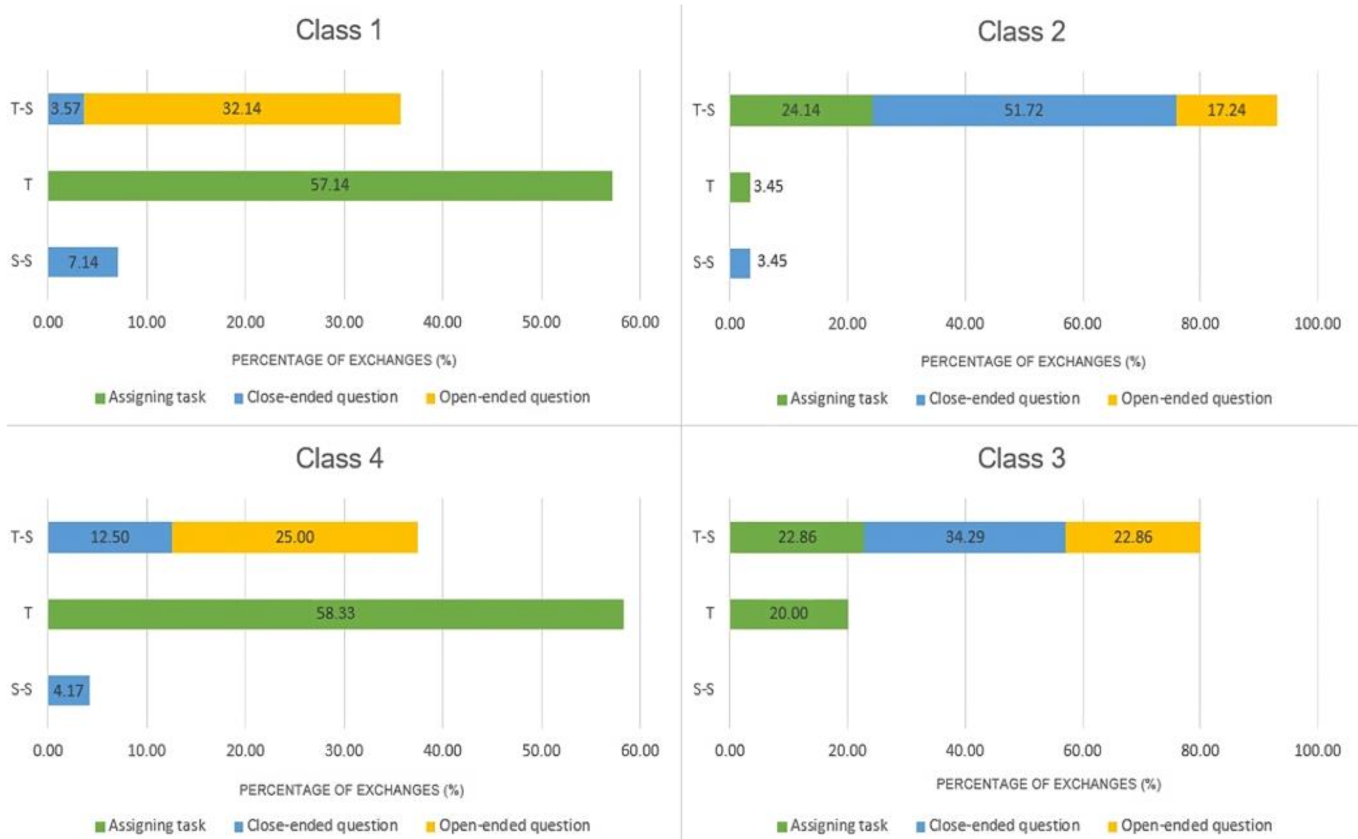

Figure 6. The corresponding interaction patterns and students' opportunities to talk in each class (Source: Authors' own elaboration, using NVIVO)

Table 5. Reflections on STEM post-teaching

Theme	Category	Code	N
Reflections of 6E-STEM CCR class	Reflections on instructions	CCR	3
		Content	1
	Reflections on students work	Feelings	3
		Impressive moments	2
Comparations between lesson plan and implementation	Adjustment	Learning materials	4
		Teaching sequences	5
	Expectation level	As expected	10
		Better-than-expected	4
		Unexpected or lower-than-expected	3
New experiences for students	Hands-on experiments	Electric components	1
		Experiments	2
		Making productions	3
		Target skills	3
	Technology	Technology-based learning	1
		Technology platform	1
		Using smartphone	1
The next of 6E-BEATS-CCR	Teaching adjustment	Teaching sequences	5
		Teaching strategies	1

related to the LED curriculum to reinforce students' knowledge. For example, melting and solidification, conversion of energy. Hana supplied new scientific knowledge in teachers' evaluation on students' response, such as "… this knowledge you will learn in grade 9 *[next year]*, … the convex lens". Therefore, the percentages of teachers' talks in Hana's s classes were the lowest.

Although David and Qiana were more authoritative than Hana, there was a difference in their teachers' discourse practices in David's and Qiana's classes. When assigning students to learn tasks, David regularly delivered additional engineering knowledge, such as using the engineering tools. Qiana only gives tasks, but she wants students to be proactive in understanding their tasks. David started the task by showing the students a video and presenting the video with notes or tips to make sure the students do not miss any notes. Meanwhile, Qiana did not show the video tutorial in front of the whole class. She just showed the slide and assigns tasks and wants students to clarify their tasks with her videos on CCR.

Each teacher had specific discourse practices while implementing the same 6E-STEM curriculum. David and Qiana were more *authoritative* in the classes. In contrast, Hana implemented the 6E-STEM curriculum more *interactively* with students. Still, interaction patterns in Hana's classes have not achieved higher levels of student engagement by questions, such as OQ and probing questions (Jin et al., 2016). Along with specific content of discourse in classes, there were differences among students related to what teachers desired. David desired his students to correct steps associated with designing mix-colored LED chips by *delivering engineering knowledge and noticing susceptible misunderstandings*. Qiana wanted her students to *develop creativity*. Hana desired for her students to *realize scientific explanations* related to designing artifacts.

Reflection on STEM teaching

When teachers reflected on the 6E-STEM CCR class, three teachers expressed interest in the curriculum topic. David loved the most the moment when students soldered successfully. Qiana was so excited when students were surprised on testing of students' LED chip. Hana said: "The topic is very interesting and exciting." Generally, teachers were positive feelings on the 6E-STEM implementation. Still, teachers had some concerns or considerations. **Table 5** illustrated the number of codes located in each code of teachers' responses.

Although Hana was excited about the 6E-STEM topic and much impressed with class 3, she felt CCR was not easily used and controlled. The internet in Hana's school is unstable then teachers felt perplexed to ensure having stable internets for all students. Hana spent around 20 minutes addressing this issue. In contrast, the internet quality in school A was quite strong. Therefore, it might be smoother for the operating classes of David and Qiana. Internet quality was commonly issued in online technology-based classes.

Teachers mainly shared the feelings as expectation (N = 10) or better-than-expected (N = 4) in teaching phases. Still, there were unexpected or low-than-expected (N = 3) issues. Hana complained that the class numbers were big, and it was too difficult to manage the class. Besides, a few students used smartphones and the internet for other things rather than learning activities. Qiana shared about a few unexpected situations when students could not operate the LED chips. The reason was students did not solder carefully and strongly. When getting on the 6E-STEM curriculum, she thought all students could do well on the learning product. However, it was not the same as her imagination and expectation. One of the reasons could be there was not equal students' ability on the soldering skill. However, Qiana implemented the LED curriculum for the first time. Qiana did not know whether students have soldered tin already or not. STEM lessons were implemented in the fragment topics. When there has not had a STEM national curriculum, students' background to learn the STEM topic should be considered.

After training to get familiar with the LED curriculum, teachers could adjust other detailed learning activities. Three teachers had new adjustments when teaching the LED curriculum, specifically on learning materials (N = 4) and teaching sequences (N = 5). David and Qiana created the student worksheet to ask students to find the corresponding electronic components.

They explained that the worksheet could help students avoid confusion because it was the first time students worked with these electronic components. Hana created the handout to supply some scientific knowledge related to notifications and processes for soldering. She gave students the handouts and asked some CQ to ensure that students got the critical information. For the teaching sequences, teachers were different from when formative assessment, how to use the guide videos in the class.

Teachers mentioned the most frequently students' new experiences related to hands-on activities (N = 9). All teachers agreed that the solder skill and the LED chip were too new for students. Students had never soldered or touched on the LED chips before class. Besides, students had the opportunity to do a new experiment, which was the tiny water droplets on the screen. In addition, it seems to be the first time students could touch on the real electric components. In an interview, David quoted from one student's talk, "… Oh. That's LED …" when the student group touched electric components.

Along with hands-on activities, teachers advocated technology as a new experience for students. Hana emphasized that this was the first time she and her student used smartphones and the internet in the class. Meanwhile, Qiana mentioned CCR was new in terms of the platform only. She assessed CCR as the same as other platforms used in her classes. Qiana affirmed that her students were used to learning technology-based in class. In the end, teachers expressed ideas for the betterment of the LED 6E-STEM class. Most of the ideas were about teaching sequences. Teachers would like to change the teaching sequences but mainly on the ongoing activities. Only Hana thought she needs one more experiment, which more impressive to students. Then students could more focus on the 6E-STEM lesson.

Teachers' Perceptions of STEM Education

From questionnaires

Regarding STEM competencies, teachers advocated collaboration skills and engineering abilities as the most important. Classroom observations showed that teachers spent more time on the group activities on designing the mixed-color LED chips. Especially, teachers used many strategies on organizing the teamwork to leverage collaboration skills. For example, involve all students' participations, Hana divided a task into smaller parts and assigned them for all students: "… three resistors will have six *[resistor]* legs, each student will solder for one *[resistor]* leg …". Besides, David and Hana expressed authentic problem-solving competency as the most important competency students could acquire in STEM learning. Teachers attended to engage students in authentic problems in STEM lessons. These findings, as some indicators, showed the strong relationships between teachers' perceptions and practices in STEM education.

While teachers in this current study had almost the same perceptions of STEM competencies as Vietnamese teacher's perceptions in the previous study (Nguyen et al., 2020), the perceptions of STEM difficulties were quite different. In the previous study, Nguyen et al. (2020) found that teachers felt:

(1) more difficulty in enhancing knowledge beyond majors related to STEM subfields and arranging extra time for students to learn STEM and

(2) less difficulty in STEM teaching ideas, formative assessment for students' achievement, and the cost of STEM teaching materials and pieces of equipment.

However, David, Hana, and Qiana had opposition perceptions with the previous study. They did not think it more difficult to enhance knowledge beyond majors related to STEM subfields and arrange extra time for students to learn STEM. They felt more difficulty in finding the STEM teaching topics, and formative assessments and considered for cost of teaching materials after BEATS 6E-STEM implementation. The reason behind this needs to be revealed by other evidence.

From interviews

Teachers' interviews were coded in three themes:

(1) STEM teaching,

(2) supports, and

(3) difficulties with corresponding categories and specific codes.

Table 6 showed the quantity of each code in three themes.

Table 6. Perceptions of STEM education

Theme	Category	Code	N
STEM teaching	STEM education values	Active learning	3
		Creativity	2
		Interest	1
	STEM lessons	Explore authentic problems	1
		Explore new knowledge	2
		Mathematics tool supports	1
	STEM teaching forms	Hands-on activity	1
		Learning at home	3
		Project	1
		Survey	1
STEM education supports	Collaboration	Mental supports	1
		School supports	1
	Teaching ability	Assessment	1
		Knowledge	1
		Lesson plan	2
		Skills	2
		Teaching materials	1
		Teaching strategies	2
STEM education difficulties	Difficulties	Arranging time	3
		Collaboration	2
		Target learner	1
		Teaching materials	2
		Technology integrated	1

STEM teaching

When sharing STEM teaching, the views that teachers mention are located in three main categories: STEM education values, STEM lessons, and STEM teaching forms. Teachers perceived STEM education as a way of teaching in which students learn proactively and are enhanced excited. Qiana and Hana desired their students to be developed in STEM learning rather than following the fix process. Qiana emphasized: "… if it [*STEM education*] cannot promote creativity for learners, we should not implement STEM education." Qiana explained why she changed the teaching sequences in the engineering phase. Qiana presented the steps to students with images instead of showing the videos. She desired for her students to use learning materials and find students' effective ways actively.

When talking about STEM lessons, David believed that teaching STEM enables students to acquire new knowledge. It might be why David delivered engineering knowledge to students in teachers' talks. However, David did not focus on training design-thinking for students. Meanwhile, design thinking and new systems thinking are high-level thinking, typical for STEM teaching (Duschl & Bismack, 2016). Along with developing new concepts, Qiana mentioned that STEM lessons need to create opportunities for students to explore practical contexts and need accompanying math tools. In the class implementation, David and Qiana initially planned to omit the resistor value calculation, but they organized the activity in implementation.

Teachers mentioned the importance of the combination of learning at home and in class. Teachers felt that it was hard to finish the STEM lesson in some classes in the class. Teachers should assign some tasks for students to work on at home. The students could come to the STEM class for further exploration and explanations. Hana affirmed that learning at home was essential in STEM teaching. Qiana thought of engineering skills, such as soldering skills, which students could practice by themselves. However, David was concerned about how junior high school students could practice engineering skills at home. Practice and developing skills is a fundamental features of STEM education, including practical skills. However, deciding which parts of the lesson should be done at home and which should still be done in class should be considered.

STEM education supports and difficulties

Teachers recognized that school supports were necessary to successfully implement STEM education, including emotional support, cooperation from other teachers, and resources within the school. David and Qiana expressed satisfaction that the school supported the 6E-STEM implementation. However, Hana felt very tired when she had to prepare many teaching materials by herself. Building a STEM ecosystem with support resources from schools is always a prerequisite for the success of STEM education implementation.

In addition, teachers mentioned the need for specific support for teaching materials. David shared teaching materials in 6E-STEM that are almost new to both students and teachers. Hana felt the equipment in this

6E-STEM lesson was quite expensive and worried about implementing the BEATS 6E-STEM curriculum. According to the results above, teachers thought that teaching materials were a considerable difficulty when implementing STEM teaching. However, STEM education can also be successfully implemented with recycled and very cheap equipment. Teachers might need more curriculums or professional development to reduce the anxiety about teaching materials in STEM teaching.

All three teachers expressed satisfaction when being trained and provided with lesson plans and accompanying teaching materials. STEM teaching could be going smoothly. Teachers believed that lesson plans should be provided or at least teaching topics for teachers to implement successfully. However, one in three teachers further emphasized that they need quality lesson plans. In addition, Hana also mentioned that teachers need more knowledge, skills, assessment methods, and teaching strategies.

Teachers considered the time for STEM teaching as one of the concerns, including finding the appropriate time and effectively teaching time. Hana shared that she has to spend a Physics class to implement STEM. Meanwhile, there was only one Physics class per week which is a little time. She worried about how to implement STEM successfully in a short time. David is concerned about how to balance between time and STEM competencies that students could achieve. He said that students could develop creations if the teaching time was processed, such as one month. Vietnam still has not had a national STEM curriculum yet (Lin et al., 2019; Nguyen et al., 2019). STEM lessons have been implemented in STEM-sub-subjects classes. They were finding the appropriate time or how to have a plan for STEM deployment has been considerable.

DISCUSSION

This current study evaluated teachers' instructional moves and reflections on the post-teaching to generalize teachers' epistemological framing in 6E-STEM implementation. They were *delivering an artifact* as the BEATS 6E-STEM teaching framework. During implementation, a key highlight was the role of conversation partners in assigning students tasks, particularly those related to the creation of artifacts. STEM thinking is fostered when students actively identify and solve problems rather than passively receiving tasks from teachers. High-quality STEM education is achieved when integrated engineering design enhances students' design thinking through iterative processes of designing, evaluating, and redesigning (Moore et al., as cited in Moore & Smith, 2014). However, we did not claim that teachers need to change their epistemological framing or assess these epistemological framings as low. Teachers can flexibly choose their epistemological framing when teaching depending on teachers' intentions (Wendell et al., 2019).

Although teachers are all delivering an artifact, teachers still have different desires for their students. David wanted his students to be able to acquire engineering knowledge. Hana desired her students for curiosity in scientific knowledge and reasoning. Qiana wants her students to be more creative. These frames are shown obviously through the teachers' practices in class. During instructing students to perform manufacturing tasks, David stopped at videos related to engineer knowledge and notices for students. Right from the beginning of the lesson, Hana often asks students why. When crafting, Hana also desires students to answer questions, even why tin is soldering material. Qiana changes teaching sequences to create opportunities for students to be creative.

In the classroom, teachers frequently use teachers' talks or T-S interactions. Meanwhile, S-S interactions were less common in terms of frequency. However, the duration of S-S exchanges was not shorter than that of teachers' talks interactions. Students often raised problems, engaged in group discussions, and demonstrated indicators of STEM competence. Nonetheless, this study did not focus on dialogues between or among students. Further research is needed to analyze whether students interact with each other to build and develop STEM competencies, as group work is considered a key feature of effective STEM education.

Teachers' talks generally delivered knowledge to students. While teaching STEM, some activities required students to use interdisciplinary knowledge. In these cases, what should the teacher do? Teachers should notify or transform to students. Or teachers should stop to organize another activity so that students have the opportunity to occupy relevant knowledge. This is the problem of equipping ground knowledge that the EDP mentioned. In contrast, to assign tasks, OQ were less common in the classroom. OQ enable students to express many ideas. Also, OQ allow teachers to ask probing questions and achieve the highest level of student engagement (Jin et al., 2016). However, one of the reasons is also because the training program provided for teachers is quite detailed. Some teachers also shared (Hana) that although they wanted to change more, the activities in the STEM curriculum were quite detailed.

When comparing lesson plans and actual teaching, teachers are mostly satisfied with the E phases. When students experience the lessons according to the 6E process, they can grasp the key points of steps by steps (Chung et al., 2018). Accordingly, teachers seem to switch phases in instructional moves easily. Once again, the teachers' epistemology framing confirms the effectiveness of 6E in maximizing E in STEM lessons (Burke, 2014). However, the issue of teaching time was also mentioned by the teacher. Dividing 6E phases into teaching time needs to be considered, especially when Vietnam does not have a separate time for STEM teaching.

Teachers have shown reasonable understandings of STEM education after coaching and implementing STEM teaching. STEM education is perceived as a teaching method to enable learners to solve practical problems through engineering design, acquiring knowledge, and promoting creativity. However, teachers had an individual interpretation of such perceptions, and teachers had different teaching practices. David focused on imparting engineering knowledge and skills. Hana focused on scientific knowledge and reasoning, but she imparted authoritatively to her students. Qian advocated Mathematics as a tool in STEM education. Although there are positive views on STEM education, teachers seem to have not reached the level of constructing knowledge in STEM education, specifically in engineering design (Wendell et al., 2019).

CONCLUSION

Teachers' Framings in 6E-STEM Class

This current study found that *delivering an artifact* has emerged as a pivotal strategy reflecting the teachers' approach to framing their instructional methodologies. Framing in STEM teaching refers to how teachers structure, present, and contextualize the content and learning activities. Teaching frames shape the students' understanding and engagement in STEM education. However, the teachers' framing emphasizes different aspects such as engineering knowledge, scientific explanations, or creativity when teachers uniformly deliver an artifact in STEM teaching sequences. Focusing on engineering knowledge leads students to Develop technical skills and knowledge to use in future educational or career pursuits in engineering fields. Focusing on scientific explanations with an emphasis on delivering an artifact, teachers encourage students' inquiry-based learning and connections between knowledge and real-world problem-solving. Focusing on creativity, teachers give students the freedom to explore their interests and apply their knowledge creatively. Teachers aim to nurture innovative thinkers who can contribute to advancements in STEM fields.

Teacher discourse practices exhibit three main trends: the most prevalent interaction pattern involves assigning tasks, typically characterized by an authoritative approach without eliciting student questions; T-S interactions are significant, allowing teachers to assign learning tasks and encourage student expression through questioning; however, S-S interactions are rarely organized, often limited to hands-on activities such as experiments or engineering tasks.

The Connection Between Perceptions and Practices in Deploying the 6E-STEM Curriculum

Regarding STEM competencies, teachers emphasized collaboration skills and engineering abilities as paramount. Classroom observations revealed that teachers dedicated significant time to group activities, particularly in designing mixed-color LED chips. To enhance collaboration skills, teachers employed various strategies for organizing teamwork. For instance, Hana ensured inclusive participation by breaking tasks into smaller parts and assigning them to all students: "...three resistors will have six legs, and each student will solder one leg." Additionally, both David and Hana identified authentic problem-solving as a crucial competency for students to develop in STEM learning. They actively engaged students in real-world problems during STEM lessons. These findings suggest a strong alignment between teachers' perceptions and their practices in STEM education, highlighting the importance they place on fostering collaboration and problem-solving skills.

The Technology-Based 6E-STEM Teaching

The effectiveness of STEM education is demonstrated through students' performance throughout the learning process. However, the collection of performance indicators should not interfere with students' learning or teachers' instruction. In this study, the CCR tool proved effective in recording students' performance during the learning process. However, the integration of CCR in teaching was hampered by internet issues in the school. Additionally, assessment tools need to support teachers in managing students to ensure that all results are obtained, and students are properly identified in both virtual and physical classrooms. In the context of tech-based STEM education in Vietnam, issues related to facilities for high-quality of technology should also be considered.

Strategies for Teachers' Professional Development

Adapting coaching and examining teaching and learning strategies enable teachers to have the opportunity to have professional development from theory to practice. Teachers implemented a 6E-STEM lesson after being trained about the learning content and instructional model, practiced the learning product, and analyzed the lesson plan. During the preparation process, teachers were introduced to innovative adjustments for the class implementation. As a result, teachers had better understand the 6E lesson plan and practice using information technology in the classroom as pedagogical knowledge. By understanding teachers' framing in STEM teaching different framing approaches, educators can better tailor their teaching strategies to meet the diverse needs and interests of their students.

Examining learning and teaching was advocated as the effective strategy for professional teacher learning in knowledge, implementation, and perception. However, such a strategy demands support from the STEM ecosystem, such as colleges, schools, coaches, or mentors. In addition, local context plays an essential role in teaching, especially for innovative teaching–STEM education. For example, the quality of technology facilities strongly impacts the teaching schedule in class. Professional developers could adapt examining STEM learning and teaching strategy in a local context.

Teachers recognized the difficulties in implementing effective STEM education. First, building an ecosystem in schools is a prerequisite for effective STEM education. Secondly, teachers recognize the difficulties in teaching materials in STEM teaching. In fact, STEM education can use recycled materials as teaching materials. Teachers need more STEM curriculum in which teaching materials are not a concern. The BEATS program with products might be quite complicated and detailed, causing teachers to be concerned about learning materials. Finally, the teacher expressed that the lesson programs will help teachers implement STEM education more effectively. However, professional developers also need to focus on helping teachers evaluate lesson plans and build better lesson plans than providing detailed lesson plans for teachers.

Implications

Nevertheless, this current research also has some limitations. The sample chosen was random, including both teachers and students, in a regular class setting. Hence, a more extensive study with larger sample sizes and stricter criteria to minimize differences among samples is needed for more conclusive results. The teaching material covered only topics related to LED mixed light, representing just one aspect of STEM lesson plans. Consequently, understanding how different topics affect teachers' perceptions and practices in STEM education is a potential area for future research. Besides, this current study indicates a relationship between teachers' perceptions and practices in STEM education. However, further studies are needed to verify or confirm this relationship.

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