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Primary and Middle School Teacher Experiences of Integrated STEM Education in China: Challenges and Opportunities*

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Integrated STEM education is a novel and at times controversial approach to teaching, particularly in school systems such as China where there strong are traditions of teacher-directed learning. Implementation of integrated STEM education is influenced by teachers' experiences of established and new teaching practices that shape what teachers may identify as challenges and opportunities. Our aim in this study is to address the need for understanding teacher experiences with integrated STEM education in primary and middle school contexts in Beijing, China. We adopt a methodology informed by grounded theory to explore and interpret the ideas generated by 12 teachers of integrated STEM. Our findings indicate both resonance and difference with international experiences in terms of challenges that are experienced, and the complexities of issues related to teaching practices. The interplay between integrated STEM and mathematics education is an important feature of this study, which opens a broader issue about teacher and student understandings of engagement. The study also addresses teacher professional development and professional learning to support the implementation of integrated STEM education in Chinese schools. This study highlights issues with: engaging Chinese students in integrated STEM lessons; resonance and difference between Chinese and international teachers; and, contextualized professional development. Future research should address the diversity of education in China, and access to student voice in relation to integrated STEM education.

Keywords: experiences; China; integrated STEM; mathematics; students; teachers

1. Introduction

Education communities internationally have experienced increased prioritisation of mono-discipline approaches to S.T.E.M., as well as integrated STEM (iSTEM) in school education over the past two decades [1]. S.T.E.M. refers to the traditional disciplines within science, technology, engineering and mathematics [2], whereas integrated STEM refers to a combination of two or more of these disciplines to address a problem or issue [3]. The prioritisation of STEM is often driven by concern for future STEM jobs and international competitiveness [4], with educational success measured by student performances on standardised testing [5]. In the case of iSTEM much of this recent discourse is attributed to the influence of the engineering discipline in the United States (US) [6], which has influenced STEM and STEM in schools with ideas such as engineering processes and design thinking [7]. Some scholars are questioning the rhetoric by describing the *perceived need* for STEM to support international competition as a deficit model of STEM education [8]. Similarly, in other parts of the world such as Australia, the international competition and workforce shortage discourse is being increasingly critiqued as *smoke and mirrors* rhetoric [9].

In China, STEM education is also receiving greater attention with schools implementing various models of practice [10–12], including transdisciplinary strategies [13] that nurture an understanding of fields such as engineering amongst school students [14]. China has demonstrated a *real need* for STEM education with a rapidly developing economy, which has shifted over the past three decades from being a low-cost, labor-intensive manufacturing economy to being a high-growth, technology-driven innovation economy [15]. The national discourse is driven by presidential reports to the National Congress of the Communist Party of China (CPC) and the Five-year Plans from the Central Committee of the CPC that illustrate a clear and consistent trend toward the adoption of creativity and innovation as national priorities for China. At this policy level, the concept of innovation has also shifted over the duration of three decades from adaptation of overseas innovations toward indigenous Chinese innovations, and the development of creative local talent involving both individuals and collaborations [15]. These trends in creativity and innovation

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policy have been articulated through science and technology development policies and it is this national desire for greater creativity and innovation that drives an emergent iSTEM education agenda. A recent example of this policy in action was the addition of technology and engineering to the science curriculum standards of primary schools in 2017 to drive indigenous innovation by developing local Chinese talent [16].

In contrast to this national policy agenda established by high-level political leaders, there is a counter-discourse evident in the interpretation and enactment of these policies at the classroom level of primary and secondary schooling [15]. This counter-discourse reflects the inertia of traditional teaching methods that are teacher-led and focused on teaching deep knowledge of S.T.E.M. domain-specific knowledge [17]. These forms of teaching practice are most evident in the field of mathematics which is a highly regarded core subject in Chinese schools. In the context of mathematics, creativity and innovation are typically interpreted differently to interpretations in iSTEM education that is more closely aligned with the national policy agenda. For example, creativity in teacher-led mathematics pedagogy tends to be reference-based meaning that it is dependent on comparisons to generally accepted exemplary lessons as forms of teaching. Basically, teachers have established standards on what constitutes good teaching through the performance and dissemination of exemplar lessons by expert teachers [17]. Creativity in teacher-led teaching becomes evident through each teachers' ability to learn from the exemplar lessons. The interpretation of what constitutes creativity and innovation in traditional forms of Chinese S.T.E.M. education may therefore be considered as a being different from what is intended in national policy priorities.

This policy background and the different ways in which creativity and innovation may be interpreted and performed in China is important for the present study as it contextualizes some of the complexities and challenges that arise in iSTEM education practice and research. Much of the recent Chinese research into iSTEM education focuses on education policies, ways of defining iSTEM, and ways to introduce foreign-sourced exemplar lessons, curriculum development, and models of instruction [18]. Several researchers [19–21] argue that STEM education in China should not be simply duplicated from other countries, which may reflect the more recent national policy to develop local talent and indigenous innovation. Importantly, such views would also be supported by the international iSTEM education literature where localized topics and community-focused teaching is encouraged [2].

Further issues with the recent introduction of iSTEM education into China's curriculum relate to the strength of curriculum standards, methods of assessment, and textbooks for iSTEM, which are not as well developed as other fields of education [19–21]. This lack of development evidences the need for teachers to be innovative in a broader way than the traditional approaches described above. As in other parts of the world where teachers are adapting iSTEM to align with national innovation policies [22], Chinese teachers are creatively developing iSTEM and breaking the boundaries of old curriculum and pedagogy in an effort to understand what iSTEM *could and should* look like in classroom contexts. For example, a study developed a lesson sequence called *Water Journey* for students to explore various aspects of the water cycle [23], and integrated knowledge from ecology, chemistry, agriculture, biology, engineering, and socio-scientific perspectives. Investigations into particular types of lesson designs in China have focused primarily on student experiences and parental attitudes [20, 23], emphasizing a need for the creation of learning experiences involving deeper levels of thinking [7], context-relatedness and challenging problems [20]. It is notable that such objectives are not always achieved as teachers struggle with managing multiple classroom activities leading to superficial levels of engagement [20]. In response, some teachers may also revert to stepwise instructional forms of teaching [21]. These issues emerge from the novelty of iSTEM education and the diversity of teachers' backgrounds leading to variability in what constitutes iSTEM teaching practices [24, 25]. These contradictory reports about the success of iSTEM education in Chinese classrooms point to a need for greater research to understand the experiences of teachers, if we are to see further innovations in teaching practices. In particular, there is a need to understand the experiences of teachers in terms of professional learning and professional development, and how they may apply new knowledge to achieve student engagement and learning. In the present study professional development refers to one-off learning events for teachers, whereas professional learning refers to ongoing engagement by teachers with learning experiences to enrich their practice [26, 27].

The integrated STEM education and STEM teachers' PD have received attention globally. The significant role of STEM teachers to achieve effective iSTEM education has been pointed out [28], and previous research [29–32] have explored STEM teachers' understanding of integration, identity formation, quality STEM PD and challenges in teaching practice. The requirements for STEM teachers include multidisciplinary as well as pedagogical knowledge, being comfortable with risk-taking, a growth mindset, motivation and confidence to implement STEM education [33–35]. Challenges for teachers universally have been identified such as administrative barriers, lack of quality PD, expertise in content and pedagogies, instructional design skills, effective tools and continuous instructional supports [30, 32, 36, 37].

In the Chinese literature there is much debate about teacher professional development for iSTEM including issues such as who should become an iSTEM teacher, what are the essential skills required, and who should be providing professional development [19–21]. A literature review of STEM education for teachers in China from 2011–2016 looked at the concept of integration and the educational backgrounds of teachers [38]. Of the 57 studies they reviewed, only four studies related to teacher professional development for STEM education, with their major focus on the evaluation of foreign programs introduced to China. These evaluative studies did not investigate empirical data drawing from Chinese teachers' experiences of the programs. Consequently there is a significant deficit in the literature when it comes to the representation of Chinese teachers' voice about iSTEM implementation in schools [38]. Our present study seeks to address this deficit by giving voice to Chinese teachers of iSTEM, and exploring their experiences in primary and middle school contexts of Beijing. The observations and interpretations we make from their experiences will be explored in terms of challenges and opportunities so that we may identify the needs of teachers in the innovative field of iSTEM education.

Our aim in this study is to address the need for understanding teacher experiences of iSTEM in the primary and middle school contexts of Beijing, China. We adopt a methodology informed by grounded theory [39] to address the following research questions:

1. What are the experiences of primary and middle school teachers as they teach through iSTEM education?
2. What challenges are experienced by iSTEM teachers and what are some possible opportunities for addressing these challenges?

2. Methodology

Our methodological approach in this study is informed by grounded theory [39], which guides our data gathering and analytical methods. In a grounded theory methodology people are not the focus of analysis, but rather the focus is on the ideas or concepts they produce. Importantly data are produced through the conceptual framing of interviews, the use of guiding questions, and researchers' interpretations of data. Our methodology therefore guides our sampling of the types of people who will produce ideas of interest and we evaluate data saturation as the point where initial ideas in raw data are *fully developed*. Fully developed ideas are evident in raw data by new participants repeating ideas generated by previous participants, and adding little to the growth of the dataset. Our analytical approach helps us to achieve saturation via constant comparison of ideas between sources (i.e., teachers), asking questions, and applying our own interpretive skills informed by our backgrounds as STEM education researchers.

2.1 Methods of Data Production

2.1.1 Study Context

This study was conducted in primary and middle schools across Chaoyang District, an inner-city area of Beijing with a population of 3.6M people. The schools were responding to a China national curriculum initiative to teach iSTEM, and we were interested in teacher's experiences of this way of teaching that is new to Chinese contexts [16]. This initiative has prompted a need to understand better the experiences of iSTEM teachers. The field aspects of the study were conducted in accordance with Chinese protocols for ethical research, with approval from the local university and the principals of each school. Teacher participants are volunteers and data has been de-identified.

2.1.2 Participants

Participants in this study include 12 in-service STEM teachers, who were self-selecting, volunteers responding to an invitation sent to primary and middle schools in Chaoyang District, Beijing. Secondary schools were excluded because they do not offer iSTEM programs, which were the focus of this study. There were 3 (25%) male teachers and 9 (75%) female teachers, which is consistent with the nation-wide gender distribution for primary-middle school teachers where 67% are female [40]. The average age of teachers was 28 years, with teaching experience ranging from 2 to 27 years, and an average of 6.8 years of experience. All teachers have Bachelor Degrees in one of the traditional S.T.E.M. education fields, and teach across grades 2 to 7 (7–13 years old), which aligns with primary and middle schooling in China. Selected teachers also used a variety of textbook resources including self-designed resources, and US-based books developed by Northern Illinois University STEAM Program, and Pearson company. A summary of participant information is shown in Table 1, where individual teachers are identified by code

Table 1. Participant Information

Teacher	Sex	Grade	Course	Years Taught	Textbook Source
T1	M	7	Information Technology	2	Self-developed
T2	F	7	Engineering	7	Self-developed
T3	M	7	Information Technology	4	Self-developed
T4	F	7	Information Technology	2	Self-developed
T5	F	7	Information Technology	5	Northern Illinois University STEAM Program
T6	F	4	Science	12	Pearson STEM Plus (https://stem.pearson.com.hk/)
T7	F	2, 6	Science	2	Pearson STEM Plus (https://stem.pearson.com.hk/)
T8	F	5	Science	4	Northern Illinois University STEAM Program
T9	F	4	Mathematics	5	Self-developed
T10	F	6	Science	27	Northern Illinois University STEAM Program
T11	M	5	Science	10	Northern Illinois University STEAM Program
T12	F	4	Science	2	Self-developed

such as "T1" and these codes are used throughout this paper.

2.2 Data Collection, Selection, and Analysis

Participant selection and data collection in this study was initially informed by a pilot study [10] that shaped the focus for interviews, as our conceptual framing in the present study. The pilot study collected and analyzed post-class reflections written by seven novice STEM teachers in an elementary school in Beijing, over a 12-week semester. These teacher-generated reflections documented the challenges they experienced in teaching STEM, and their suggestions for future teaching. The findings of the pilot-study reported five categories to synthesize an understanding of teacher experiences including, (1) instructional management, (2) class instruction, (3) students' group study, (4) STEM teacher's professional development, and (5) evaluation processes. These categories were coded to capture detailed sub-issues. For example, *instructional management* involved achieving STEM instructional activities within the school's class-time structure, or the ways in which activities were designed to connect across the curriculum. The second category of *class instruction* involved teacher's experiences of making explicit task statements, leading collaborative learning, and becoming fully aware of the major purpose of the iSTEM curriculum [10]. Inspired by the challenges arising from the experiences of novice teachers in the pilot study, the authors were interested in the experiences of longer serving iSTEM educators, which has led to the present study.

The conceptual framing of the present study is evident in our design of six questions that were used to guide interview discussions. The term *STEM* was used as an abbreviation for *iSTEM* in these questions because the study was being conducted in the context of iSTEM programs where this abbreviation was part of the local terminology. The guiding questions were: (1) how do teachers integrate disciplines and utilize connections between disciplines; (2) what are the essential skills and competencies of STEM teachers; (3) do administrative leaders support STEM education; (4) what do you think of online STEM teacher education; (5) what impact will STEM education have on students; and, (6) what are the challenges of STEM education? These questions enabled us to inquire more deeply into the challenges identified in the pilot study.

In the present study, data were collected from 12 semi-structured, in-depth, audio recorded interviews of approximately 40 minutes each. Interviews were transcribed and then analyzed with NVIVO 11.0 software, enabling us to interpret the data and generate categories through a constant comparative method [39, 41]. The constant comparative method involved analysis of teachers' interview responses to each guiding question across three stages involving open-coding, axial coding, and selective coding. By open-coding, the raw data was broken down, examined, conceptualized and categorized to form thematic codes. During axial coding, a coding paradigm involving conditions, context, action/interactional strategies and consequences were applied to make connections among categories [39]. In this way, teacher-specific statements were compared against each other to develop more refined themes, including sub-themes. During selective coding, core categories were selected, filled with more sources (i.e., data from teacher interviews), and systematically related to other categories, as a way of refining them further.

Authors 1 and 2 individually conducted open coding, followed by a collaborative analysis of our individual coding to derive emerging themes relating to the research questions. Six categories were produced, corresponding to the six guiding interview questions with codes filling each category.

For example, when talking about suggestions for online STEM PD, one teacher stated, "We have no access to exemplar lessons as references, and we are not good at integrated instruction. So we need more example lessons as references to gain some inspiration" (T4, information technology teacher with 2 years of experience). That teacher statement was coded as "challenge: lack of teaching resources", "challenge: difficulties in integrated instruction", and "suggestion: the need for example lessons". Every other source coded with the same theme will then add one frequency count to its theme. After comparison, a total of nine sources mentioning "example lessons" such as "what to take away from example classes" were connected as subthemes under the category "online example classes." Upper level codes were identified during the axial coding. Finally, five sources under this theme "example classes" talked about the necessity to provide example classes, and another four teachers mentioned focusing on the essential parts of a real lesson instead of the entire class. The content and frequency of sub-themes and themes developed and strengthened different categories, and were finally interpreted into teachers' calling for exemplars in terms of suggestions for online professional development.

The data analysis process was iterative and dialogic [42]. Author 1 and 2 regularly met, debriefed and shared each other's thoughts about the themes they built over a period of two weeks. Then they worked on the sense-making process until reaching a consensus about the findings. They negotiated on the interpretation of each category and reviewed the raw data source as needed during the whole analysis process.

3. Findings

In this section we outline the themes emerging from our analyses to address each of the research questions. As stated earlier our research questions relate to identification of teachers' experiences, and the challenges arising from implementing iSTEM in primary and middle school classrooms in Beijing, China. Emerging from our themes we consider opportunities arising from this study, many of which were initially coded by us such as teachers' "suggestions."

3.1 RQ1: Teachers' experiences of iSTEM

Research question 1 focuses on identifying teachers' experiences of iSTEM education. Through our analyses we have generated three major themes, which we describe as: *every discipline is important*, *benefits for Chinese students*, and *administrative support*.

3.1.1 Every Discipline is Important

The theme that *every discipline is important* was generated from 50% of teachers. For example, T4 stated, "It is hard to say which subject is more important. The key is how to integrate them." The focus away from prioritizing disciplines and toward the conundrum of how to integrate was also reflected by a science teacher with 27 years of experience, T10, who stated, "STEM is a comprehensive process of applying integrated knowledge and disciplines which complement each other." These data portray the experiences of teachers that, regardless of their own disciplinary backgrounds, understood the integration of STEM was their priority.

Our interpretation that teachers were willing to move to an integrated approach was further supported by a willingness to adjust teaching practices, which was evident in the way they recognized the foregrounding of projects rather than prioritizing specific disciplinary content knowledge. This was evident in T8's (science teacher with 4 years of experience) statement that, "Different projects focus on different disciplines." It is important to note however that although half the teachers suggested *every discipline is important*, there is also recognition of the limitations and challenges to counter this notion. For example, two teachers mentioned that mathematics is usually regarded as a tool in a project and is difficult to integrate with other subjects, such as information and technology classes in junior high school. These reflections on their experiences with mathematics are interesting because it reflects a possible challenge to STEM integration, which may be related to the strong tradition in Chinese mathematics education to foreground domain-specific knowledge as a priority in mathematics [17]. This tradition places significant emphasis on the need to develop deep domain knowledge before working on contextualized and creative problem solving typically associated with iSTEM education. In this study we identified this in the way some teachers commented on the need for basic knowledge and skills to be taught in primary and middle school, with projects involving design mindset needing more attention in high school. Adding to this contrarian positioning against iSTEM, the lack of mathematics teachers self-electing to participate in this study tells us something about the way these teachers may view iSTEM as unsuitable or not relevant for teaching mathematics. Understanding the complexities of this issue is important if notions of iSTEM, creativity and innovation are to be implemented to support national policy priorities addressing indigenous innovation and the development of Chinese creative talent.

A final interpretation on this theme that every discipline is important, relates to the willingness of technology teachers to participate in the study, and consider ways to integrate mathematics into iSTEM education. This possibly reflects the innovative status of digital technologies as a discipline, meaning that technology teachers may feel less constrained about what creativity and innovation should look like in the classroom. For this reason, iSTEM in China may require upskilling of technology teachers with particular mathematical skill sets to enable mathematics integration. This would mean a shift in teacher education policy where teachers possess a degree in a specialist knowledge domain, rather than a collection of knowledge from different domains.

3.1.2 Benefits for Chinese Students

This theme of *benefits for Chinese students* was one of the stronger themes in terms of the diversity of categories teachers used, but also the number of times sub-categories were discussed. This is an important theme as it may be a motivating factor for teachers' interest in iSTEM, and it is notable how teachers in this study draw on their recent teaching experiences. For example, T10 comments that, "Students' ability to cooperate improves greatly. In China, students are hardly capable of collaborating with others, and STEM courses help solve this problem." More than 50% of teachers had similar comments indicating similar experiences involving students' collaboration abilities and a perceived need to improve collaboration by learning *through* iSTEM education.

A strong sub-category under *benefits for students* was *independent thinking, imagination, and creativity*. One example includes T8 who stated, "Their [the students] creativity was enhanced significantly. We require students to design their work independently so everyone should have their own ideas." Another teacher (T7, science teacher with 2 years of experience) asserted how "It seems obvious that they are now capable of thinking independently and unrestrainedly."

Consistent with these themes, improvements in student problem solving skills were also commented on by 33% of teachers, which they attributed to a capacity for applying formal or theoretical knowledge. T10's comment summarizes this very well with, "Students used to know theories very well, but they had no idea how to apply the theory. STEM education focuses on the application of theories and knowledge because they [students] must solve real problems." This appreciation of iSTEM by T10 reflects claims in the literature that mathematics and science knowledge may be brought to real life to solve problems in iSTEM, instead of being taught in a vacuum [43].

Notably these more commonly discussed sub-categories about the benefits of iSTEM were also supported by mentions of other important benefits for students. These other categories included communication skills, emotional engagement with greater confidence and a sense of accomplishment, and an improved sense of social responsibility as students become problem solvers. The fact that these teachers generated this collection of ideas is significant in the context of current debates about what iSTEM is, what it could be, and what students could possibly achieve through this style of learning. Author 3 has previously explored similar benefits for students in a study where entrepreneurial thinking was embedded into an iSTEM course for pre-service teachers in Australia [22]. For example, the notion of social responsibility may be highlighted through integration of STEM with entrepreneurial thinking where values and adding value for others can become an important part of problem formation, and design thinking in STEM. By introducing broader ideas about creativity and innovation from other fields such as entrepreneurship education, it may be possible for Chinese iSTEM teachers adopt new understandings of what constitutes good teaching in this multidisciplinary field. An openness to broader ideas about creativity and innovation by these teachers from Beijing is an important element to recognize as they reflect on their experiences with iSTEM, because it opens opportunities for new possibilities and new directions for Chinese education.

3.1.3 Administrative Support

There was a consensus between teachers' beliefs that they were well supported by administration and school leaders to implement iSTEM education. During interviews teachers remarked on their access to teacher education programs, lectures by STEM education professors invited by the education department in their district, and sufficient financial support for resources. Evidence of this resourcing was indicated in terms of textbook availability, and the employment of teacher aides, particularly in primary school contexts. Given the innovative status of iSTEM, teachers did provide evidence of varied experiences across schools in terms of the allocation of time and space. Some participants were commented about a lack of time to implement STEM projects, due to tight and sometimes rigid school schedules. In contrast, others commented on receiving much more support with the allocation of two lessons per week and dedicated iSTEM spaces such as different labs for doing practical STEM activities. This variability is also reflected in the broader literature on iSTEM programs [37].

3.2 RQ2(a): Challenges Experienced by iSTEM Teachers

In addressing the first part of research question two we describe teachers' experiences in terms of: *disruption to classroom discipline*; *the need for exemplars*; and, *multidisciplinary knowledge and skills.*

3.2.1 Disruption to Classroom Discipline

One of the notable challenges experienced by teachers included their responses to classroom discipline during iSTEM inquiry projects. These experiences are evidenced by T7 who stated, "Students are less likely to follow classroom discipline in STEM classes and it's hard to focus their attention." What this teacher was referring to was the way in which students could become absorbed in their own projects such as an experiment and not listening to the teacher or other students. Other examples included students being distracted by the color of materials rather than the substance of the topic being taught, or having conversations about things the teacher considered to be off-topic. These experiences were noted in terms of the teachers' tolerance for a noisy and disorganized or student-led classroom, and contributed to the teachers' describing some students as being disengaged. The issue of a noisy and seemingly disorganized STEM classroom is challenging for some teachers who may have deeply ingrained experiences as both students and teachers in quiet classrooms with passive behaviors, evident in the way Chinese teachers commonly conflate quietness with student attentiveness and engagement [47]. These experiences suggest a possible opportunity for teachers to re-think what student engagement looks like in a noisy project-focused iSTEM classroom that is student-led, and self-organizing [cf. 26].

Similarly, teacher's observations about some students not engaging are also important. Student disengagement may be due to student expectations about being in a quiet passive classroom where they do not need to initiate actions to be seen to be engaging. It may also be related to not knowing how to engage or not having the self-confidence to engage in iSTEM open-learning environments. In such situations teachers probably need to consider the scaffolding or structuring of iSTEM inquiry lessons to differentiate for less-confident students.

3.2.2 The Need for Exemplars

The need for exemplar lessons is a theme that captures teacher experiences and preferences for teacher professional development, which we touched upon in the introduction where we described the notion of creative teaching practices in mathematics. The notion of an exemplar lesson is itself a Chinese cultural peculiarity in mathematics and iSTEM education. As indicated by Niu et al. [17] an exemplar teacher-led lesson typically involves the performance of an idealized way of teaching that other teachers seek to imitate. The teacher generated term *exemplar lesson* was evident in this study and it was further suggested by teachers that such lessons should be delivered online. This theme also raised the issue of professional learning and development to be culturally relevant, which may have been referring to the notion of exemplar lessons. For example, a science teacher with 2 years of experience, T12, stated that "There should be more exemplar classes rooted in Chinese classrooms and given by Chinese teacher, instead of those from foreign classes." This sentiment partly reflects the need for Chinese STEM contexts to be reflected in teaching, but also the need for STEM to be taught in the Chinese language, and in a Chinese way. This was further indicated by a mathematics teacher with five years of experience, T9, who stated, "I believe teacher training would be more effective if it is based in Chinese curriculum standard, which Chinese teachers would easily understand." The notion of a curriculum standard and exemplar lessons was further iterated by T4 who commented "We have no access to exemplar lessons as references, and we are not good at integrated instruction. So, we need more exemplar lessons as references to gain some inspiration." T4 was a technology teacher with two years teaching experience, and this comment evidences a strong alignment with Niu et al.'s analysis of teaching practices [17]. The training of Chinese teachers is clearly embedded in reference-based learning about what a good lesson should look like. In iSTEM education where classes are handed over to student-led inquiry, the challenges to teachers becomes very apparent. The content of these suggested exemplars was also discussed with T9, the mathematics teacher, stating, "It would be better if more effective lessons were provided so we will know what classes should be like in reality, what we need to prepare, and what students will do." Several teachers also suggest that online classes should focus on the important parts of a real lesson, instead of entire courses, where less important sections, such as students performing experiments, can be skipped. The notion that performing an experiment was a less important part of an iSTEM lesson further reinforces a divide between what teachers identify as valuable in learning and broader policy intentions. If creativity and innovation are the rationale for teaching iSTEM in

Chinese classrooms, then the meaning of creativity and innovation needs to be more clearly defined. This is particularly important to achieve alignment with the national policy vision of developing indigenous innovations skills to replace the adaptation of foreign innovations.

In addition to the need for learning through exemplar iSTEM lessons or lesson stages, teachers also commented strongly on the need for professional development on iSTEM to be delivered in Chinese. Teachers revealed during interviews that foreign STEM instructors were difficult to understand even with a translator. This was particularly the case for teachers with 10 years or more experience as they typically lacked the same level of English and multi-lingual skills compared with younger teachers. In addition, teachers also commented that both themselves, and their students, commonly struggled to understand foreign textbooks. This latter point is especially problematic given that more than 50% of the teachers claimed to use a foreign textbook written in English (see Table 1). In summary the cultural relevance of professional development and resources, including the language and therefore idioms, in which it is delivered, is perceived as a challenge to iSTEM by these Chinese teachers.

3.2.3 Multidisciplinary Knowledge and Skills

The third major challenge that became evident through our analyses was the need for multidisciplinary knowledge as indicated by an information technology teacher with two years of experience, T1, who stated, ". . . teachers should be equipped with skills from multiple disciplines. . . . I am a teacher of information technology, so I have to know about the framework of science classes and mathematics classes." T1's statement indicates that this need for knowledge is not just about disciplinary content, but also pedagogical knowledge specific to different disciplines. T1 expanded on the issue of the diversity of pedagogical approaches needed in iSTEM, with the comment "Designing a class is very important, such as considering class activities and how to connect them with reality." How this new knowledge could be obtained was also reflected upon by teachers during the interviews, such as an engineering teacher with seven years of experience, T2, who stated, "I regard learning skills as the most important ability. I majored in engineering, but I have to learn history, mathematics, and literature." This is an insightful observation by T2, which was echoed by others, and in part may provide a solution with teachers recognizing their own needs for ongoing professional learning beyond the formal professional development provided by the school system.

3.3 RQ2(b): Opportunities that Address Challenges

Arising out of this interpretive, grounded theorization of Chinese teachers' experiences of various challenges when teaching iSTEM are some rich opportunities. We have summarized these in the following sections as; *new ways of thinking; STEM teachers' competencies;* and, *advice for PD providers.*

3.3.1 New Ways of Thinking

This study indicates that Chinese STEM teachers feel very well supported by school leaders in the implementation of iSTEM and these teachers also display a high degree of openness to new ways of thinking about iSTEM. Part of this innovative thinking and openness to learning is the self-acknowledgment by these teachers that integrating mathematics is one of their weaknesses. For example, a science teacher with 12 years of experience, T6, stated that "Mathematics knowledge was hard to integrate and were mostly applied as a calculation tool in a project." This is a common issue with teachers and iSTEM internationally, where the setting aside of mathematics has been raised as an issue in some STEM education contexts [44]. We have highlighted the issue of mathematics as an important opportunity that could be addressed with targeted professional development and ongoing professional learning. In China, this might focus on information technology teachers and at the same time, the introduction of more mathematics teachers to the iSTEM community may also be beneficial. As reported by the teachers, mathematics was found to be difficult to integrate, not only because their lack of professional knowledge but also due to the absence of mathematics teachers' participating in iSTEM in China. This may be a unique issue for the China context where mathematics is typically regarded as the most important subject in Chinese schools [17]. Consequently, mathematical domain knowledge is highly valued leading to high demand for mathematics teachers to be teaching using direct knowledge-transmission styles of pedagogy, rather than engaging in iSTEM practices that are not fully accepted in China. Clearly, if iSTEM education in China is to be more inclusive of mathematics there needs to be a change in the way preservice and in-service teachers are educated in how mathematics may be applied to authentic contexts and problem solving. The authors interpret the data as evidence of mathematics teachers in Chinese K-12 schools being overloaded with single discipline pedagogical priorities, leading to less involvement in integrated instruction and collaboration with multi-disciplinary teachers. These findings should raise more attention from policymakers and researchers to more explicitly define and evaluate creativity and innovation when teaching for mathematics through iSTEM education practices.

3.3.2 STEM Teachers' Competencies

Unlike traditional single-domain teaching, iSTEM education requires multiple competencies from teachers, involving multi-disciplinary knowledge, different ways of thinking, instructional design and learning new skills, as mentioned by most participants. Five teachers expressed their valuing of the importance of multi-disciplinary knowledge and skills: "Teachers should be equipped with skills from multiple disciplines. I am a teacher majoring in information technology, and I have to know about the framework of science classes and mathematics classes before teaching STEM classes" (T1). One participant indicated that STEM teachers should prepare themselves to respond to students' questions: "Teachers should be knowledgeable in a broad range of disciplines because STEM classes involve many areas of knowledge and skills and teachers must be ready to respond to varieties of questions from students. It is different from the science classes which contains specific knowledge points" (T3, information technology teacher with four years of experience).

Instructional design, was reported as the biggest challenge by eight teachers, and was mentioned by five participants as an essential skill. One teacher stated "Designing a class is very important, thinking about how to plan class activities and fit them into a 45-minutes' class" (T6). Teachers reported being involved with many concepts and activities, including hands-on activities, project-based learning, inquiry learning and collaborative learning. They further commented on how these experiences were challenging for STEM teachers in China, many of whom have limited access to related PD resources.

Learning skills and collaborative teaching were issues further raised by teachers. Three teachers experienced their own *professional learning skills* as being essential, such as "I think learning skills are the most important ability. I majored in engineering, but I have to learn history, mathematics, and literature to teach STEM classes." And accordingly, teachers often collaborate with other subjects' teachers to absorb multidisciplinary knowledge by teaching and learning together. One teacher mentioned there was a STEM class in her school designed and taught by Chinese, mathematics and physical education teachers together, which integrated knowledge and practice from different subjects. To achieve this, teachers need to meet, learn from each other, discuss and polish their lesson plans collaboratively. In this way, iSTEM education provided opportunities for in-service teachers' to be active learners and to engage in peer collaboration, while delivering innovative teaching content and formats to their students.

3.3.3 Advice for PD Providers

The final category we interpreted from our data related to some important opportunities for providers of professional development in iSTEM education. Firstly, broad one-size fits all professional development (PD) is not in demand from the teachers we studied. As many teachers have suggested, most of the currently available PD resources are imported from abroad without being tailored to fit Chinese classrooms. As one teacher pointed out, "For future teachers' education, I recommend that we should observe STEM lessons given by other schools in China instead of those given by foreign experts" (T12). This is an interesting issue and may be related to the way ideas such as creativity, innovation, engagement and learning are understood in Chinese and foreign contexts. While the barrier of language was a commonly raised, the communication barrier most likely runs deeper to the idioms related to some of these foundational ideas upon which iSTEM education has been established.

Some teachers struggled with the challenge of multiple disciplines and suggested that PD be targeted to emphasize specific knowledge domains. For instance, one teacher stated, "I suggest that teacher education should be classified. Some courses are mathematics-centered, some are science-centered and others are engineering-centered. It is not reasonable to require teachers of all disciplines to attend all courses without differentiation" (T9). This is an important consideration for PD with Chinese teachers because of their educational background that tends to be very strong in a particular knowledge-domain. In contrast, foreign PD providers are more likely to come from school systems where teachers have less domain knowledge depth in any particular field, but greater breadth across a number of fields. Understanding this difference with Chinese teachers is therefore important when considering the differentiation of teacher PD.

Differentiating teacher PD may also be addressed by listening to teacher demands for PD to be deliverable online, and micro-focused to address specific aspects of teaching challenges. These forms of PD may also include exemplar video samples to clearly demonstrate iSTEM in-action. More than half of the participants indicated a lack of references and resources when they were designing their lessons, especially resources on how to integrate knowledge and how to design class activities, which is also indicated in international research [37, 45]. The authors suggest this gap in teacher PD may be addressed with systematic instructional resources in PD, which could be diverse in instructional design, and developed from within Chinese educational contexts. This would address an important theme in iSTEM that is relevant to this study as well as international contexts around the need for localized community-focused projects [2].

4. Discussion

This study makes a significant contribution to understanding the experiences of teachers of iSTEM education in Chinese primary and middle school contexts. In this section we synthesize the findings and draw together the implications of this study around the issues of: *engaging Chinese students in iSTEM lessons*; *resonance and difference between Chinese and international teachers;* and, *contextualized professional development.*

4.1 Engaging Chinese Students in iSTEM Lessons

Internationally the adoption of iSTEM education is driven by a need to engage students with contextualized, project-based and/or community-focused learning experiences [2]. In the context of the present study, teachers' experiences of engagement became an issue, which was evident in two different ways. Firstly, some teachers at times felt disrupted by noisy, seemingly disorganized classrooms that were contrary to conventional quiet and passive classroom situations to which they were accustomed. As we noted in the findings, Chinese teachers who engage with iSTEM may require retraining in what constitutes engagement and how engagement may be individualized through student-directed learning. The student-directed quality of iSTEM activity-focused classrooms, means that different student groups are focused on different ideas, leading to many diverse and sometimes loud conversations at the same time. Even in non-Chinese contexts, forms of engagement around student-led learning events that may involve overt emotive experiences, and self-organizing social engagement are still considered innovative in many school contexts [46]. Teachers who are typically experimenting with iSTEM education are therefore highly innovative in the Chinese context, which has passive and quiet forms of engagement embedded in a long tradition of teaching practice [47].

Connected with this first issue is the way in which mathematics is taught in Chinese schools, most typically using teacher-led pedagogies [23, 38]. This situation is particularly dominant in the Chinese context where mathematics is held in such high regard within Chinese society, arguably more so than many other cultures. This leads to a school system that emphasizes a high level of mathematics domain knowledge and limits the ways in which mathematics teachers are able to teach, evident in the reference-based, exemplar lesson culture of teaching practices. In essence mathematics is viewed as high value, and we interpret this situation as evidence of high levels of risk aversion when it comes to experimenting with pedagogy. Supporting this interpretation, there was only one mathematics teacher who volunteered for this study, and many of the other teachers noted the challenges in teaching mathematics due to their lack of background in that field. In the Chinese context, this may be addressed by finding communities who are less risk averse toward different methods of mathematics learning so that different ways of engaging may be explored. The inner-city, Beijing context of this study may have played a role with pedagogical risk aversion, given that such schools bring much prestige to China as world leaders in international standardized assessment in science and mathematics [17]. To broaden the possibilities for different ways of teaching iSTEM in China, we suggest future studies could focus on regional and rural areas where communities may be more open to evaluating different ways of engagement and learning with mathematics and other domains of STEM.

The other notable feature around student engagement in this study involves teachers' observations of some students disengaging from iSTEM. This is in contrast with previous international research where students showed inherent motivation and overwhelmingly positive responses toward STEM challenges [37, 48, 49]. There may be many reasons for the inactive students mentioned by teachers in our present study. One reason may be that most Chinese students are accustomed to teacher-led learning approaches and it takes time to for them to learn how to engage with the practices of STEM inquiry, group work, problem-solving and independent thinking. It should be noted that such skills do not appear simply through doing STEM activities. These types of thinking skills and ways of engaging need to be explicitly taught by STEM teachers, usually through conversations and developing reflective practices with students as part of the *doing of inquiry activities* for example [22].

Another reason may be the design and implementation of STEM activities at different knowledge or skill levels, not fitting with all students, which suggests a need for more fine-grained student support and scaffolding of activities. An example of how this type of scaffolding plays out includes the questioning skills of teachers during STEM inquiry lessons [50].

A third reason may be that some of the STEM subject content or topics, especially those borrowed from foreign textbooks, may be too far removed from the localized contexts of Chinese students' real life, making it difficult for students to make connections with STEM. All of these are valid reasons for student disengagement from iSTEM education in the Chinese context that teachers should consider when planning learning experiences.

4.2 Resonance and Difference between Chinese and International Contexts

Many of our findings resonate with previous international research focusing on challenges and opportunities in the field of STEM education. For example, there is an absence of role models for preservice teachers, who served as an experienced member of the iSTEM education community [37, 51]. Teachers in our study also said they could not observe exemplar iSTEM classes because the field was very innovative and lacked a pool of experienced teachers. Another finding with resonance in international contexts included teachers experiences of tight time schedules with 45 minute classes and rigid school structures that challenged teachers [52]. However, there were also several teachers in our study who felt very well supported by their school. Our study suggests a need for schools to reschedule double lessons for iSTEM programs to be effective, and we also highlight the need for innovative and dedicated facilities and technologies to make iSTEM education effective.

As previous research pointed out [32, 53, 54], mathematics was regarded as a barrier in iSTEM integration, and teachers in this study reported it to be the most difficult to integrate. One common challenge of integrating mathematics, in both China and other countries, is that mathematics often exist as a tool (such as graphical work, or calculation), instead of more in-depth mathematical thinking [53, 54]. Moreover, mathematics teachers reported the need for valuable support to "identify, interpret, and create mathematical opportunities pertinent to particular STEM tasks", especially for mathematics teachers who already adapted to the systematically framed curriculum [32].

There could be several reasons why mathematics become the most difficult to integrate for iSTEM teachers in China. In part, this difference may be explained by different mathematics curriculum standards, or it may be the way those standards are prioritized and taught with traditional knowledge transmission styles of pedagogy. Besides, the challenge may be due to iSTEM teachers' lack of content knowledge [31], especially when most iSTEM teachers in China have accepted single subject PD, with only one subject background. Previous researchers raises this issue of pedagogical limitations where mathematics is commonly perceived as an analytical way of objectively producing knowledge independent from the subjective experiences of the knower [22]. Such thinking in education leads to pedagogies that are over-reliant on instrumental and procedural approaches to teaching and learning. In contrast proponents of iSTEM seek to teach mathematics in relation to authentic contexts. The problem encountered in China with teachers in other subjects classes to help with problem-solving, giving students more chances to apply mathematics knowledge. It is also helpful to create a culture of open investigation that brings students to real-world mathematics, instead of routine or abstract concepts [31, 32, 53, 54]

4.3 Contextualized Professional Development

The final major theme to emerge from the present study are the features of teacher professional development for iSTEM education. Professional development can significantly improve teachers' confidence, knowledge and efficacy to teach iSTEM [30, 36, 55]. However, the teachers in our study described their experiences of PD in terms of limitations and challenges. This outcome was concerning given the investment of resources by local government and school administration, and is therefore an important finding that needs to be addressed. The teachers in this study indicated an expectation that PD be contextualized specifically for Chinese cultural contexts. In addition, teachers expressed concerns that their own knowledge and experiences were not considered and differentiated for, with the PD they received for iSTEM [56]. To be more effective, PD for iSTEM education in China needs to be more responsive to individual needs, taking into account prior teaching experiences with inquiry-based, student-centered models, questioning strategies, and problem-based learning [37, 57, 58].

A final point on the contextualization of professional development is the clear need to explicitly articulate the long-term trends in China's national policy initiatives that focus on the need for creativity and innovation to be developed across the education system. Being explicit with teachers about these policy priorities and having teachers reflect on what it means to be creative and innovative, and what these ideas look like in practice is important is iSTEM education is to truly succeed in Chinese contexts. Such big picture and conceptual contextualization may provide innovation around what it means to have a reference-based teaching system that focuses on idealized exemplar lessons.

5. Conclusion

This paper addresses the experiences and challenges of primary and middle school teachers as they teach *through* iSTEM education. The context of this study is an important feature because teachers were implementing a novel curriculum in China that explicitly included engineering in the STEM school curriculum, situating the applied nature of iSTEM. In addition, this paper presents the novelty of iSTEM education in schools, interpreted from a uniquely Chinese perspective. To conclude this paper and point toward further opportunities for research and practice improvements, we close this paper with five key points. First, if iSTEM education is to be implemented in Chinese primary and middle schools there is a clear need for teachers, STEM educators and professional development providers to explicitly think about what student engagement looks like in project-driven, student-led classrooms. There is much research in international literature that could support this innovation in Chinese schools. Second, associated with this first issue is a need for understanding how teachers could teach mathematics differently through iSTEM approaches, which may be of benefit to students in regional areas of China who may engage differently with mathematics compared to children in inner city Beijing schools. Third, a further issue related to engagement is the smaller number of students who did not engage with iSTEM, suggesting that student engagement with innovative teaching strategies may also require explicit teaching of students in new ways of learning. Fourth, in making these changes happen, there was clear vocalization from the teachers in this study that they needed local Chinese role models, as STEM champions, to provide exemplar STEM lessons, and teaching strategies that are contextualized to the particular Chinese communities in which they teach. These examples should be linked to defining creativity and innovation more explicitly so that primary and middle school iSTEM education may contribute more effectively to the national agenda of building indigenous innovations and developing local Chinese creative talent. Finally, the understanding of iSTEM should be broadened to involve more possibilities for students, such as entrepreneurial thinking, creativity, a sense of social responsibility, emotional engagement with greater confidence, identity formation and leadership development. To achieve these potentials, iSTEM classes should take the best advantage of its multidisciplinary nature and always encourage openness and flexibility for both students and teachers.

6. Limitations & Future Research

A limitation of this study is the very specific context in a single district of Beijing. We acknowledge the diversity of cultural, social and economic factors that may influence iSTEM education across the many diverse regions of China. For this reason, further research is encouraged to explore more fully the challenges and opportunities for teaching iSTEM across many Chinese contexts. Such research should address the possibilities for new ways of teaching mathematics within integrated contexts. Finally, deeper understandings of teacher experiences may be gained through research that explores classroom interactions and student voice in teaching and learning. This may be achieved with more diverse research methods such as co-generative dialogue [59] which involves productive conversations between teachers and students around various localized topics of learner experiences. This form of research method would be greatly informative of Chinese contexts where iSTEM education is being introduced.

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