Received 26 April 2023
Revised 14 July 2023
Accepted 18 July 2023

A case study of teacher learning in enacting maker pedagogy through lesson study

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Abstract
Purpose – This study explores how lesson study (LS) can promote elementary Science, Technology, Engineering, and Mathematics (STEM) teachers' professional development (TPD) in terms of new pedagogical practices, attitudes and beliefs in the maker education (ME) context.
Design/methodology/approach – This is a case study of a LS conducted in China involving four primary school teachers, 20 grade-4 students, and one researcher who also acted as a facilitator. This study adopted an integrated model that combined the unique characteristics of Chinese LS (CLS) with the Dutch LS (LSNL) model.
Findings – This study revealed that LS participation facilitates teachers' integration of new ME pedagogical practices in their classrooms, while their attitudes and beliefs regarding teaching and learning are increasingly aligned with ME principles. However, challenges such as time constraints, lack of research skills, and insufficient learning resources have also been identified.
Research limitations/implications – This was a small-scale study, which may limit the generalizability of the findings.
Practical implications – This study expands the use of LS in the ME context by highlighting its effectiveness in enhancing teachers' PD in terms of new pedagogical practices, attitudes, and beliefs. It also recommends incorporating diverse international LS models to address the limitations associated with localized models of TPD.
Originality/value – The originality of this study lies in its adoption of an integrated LS model to enhance STEM teachers' PD in an ME context. The findings of this study further strengthen evidence supporting the positive impact of LS on teachers' PD.

Keywords Maker education, Teacher professional development, Lesson study
Paper type Case study

Introduction
In this study, we investigated teacher professional development (PD) in terms of pedagogical practices and beliefs related to student learning within the domain of maker education (ME) by participating in lesson study (LS). Our research was conducted in the context of the national curriculum reform at the elementary school level in China, emphasizing the integration of

The authors would like to express their heartfelt gratitude to the participant teachers, Li Zhuang, Liu Ziang, Yin Xiaohui and Han Chengdong, from Livon Elementary School in Changchun, Jilin, China, for their valuable support in designing maker projects and assisting in data collection. Their dedication and cooperation were instrumental in the successful execution of this research.
Funding: This work was supported by the Chinese Government Scholarship No. 202008300032.

2046-8253
DOI 10.1108/IJLLS-04-2023-0042

constructivist approaches into pedagogical practices. ME is a hands-on project-based learning approach that emphasizes creativity, problem-solving, and practical skills by creating, designing, building, and tinkering. It promotes interdisciplinary learning, collaboration, and a growth mindset, often occurring in dedicated makerspaces or classrooms (Blikstein and Worsley, 2016).

In a case study, we explored teachers' PD in ME classrooms in a typical urban elementary school, who had participated in successive cycles of LS over a period of three months. We followed Ni Shuilleabhain and Seery's (2018) study, using King's (2014) comprehensive, evidence-based PD framework, defining teacher professional learning as the process by which teachers update their pedagogical practices, attitudes, or beliefs, resulting in a change in practice that enhances student learning outcomes. Because ME is a constructivist project-based learning approach, the High-Quality Project Based Learning (HQPBL) framework (Mergendoller, 2018) that takes developing and exercising the specific knowledge, skills, and behaviors as learning goals was adopted to analyze collected data and answer our research question of how teachers' pedagogical practices change during LS, the change in teachers' pedagogical practices. For the change in teachers' attitudes and beliefs, we specifically focused on the attitudes or beliefs valued by ME, such as process-oriented, failure-celebrated, and learner-centered (Martin, 2015; Doughtery, 2013; Regalla, 2016).

Maker education and design thinking

ME has garnered significant attention in educational research, owing to its emphasis on integrating knowledge, skills, and attitudes that foster students' readiness to engage with real-world problems and develop a confident self-view. ME is grounded in Papert's (1991) theory of constructionism, which underscores the importance of interactive, open-ended, student-centered, and multidisciplinary learning experiences. Through ME, students are encouraged to imagine, design, and create projects that involve hands-on applications, such as working with cardboard and duct tape, an old car, robots, LEDs, or even butter, sugar, flour, and heat. This approach embodies project-based learning and transforms the traditional teacher-centered educational paradigm. ME promotes students' active participation in making activities, allowing them to develop knowledge and skills in STEM fields and cultivate a maker mindset (MM). The concept of MM encompasses cognitive, affective, and behavioral aspects that foster an open and constructive stance towards solving complex problems (Doughtery, 2013; Martin, 2015; Regalla, 2016), making it a holistic approach to education.

Despite these advantages, there are concerns that ME may not be a sustainable element in the school environment (Blikstein and Worsley, 2016; Kim *et al.*, 2022). This may be a consequence of ME being product-oriented rather than process-oriented (Blikstein and Worsley, 2016), and may impede MM internalization, restrict maker culture expansion and hinder the repetitive and cyclic nature of making activities (Kim *et al.*, 2022). Furthermore, some drawbacks have been identified in students' learning, such as a lack of systematic steps in problem-solving methods, consideration of viewpoints on problem-solving targets, and detailed observation emphasis (Blikstein and Worsley, 2016; Kim and Zimmerman, 2017).

To overcome these drawbacks, several authors have suggested using Design Thinking (DT) in ME (Bethke Wendell and Rogers, 2013; Iversen *et al.*, 2015; Siverling *et al.*, 2019). DT refers to the project management process by which designers solve ill-defined problems, which can be performed in a set of stages: Empathize, Define, Ideate, Prototype, and Test (Plattner *et al.*, 2010). DT fosters students' competencies through a variety of activities, including problem identification, analysis, understanding situations, searching for possible solutions, generating several ideas, modeling, sketching, prototyping, and evaluation. Thus, DT can be seen as an approach that is complementary to project-based, problem-based, and inquiry-based learning approaches and is a suitable approach to capture the nature of the design and learning process taking place within the ME context (Alden and Tramonti, 2020; Kolodner *et al.*, 2003).

Empirical evidence has shown successful implementations of DT to ME across all age groups, such as extensive experience with the K-12 program provided by Stanford d.school in the USA (Chin *et al.*, 2019). However, applying DT in a targeted manner to ME in the curriculum is still at an early stage, as it has higher requirements for teachers in terms of pedagogical content knowledge and subject knowledge such as using digital tools for construction and models and supporting students to concentrate on the construction process as difficulties arise (An and Oliver, 2021). Therefore, training teachers in the DT process and the relevant toolbox before they design projects, learning materials, and resources for their students is essential. In this study we define DT-making pedagogy as a new pedagogical practice that applies DT to ME curriculum design. We propose LS as an approach to stimulate teachers to collaborate to investigate DT-making pedagogy from an inquiry perspective. LS is well known as an effective model for addressing the gap between theory and grounded practice in terms of curriculum standards, effective instruction and building teachers' capacities (Huang and Bao, 2006; Ni Shuilleabhain and Seery, 2018; Schipper *et al.*, 2020).

Lesson study and teacher professional development

LS is a collaborative approach to PD in which teachers engage in the process of developing a research theme, studying curriculum materials, planning, conducting, observing, and reflecting on research lessons to improve practice, and enhance student learning (Dudley, 2013; Lewis *et al.*, 2006).

Existing literature indicates that LS has been successful in enhancing teacher knowledge and advancing student-centered pedagogy across a range of international contexts (e.g. Ni Shuilleabhain and Seery's, 2018; Lewis *et al.*, 2012). Several modifications and practical adaptations of LS have been developed to suit the specific needs and cultural constraints of various contexts, resulting in distinct LS models, such as the UK model for curriculum innovation (Dudley, 2013), the Dutch model for inclusive education (LSNL model; de Vries *et al.*, 2016; Goei *et al.*, 2021), Learning Study for lesson planning and pedagogical design (Pang and Marton, 2003), and the Chinese-model for classroom experimentation and the implementation of new curriculum (Huang and Bao, 2006) Considering that this study was conducted in China, we built an integrated model by drawing the unique characteristics of Chinese Lesson Study (CLS) with the Dutch model. CLS is teaching content-focused and strategy-oriented, with aims to shape exemplary lessons (Huang and Bao, 2006), while the Dutch-model is "case pupils"-centered, specifically, lesson plans, observations and post-lesson discussions are organized around pre-selected case pupils with different abilities (Goei *et al.*, 2021). Despite its global popularity, there is little evidence for the use of LS as a PD model for curriculum reform in the field of ME, particularly in interdisciplinary project-based ME.

Thus, the overall aim of this case study was to explore how LS changes teachers' PD in terms of new pedagogical practices, attitudes, and beliefs in a project-based ME context. To this end, three research questions were addressed:

RQ1. How are teachers' pedagogical practices transformed in Maker project design?

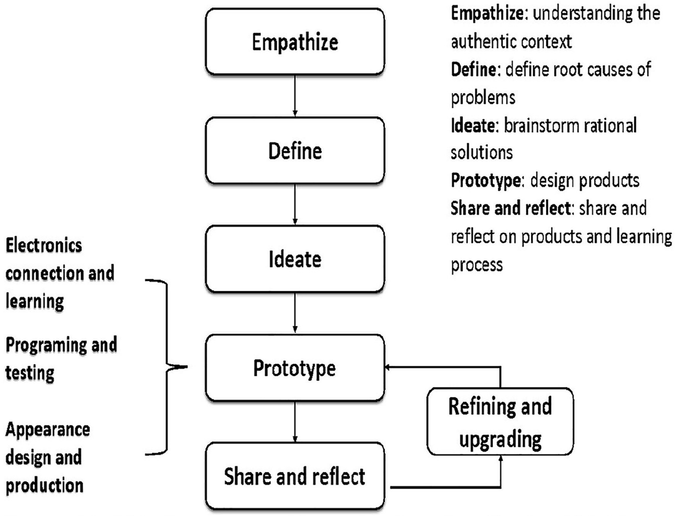
RQ2. How are teachers' attitudes and beliefs about teaching and learning affected by LS?

RQ3. What are the challenges encountered during LS implementation, and what kind of support do teachers require for future implementation?

Method

Research context

In this study, the participating teachers designed four research lessons that implemented the DT-making pedagogy. The research lessons centered on four different maker projects. All the participants followed the same pedagogical structure, as shown in Figure 1.



Source(s): This figure created by author based on Design Thinking process model developed by Stanford d. school

Figure 1. Pedagogical structure

This study was conducted in a Chinese elementary school from April to July 2022. The LS team consisted of four STEM teachers and the first author, who acted as LS facilitator. Twenty grade-4 students voluntary participated in the lessons. All teachers and parents of the students provided their consent.

Following the initial training in DT-making pedagogy, the participating teachers engaged in LS cycles (Figure 2), each comprising of the following:

(1) A pre-meeting was held in which the 20 students were divided into five groups. The selection of three case students representing from low, medium, and high academic performance levels was based on their prior academic performance relevant teachers' opinions. And the central problem was formulated for the maker project by integrating the curriculum standards.

(2) A planning meeting to create lesson plans, including learning tasks, maker toolkits, and instructional scaffolds such as prompts, handouts, and hints.

(3) A research lesson in which the lesson plan was conducted, and the case students were observed, using observation sheets.

(4) A post-lesson discussion was conducted to analyze and refine the research lessons based on case student observations and the interview results of other students, leading to a discussion meeting.

Data collection

To explore how LS impacts teachers' pedagogical practices, beliefs, and attitudes towards student learning, an array of data was collected. These data included transcripts from eight collaborative meetings, four individual pre- and post-interviews with the participating teachers, teacher notes spanning all phases of LS, teacher artifacts including written teaching plans, designed worksheets, samples of student work, and field notes taken during all meetings and research lessons. While the first author acted as a facilitator to guide the

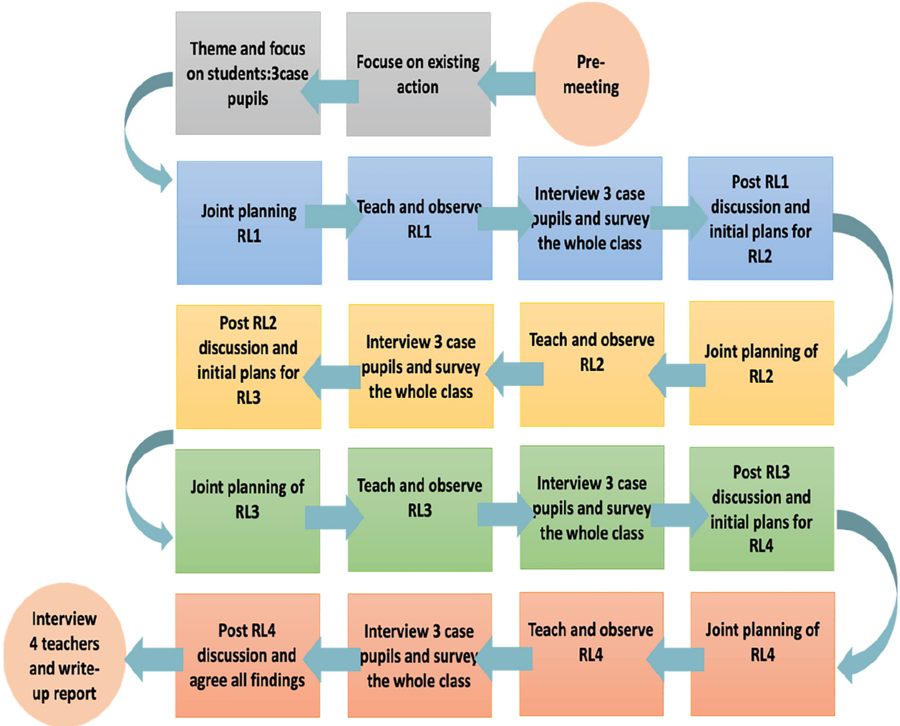


Figure 2.
The lesson study process as performed in the current study

Source(s): This figure created by author based on Chinese Lesson Study model (Huang and Bao, 2006) and Dutch Lesson Study model (de Vries *et al*., 2016)

teachers through the LS cycle, the participating teachers had autonomy over the topics taught in each research lesson, and scheduling meetings. On average, these meetings took place twice a week, with each meeting lasting approximately one-and-a-half hours.

Data analysis

Data analysis did not commence until all data were collected (King, 2014). To analyze the change in teachers' pedagogical practice, considering DT-making pedagogy as a constructivist project-based learning approach, transcriptions of individual teacher interviews and teacher meetings were coded according to the Buck Institute for Education's (Mergendoller, 2018) High-Quality Project-Based Learning (HQPBL) frame, which specifies six criteria for a high-quality project: *Intellectual Challenge* and *Accomplishment*, *Authenticity*, *Public Product*, *Collaboration*, *Project Management*, and *Reflection*.

To analyze the change in teachers' attitudes and beliefs towards teaching and learning, we compared the pre-and post-interview results, with a special focus on teachers' discussions of their past and current pedagogical practices, and formulated strategies for future improvement. Following Zeichner and Liston's (1990) recommendation to evaluate changes in teachers' beliefs against established professional standards, we evaluated the degree of consistency with the principles upheld by ME (e.g. process-oriented, failure-positive, and student-centered, Martin, 2015; Regalla, 2016).

We ensured validity by triangulating data from multiple sources and participants, such as teacher notes, research lesson plans, and student artifacts.

The baseline pictures of participant teachers

Our study began with a baseline of participating teachers' pedagogical practices, beliefs, and attitudes toward ME, as recommended by Bubb and Earley (2010). Teachers from the same department were required to regularly participate in school-based CLS activities. CLS's primary goal is to create exemplary lessons and analyze and improve teachers' teaching behaviors, rather than to improve student learning outcomes (Huang and Bao, 2006).

These teachers were actively involved in collective planning, studying, and evaluating various types of lessons in their daily work, but had no prior experience with formal or informal classroom observations. They volunteered to participate in our study due to the recent shift in the curriculum from "education for examination" to "education for key competences and basic skills" (Chen and Yang, 2013), their desire for PD, and personal interest in the study's subject matter.

The initial interviews conducted with the teachers revealed mixed attitudes towards our pedagogy. To provide a clearer picture of the LS group's composition, we have included information on their teaching experience and qualifications in Table 1. This information is essential for providing a contextual understanding of the participants and their attitudes towards LS.

Results and findings

This section outlines five essential aspects of how teachers improved their designed projects according to HQPBL (Mergendoller, 2018). Furthermore, four changes in teachers' beliefs and attitudes towards teaching and learning were presented. A brief introduction to the four projects is presented in Table 2 to support readers' understanding.

Change in pedagogical practice

Following HQPBL (Mergendoller, 2018), we present the changes in teachers' pedagogical practice in terms of *Intellectual Challenge and Accomplishment*, *Authenticity*, *Project Management*, *Public Product and Reflection*, and *Collaboration*.

Name	Teaching experience	Participating LS before (Yes/No)	Reasons for participating research	Attitudes towards designed pedagogy
LZA	6	Yes	PD, personal interest	Positive about designed pedagogy, but never conduct similar pedagogical practice
YXH	5	Yes	PD, curriculum reform	Hesitate about designed pedagogy, lack of confidence in practicing
LZ	7	Yes	PD, curriculum reform, personal interest	Enthusiastic about designed pedagogy, and attempt similar kinds of pedagogical practice
HCD	8	Yes	PD, curriculum reform	Suspicious about designed pedagogy, but heard about similar pedagogical practice

Source(s): This table created by author

Table 1. Baseline picture of participant teachers

Table 2.
Teaching objectives of RLs

RL1 smart elevator button Design the smart elevator button solving canteen staffs' problem of using elevator • Understand "variable" and applicate it to design product • Connect the button with four digital displays • Collect, classify, and summarize users' problems after interview • Brainstorm solutions based on material constrains • Build prototype within a group and record trial-and-error • Reflect based on assessment feedback	*RL2 smart bags* Design smart bags with function: 1. Correct students' hunchback; 2. Remind students of zipping bag by light sensor; 3. Explore another function • Label different sensors and explain its function • Brainstorm solutions based on material constrains • Wire and program the button with light sensor • Test protype and record the causes of errors • Reflect on the whole process of DT
RL3 Smart phone holder Design smart phone holder with functions: 1. The button is released after picking up the phone and the program starts timing; 2. The buzzer starts alarming after timing exceeds the specified time; 3. After the phone is put back, the button is pressed, the program timing ends, and the buzzer stops alarming • Review wiring, programming, and testing a button • Program button with buzzer, and controller • Brainstorm solutions based on materials and ability • Evaluate presented sketches and create sketches by taking size, aesthetics into consideration • Generalize the whole DT-process	*RL4 Smart parents communicator* Design smart parents communicator with functions: 1. Testing button and LED; 2. Using one LED representing information; 3. Using two LEDs representing multiple information; 4. Explore another function • Review wiring, programming, and testing a button to justify its importance • Define root causes of communication problems to justify analyzing them • Brainstorm solutions based on materials and ability to address communication problems • Record prototype problems, solve them within a group, and explain their causes • Create sketches considering size, aesthetics, and user-friendliness • Reflect on the value, meaning, and process of DT

Source(s): This table created by author

Intellectual challenge and accomplishment. This criterion refers to the content and level of challenges designed in a project, emphasizing the need for students to develop and apply knowledge, skills, and behaviors to solve problems beyond surface-level learning. A suitable level of challenge is necessary for academic content and success skills, as well as project structure (i.e. closed-, ill-, or open structure). However, excessively challenging projects can impede learning (Blumenfeld *et al.*, 1991). It was found that the teachers adjusted the project difficulty level by providing pre-training courses, reintegrating content knowledge of the projects, designing research-supported worksheets, and by expanding their role in the classroom.

First, they provided pre-training courses and integrated content knowledge aligned with the Information and Technology National Curriculum Standard (Ministry of Education, 2022). In the first RL, teachers were dissatisfied with students' learning outcomes after assessing their Test Log worksheets (Figure 3) and observing the results of their behaviors in engaging in projects.

They acknowledged that they did not conduct a comprehensive learning analysis to ensure that the students' skills and knowledge were necessary for project success. To address this, teachers discussed several strategies, including incorporating coding into PowerPoint presentations, reviewing curriculum standards to ensure alignment with students' current skill levels, and providing pre-training courses. As they discussed:

HCD: Maybe we can put the code on a PowerPoint presentation.

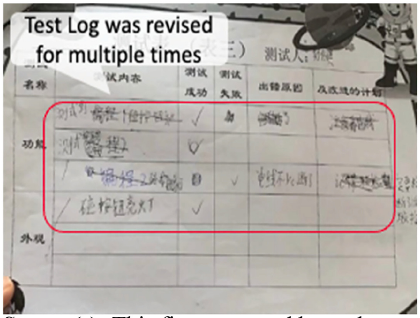


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Figure 3.
Students' test log worksheets results

LZ: I disagree, it is like copying!

HCD: But students can finish.

LZ: What about students learning? We need to bring back curriculum standards.

YXH: . . . back curriculum standards are necessary. They also lack skills and abilities.

. . .

YXH: I suggest that you give students a 3-h pre-training course.

Teachers reintegrated the content knowledge of math and technology according to the national curriculum during the 2nd RL pre-meeting. In addition, YXH provided pre-training to the students in terms of electronic components and connection skills, equipping them with the foundational skills necessary for successful project completion.

Second, the teachers strived to provide research-supported instructional worksheets. The structure of the designed worksheets was reorganized from an open form for the 1st RL to a semi-structured form for 4th RL with clear descriptions, criteria, and guidelines to scaffold students' learning processes. Figures 4–6 show an example of a designed worksheet that was changed across the four RLs.

Third, the teachers increasingly expanded their classroom roles to enhance student engagement. They actively sought strategies to provide guidance, instruction, and feedback to deepen their students' conceptual understanding and to foster self-directed learning. For instance, XYH proposed setting up a test center for supervised testing and feedback

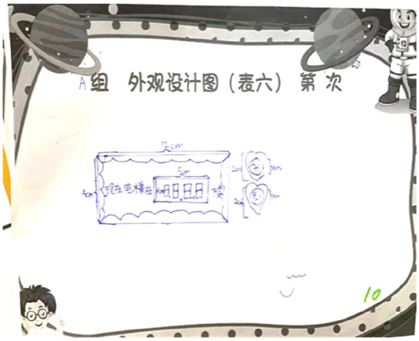

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Figure 4.
Open structured worksheet

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Figure 5.
Semi-structured worksheet with prompts

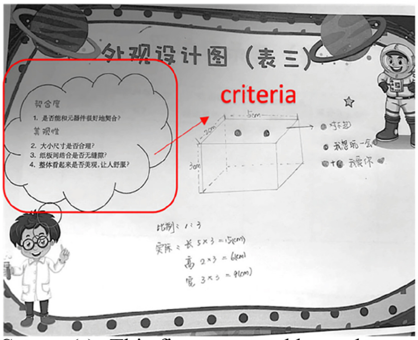

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Figure 6.
Semi-structured worksheet with criteria

(Figure 7) during the 2nd planning meeting. HCD suggested sharing examples of high-quality project work with previous students during the 3rd planning meeting, and LZ recommended using questioning strategies to frame discussions on problems, issues, or topics. These strategies were found to improve classroom performance, and teachers decided to adopt them as standard practice in the future.

Source(s): This figure created by author

Figure 7.
Test under teacher's supervision

Authenticity. Authenticity pertains to the project context in which the students work. It was observed that the project context (Table 2), which initially centered on school-related issues, designing smart elevator buttons to help staff use elevators (RL1), evolved to encompass more personal problems, such as addressing bag-related issues, spending too much time on the telephone (RL2), communicating with parents (RL3), and addressing bag-related issues (RL4). The reason for participating teachers to do so can be observed in their LS report: “The farther away from students the real problems are, the greater the cognitive load they will impose on students, affecting their learning. Therefore, students should gradually transition from personal problems to solving problems in their immediate environment and eventually to social issues.”

Project management

Project management involves “applying knowledge, skills, and resources to accomplish activities that are intended to achieve a specific goal” (Partnership for 21st Century Skills, 2014). By examining the four RLs teaching plans, it became apparent that the teachers intended to scaffold the students to complete the projects by following the DT process model (Figure 1). HQPBL (Mergendoller, 2018) regarded the DT process, itself, as a project management process. Zooming in on the objectives of the four RLs (Table 2), it was found that the teachers gradually specified the teaching objectives at each stage and designed concrete steps or tasks to achieve these objectives during the chronological evolution of the four RLs. To achieve these goals, the teachers adopted various DT tools, including the 5-why and 2×2 metrics, to monitor, scaffold, and coach students’ thinking as the projects progressed. At the end of the whole LS cycle, teachers reported that “incorporating DT tools helps to ensure that the students are on the right track, that they are developing the necessary skills and knowledge to achieve their project goals, and that they can effectively solve real-world problems.”

Reflection. This criterion concerns students’ reflections on products and their learning throughout the project. It was observed from the 1st to 4th RL meetings that teachers discussed different strategies to improve students’ reflection abilities. In the 1st planning meeting, teachers designed reflection worksheets that required students to fill in “what they learned” and “what they want to improve”. However, the teachers were dissatisfied with the students’ filling results during the 1st post-discussion meeting:

> LZ: Students just reflect on products!
>
> LZA: Yeah, most of them just fill in what I said in the classroom.
>
> HCD: Students do not know what reflection is, we have never told them. You cannot expect students to do it. We need to guide them!

In the planning meeting for the second RL, they discussed how to guide the students:

> LZ: I think this (refers to the worksheet) still needs to be done. But YXH should explain how to fill it in.
>
> YXH: Before asking them to fill it in, I demonstrate to them how to do it, right?

In the third post-discussion meeting, three teachers were satisfied that students’ reflection abilities had improved from description (simply reporting what was done) to justify why they did it. LZ still believed that students could improve further:

> LZ: I think students should also know why we asked them to experience each stage of DT. In other words, students should know what the role of each DT is.

Thus, he employed PowerPoint slides with outlined questions to prompt students to explain and justify their actions in his class.

Collaboration. Collaboration, a key aspect of engaging in projects, was found to be a challenge for four participating teachers in the post-interview results. However, they remained optimistic about improving their students' collaborative abilities. Challenges in this regard include insufficient maker toolkits, group size, and group dynamics such as gender, ability, and personality. As LZ said:

> The biggest problem for us is how to improve students' collaboration ability, there are too many needed to control, but we cannot control, such as students' personality.

And LZA also added that students did not know how collaborate with each other, the girl who was observed always got mad when other team members did not follow her advice.

Public product. Publishing products requires students' work to be publicly displayed, discussed, and critiqued. It was observed that teachers did not focus much on improving these aspects during the RLs meetings.

In conclusion, the designed projects were gradually aligned with criteria set by HQPBL (Mergendoller, 2018) in terms of *Intellectual Challenge and Accomplishment*, *Authenticity*, *Project management*, and *Reflection*. However, less attention has been paid to *Public Project* and *Collaboration*. This alignment indicates an improvement in teachers' pedagogical practices during the LS cycle, through shared planning, classroom observation, and critical reflection in post-lesson meetings. It is worth noting that individual attitudes and experiences in the teaching profession may influence receptivity to new pedagogical approaches. However, exposure to other teachers classroom performance and critical reflection can potentially facilitate attitude shifts.

Change of attitudes and beliefs towards learning

The following section outlines the changes in teachers' attitudes and beliefs across the five key areas within the ME context.

Making for hard fun over making for pure fun. LS changed participating teachers' belief from "making for pure fun" to "making for hard fun" (Dougherty, 2013). "Making for hard fun" underscored interdisciplinary STEM knowledge and skill acquisition and positive attitude building such as failure-celebration, perseverance, and learning from mistakes when students made projects (Regalla, 2016; Chu *et al.*, 2015). This change was evident in the teachers' interviews, as they reflected on past and present pedagogical practices, and articulated strategies for future improvement. In the pre-interview, HCD mentioned:

> Previously, we pursued class atmosphere, students' pleasure, but it is difficult (for students) to learn knowledge, and we also never knew what students learned.

After observing classroom performance, he realized that a lack of content knowledge and skills behind projects hinders students working efficiency and motivation in completing projects. Therefore, he decided to prioritize the teaching of programming logic and making skills. As he stated in the post-interview:

> Observing students' programming, (I found) most students lack computational thinking, do not understand algorithms, which demotivates them … Another issue is the cutting and hot glue sticking, which creates a great deal of safety pressure for us, negatively affects students' production processes … in future, I will demonstrate more.

In addition, LZA used the term "evidence-based teaching practice" to describe LS, which shaped him into a new mindset for future project design:

> I will consider why I designed this project, how students learn this project, and whether students learn this project in an effective way.

The other two teachers realized the importance of learning analysis in project design. They reflected that their insufficient learning analysis resulted in the design of their first project far exceeding students' cognitive load. They expressed that they would use interviews as a learning analysis method in the future to better understand students' cognition and abilities. As LZ said:

> We previously defined teaching objectives based on some materials or experience, but this time we found we should conduct learning analysis, which help us design a project at an optimal level, suitable to students' cognitive development.

Similarly, YXH acknowledged that they previously defined teaching objectives based on their "own judgment, never using interviews." After LS, he expressed "that I found that interviews can help me understand students' cognitive abilities better. In the future, I will try to use interviews more often."

It was evident that teachers recognized the importance of maintaining consistency in planning the ME curriculum, including learning goals, content, activities, and assessment, to promote effective student learning, as suggested by van den Akker (2003).

Making for inclusion over making for elites. ME advocates "a growth mindset, where, given effort and resources, anyone can learn the skills needed to complete any project they can imagine" (Martin, 2015). However, in China, participation in ME is limited to high-achieving students who are trained to compete and achieve recognition. The post-interview results demonstrated that the teachers broke this stereotype and recognized that ME was suitable for students with diverse abilities, personalities, and gender identities. Their attitude changes came from observing the low-achieving case pupil, QXR, an introverted girl, based on teacher evaluations and academic performance.

"QXR's learning attitude" surprised YXH; he expressed that "she was able to persist with the teacher even after failing many times." Thus, he planned to "divide tasks into different levels, and assign different tasks to children with different levels of ability."

Additionally, LZ observed a positive shift in QXR's motivation from "avoiding criticism" to "enjoying the class," which prompted him to "create a safer and more open atmosphere in the future."

Furthermore, LZA suggested a method to make the classroom more accessible. He suggested: "a written solution that would be effective for most students' learning and allowing them to go through the learning process, rather than just listening to a few students' ideas".

The interview results revealed teachers' intentions to promote inclusive education in the future through diverse project designs, fostering a positive learning environment, and developing learning scaffolds. This reflects a shift in their perception of ME from focusing on competition to one that prioritizes inclusive and individualized learning.

Progress-oriented over product-oriented. The belief in ME posits that making is a process that embraces failure as a necessary and positive element, wherein learners encounter difficulties and subsequently overcome them (Martin, 2015). The interview results showed that the immersive experience of trying a new pedagogy deepened the teachers' understanding of this belief.

During the interview, YXH described an event, in which a group of students persevered in failure, which led him to realize that focusing on the students' project management processes contributed to MM growth. As he described:

> During my class, I find students who try many times during testing, but always fail, about seven or eight times, but they still test after class.

In the interview, LZ described their previous and new pedagogical practices as "step-by-step" and "prioritizing students' thinking processes." He admitted that the latter approach motivates students and gives them a better understanding of the problem and its solutions. As he said:

> Students go through the entire process from finding problems to solving this problem, which motivates them a lot . . . students not only know what to do, how to do, but also know why to do.

Additionally, LZA expressed a preference for employing multiple formative assessments to evaluate students' learning, rather than relying on the final product as the sole indicator. As he expressed:

> I will focus more on students' thinking development processes, using various written materials, like this time, to evaluate students' performance, rather than merely focusing on the function of the final project.

The results revealed that the teachers recognized the significance of the product-making process for students' development of MM, including self-efficacy and problem-solving ability. They acknowledged that their previous pedagogical practice lacked consideration for the multifaceted nature of learning such as its cognitive, affective, and behavioral aspects (Regalla, 2016). To better assess the students' learning processes, LZA decided to shift from product to formative assessments.

Deeply student-centered over superficially student-centered. Although ME, as a learner-centered project-based learning approach, has gained popularity in China, participating teachers expressed skepticism in their pre-interviews. They worried that increased student agency in the learning process would negatively impact academic achievement and result in loss of classroom control. This sentiment is captured by the following HCD's statement:

> Learner-centered practice is unrealistic (to practice), we only have 45 min, giving students too many choices, you may find that students do not know what to do, you cannot expect students to learn.

Post-interviews showed that the teachers had developed a nuanced understanding of implementing a learner-centered approach in their classrooms. They described themselves as key actors in their students' learning process, taking on roles such as "designers," "facilitators," "motivators," and "researchers." HCD changed his view and redefined the learner-centered approach in the post-interview:

> The importance of our roles as teachers was not diminished by adopting a learner-centered approach. Rather, we take on more responsibility, such as assessing the appropriate level of choice for each student and project, considering the students' prior knowledge, and providing adequate support and guidance when necessary.

The different definitions of the learner-centered approach in the pre- and post-interviews demonstrated that LS led participating teachers to hold a positive outlook on this approach. They were also aware of the importance of balancing student autonomy with academic rigor, which can be accomplished through careful planning, effective implementation, and ongoing reflection on pedagogical practices.

Challenge and need for support

Although the participating teachers acknowledged the significant impact of LS on improving their instructional practices and changing their attitudes towards ME teaching and learning, the post-interview results revealed that they still faced challenges that required additional support.

The most significant challenge identified by the participants was the lack of time to implement the DT-making pedagogy. The teachers emphasized that effective implementation of this pedagogy required at least three hours of class time, divided into multiple 45-min sessions, which proved difficult within the typical 45-min timeframe of formal schooling classrooms. They expressed concern that breaking down the entire project into smaller 45-min lessons within the formal schooling system would result in a forgetting effect, in which students would struggle to retain acquired knowledge and would lose motivation.

Another challenge is that the teachers lack research skills. They were concerned that, without expert guidelines, they would struggle to identify research questions, gather and use appropriate evidence, and evaluate outcomes. They emphasized the importance of expert guidance that considers their competencies and needs, as well as curriculum standards and school priorities.

The third challenge is the lack of access to high-quality and relevant learning materials. They found it difficult to locate practical learning resources that provide concrete details for the implementation of new pedagogies. In most cases, they found the learning resources too theoretical to apply in practice.

To address these challenges, participants emphasized the need for additional support, including additional time to implement pedagogical changes, expert guidance, and access to high-quality and relevant learning resources.

Discussion and conclusion

Our study was conducted in the context of the national curriculum reform at the elementary school level in China, emphasizing the integration of constructivist approaches into ME pedagogical practice. This study investigated changes in teachers' practices and beliefs about teaching and learning related to the revised curriculum, because of their participation in 3-month LS.

The findings of this study demonstrated that participating teachers' pedagogical practices, beliefs, and attitudes were enhanced by participating in LS cycles, resulting in maker projects that met high-quality criteria for HQPBL (Mergendoller, 2018). Pre- and post-interviews revealed a significant shift in teachers' attitudes and beliefs towards ME, including changes in their perspectives on "making for hard fun", being inclusive, progress-oriented, and student-centered. These changes align with the ME principles and address the challenges identified in the literature. Teachers' changes were mainly the result of observing case students, especially the low-ability student, which is fundamentally different from CLS that focuses on teachers' teaching. This key finding was also discussed by Dudley (2013), who found that teachers often hold stereotypes of low-ability students and assigned easier tasks to them. However, his observations revealed that these students could operate at or above the level of middle-attaining groups. Therefore, he recommended observing case students' learning to inform pedagogical adjustments aligned with their actual progress and learning needs. Norwich and Ylonen's (2013) 2-year longitudinal study also admitted that observing case students and tracking their progress benefited for teachers to set appropriate lesson goals and monitor goal attainment. In addition, our study also suggests that shifting focus from teacher teaching to student learning is more suitable for teachers to PD development at the time of Chinese curriculum reform. Ni Shuilleabhain and Seery's (2018) study showed that after participating in an LS participant mathematics teachers developed their constructivist pedagogical practice. In this case, we propose building an integrated LS model by incorporating diverse international LS models to address the limitations of localized models.

However, several challenges have been identified in the context of implementing LS approaches. These challenges include time constraints, limited research skills, and inadequate learning resources. Among these challenges, a notable issue is the lack of research skills among participant teachers. This challenge is particularly significant because participant teachers are required to design various materials, such as learning materials and observation sheets, to collect students' data and gain insights into their learning processes. This practice differs greatly from their previous experience, where the focus was solely on their own teaching rather than understanding student learning. These challenges mentioned above have also been discussed in previous studies, such as Fernandez (2002) and Takahashi and McDougal (2016). Hence, further research on LS and collaborative research endeavors involving teachers are essential to address these challenges effectively. Furthermore, providing effective support for teachers in adopting new pedagogical practices necessitates alignment with school priorities, curriculum standards, teachers' competencies, and the essential needs of facilitators or experts who offer training and mentoring.

This study's limitations include limited participant diversity as the study only included STEM teachers from a well-resourced urban Chinese school. The findings may not be generalizable, because not all STEM teachers from the school participated in this study. These limitations suggest that the conclusions of this study are only applicable to similar schools and contexts. Therefore, future research will refine DT-making pedagogy and integrate the LS model to optimize its impact on STEM teachers' PD, testing it in various contexts for efficacy and generalizability.

Our study provides some theoretical and empirical contributions to existing research on LS's impact on teacher PD. Theoretical contributions include exploring the integration of international LS models to address local limitations, while empirical contributions demonstrate some positive impact of LS on teacher PD, including some changes in pedagogical practices, beliefs, and attitudes towards student learning. The implementation of constructivist approaches to teaching and learning has been challenging, and our research adds some insights to this body of knowledge.

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