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Chinese Pioneering Educators' Understandings and Practices of STEM Education

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Abstract: The Chinese education system issued a series of policies to encourage educators to explore science, technology, engineering, and mathematics (STEM) education and selected a number of schools and educators as pioneers of STEM education. Through the education policy implementation framework, this qualitative study explores eight pioneering educators' interpretations of STEM education, their knowledge of STEM education policies, and how they transform their understandings into practice. The results show that the pioneering educators hold a similar understanding of the definition of STEM education and how STEM education should be conducted. However, they adopted diverse STEM practices due to their different academic backgrounds, administration roles, school environment, available resources, and personal abilities and interests. They displayed tension and confusion over their own STEM practices and requested official guidance. The tension may have emerged from the conflicts between the top-down policy operation system and the place-based, bottom-up nature of STEM education. Further, STEM policies played a positive role in increasing educators' openness and confidence in trying new STEM education strategies; however, they could not influence how educators performed their STEM practices. The educators proposed four kinds of policies to support STEM practices. This study highlights the importance of including teachers' ownership and agency while drafting STEM education policies and proposing practices. The implications for better STEM education policy design and implementation are discussed.

Keywords: STEM education; Chinese educational reform; STEM teacher understandings; Chinese STEM educator; STEM policy implementation

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Background

In China, science, technology, engineering, and mathematics (STEM) education was recently included in strategic national development with a series of policies (An et al., 2020). The Chinese education system has been highly content intensive, exam oriented, and competitive. Even though it performed well in international assessments, the Chinese exam-oriented education system has been criticized as detrimental in developing students' abilities, creativity, and innovation. STEM education in China is expected to cultivate future talents by improving students' creativity and innovation. In February 2017, the Chinese Ministry of Education issued the new *Compulsory Education Primary Science Curriculum Standards* (2017). For the first time, these standards officially defined STEM education as a way to organize curricula, which is project based and involves problem solving (Standards, 2017, p.2). The standards state that the purpose of STEM education is to foster students' awareness and capability to innovate. In the new Standards, engineering practices and technology were added. Teachers are expected to teach science in a more integrated way.

To better help and encourage teachers to practice STEM education, in 2018, the National Institute of Educational Sciences issued the *China STEM Education Action Plan 2029* (2018), whose purpose is to explore ways to allow as many students as possible to benefit from STEM education and improve their abilities to think scientifically and be creative (p.10). In the same year, the *China STEM Education White Paper* (Chinese Ministry of Education, 2018) and *STEM Teacher Competency Rating Standards* (Pilot Version, National Institute of Educational Sciences, 2018) were issued. In the meantime, 11 STEM Education Collaborative Innovation Centers were established in different cities across the nation.

Frame the Issue

Context of Curricula in China

In China, the National Curriculum Standards are widely used in schools for teaching various disciplines, such as mathematics, science, and Chinese language and literature. Most provinces utilize standardized textbooks for these subjects, although some provinces have customized textbooks that incorporate local cultural elements. Unlike the approach in many North American countries, such as the U.S., where elementary teachers are often in charge of multiple subjects for whole classes, Chinese elementary school teachers typically specialize in teaching individual subjects such as mathematics, science, or language.

Recently, there has been a growing emphasis on STEM education nationwide, supported by a series of STEM education policies. Teachers are encouraged to integrate STEM into their teaching practices. However, the Chinese education system—from curriculum standards to textbooks and teacher education—remains predominantly structured around single disciplines. This presents numerous challenges, particularly in implementing STEM effectively. Although STEM has been incorporated into elementary science standards since 2017, there is insufficient guidance for teachers on how to integrate it effectively into their teaching practices. This issue extends beyond science to other disciplines, such as mathematics and language. Overall, while there is a concerted effort to promote STEM education in China, the current education framework presents obstacles to fully realizing these goals across different subject areas.

To realize the integrated nature of STEM and overcome its challenges in finding ways to practice it, as part of the *Chinese STEM Education Action Plan 2029* (2018), a batch of schools and educators was chosen as STEM education pioneers, including 79 STEM Pathfinder schools, 228 STEM Seed schools, and 76 STEM Seed teachers nationwide. The plan is to domestically and internationally offer these schools and teachers more professional STEM training, supported by the government, and encourage them to independently and cooperatively explore effective approaches to STEM education in their local contexts. In this way, the Chinese Education Institute and government hope the pioneering STEM schools—and, first and foremost, teachers—find the most effective and suitable ways to support the development of STEM education with academic, financial, and political support. Following this, it is intended for these schools and teachers to act as foregoers who will lead STEM education by helping other teachers and schools in local areas.

Research Purpose

Since the first batch of STEM pioneering schools and teachers was chosen, STEM education has been highly focused on and encouraged throughout the country (Fan & Li, 2018; Wu et al., 2018). Many local governments and educational institutes used a similar way to award their distinguished STEM teachers with titles such as provincial STEM Seed teacher and to provide local support for their explorations in STEM education (Ma, 2021). It has been three years since the naming of the first batch of STEM pioneering educators and schools when this study was conducted, and the number of such educators and schools has increased every year. As pioneers and implementers of the new educational approach, the practices of these teachers are likely to determine how successful STEM education will be. It is important to learn how these pioneering educators interpret STEM education and how they translate their understanding to practice in local settings. However, research on these types of endeavors is uncommon. To fill this gap, the primary purpose of this study is to investigate the STEM pioneering educators' understanding of and practices in STEM education. In addition, this study aims to investigate the educators' knowledge of STEM education policies and how the policies influenced their practices. It also aims to inform STEM education leaders and policymakers about how closely the pioneering STEM educators' understanding and practices are aligned with the STEM education goals that the country hopes to achieve. The results can be used as a reference for more effective STEM policies to support STEM educators.

Theoretical Framework and Literature Review

This study used the education policy implementation framework developed by Viennet and Pont (2017) as its guiding framework. Education policy implementation is defined as "a purposeful and multidirectional change process aimed at putting a specific policy into practice, which may impact an education system on multiple levels" (p. 10). The key determinants for successful policy implementation include a "smart policy design, inclusive stakeholder engagement, a conducive institutional, [sic] policy, and societal context, and a coherent implementation strategy to reach schools" (p. 42-43). However, this study focuses specifically on one determinant: inclusive stakeholder engagement.

Essentially, inclusive stakeholder engagement entails aligning stakeholders' (1) beliefs, interests, and motivations; (2) responses and reactions; and (3) capacities to collectively influence their reactions to policies and thereby shape the course of policy implementation (p. 43). Among the crucial factors influencing education policy implementation, stakeholders play a pivotal role in translating policy into action. They interact with other determinants and leverage their understanding and capabilities to enact policy changes. In fact, teachers, school principals, and district superintendents are critical actors in policies aimed at classroom-level transformations. Guided by this framework, this study examines how educators perceive and implement STEM education in their local contexts and their knowledge of STEM education policies. As the stakeholders of STEM education policy implementation, their understanding, interests, beliefs, motivations, and teaching capacities are crucial in determining what kind of and how STEM education is taught in China.

Teachers' Central Role in Education Policy Implementation

For the successful implementation of an education policy, teachers need to change or adapt their belief systems and practices. Teachers' beliefs and attitudes influence and shape the way they respond to constant educational reforms, which include standards, curricula, and assessments (Jones & Leagon, 2014). Whether the new educational approach will be successful is largely dependent on the teachers' buy-in because they are the implementers and practitioners of new approaches (Haney et al., 2002; Jamil et al., 2018; Keys & Bryan, 2001). The new practices advocated by the policies may conflict with the values of teachers, which causes resistance to change (Witz & Lee, 2009).

As the key stakeholders of policy implementation, teachers' practice is influenced by not only how they interpret the policy but also their capabilities of translating the policy to practice (Cavendish et al., 2020). Educational reforms often ask teachers to provide students with better learning opportunities, such as those including scientific inquiries, engineering practices, and STEM projects in their teaching (e.g., National Science Standards (NGSS) Lead States, 2013). Such practices require teachers to have advanced knowledge of the discipline, pedagogy, and learning theories, among others. For instance, in STEM education, teachers are asked to integrate science teaching with mathematics and engineering (NGSS Lead States, 2013). However, even though teachers agree with the value of such practices that are beneficial for students' learning, they demonstrate a lack of confidence and competence in following these practices (Aminger et al., 2020; Ntho-Ntho & Nieuwenhuis, 2016). Unfortunately, policymakers often do not prioritize directing implementation (Hess, 2013). For instance, Lowell et al. (2021) investigated whether the curriculum used in two middle school classrooms provided sufficient guidance and instruction for NGSS-aligned teaching. They discovered that the curriculum and instruction oversimplified the complex vision of science learning required by the NGSS, thereby failing to equip teachers with the tools necessary to implement NGSS-aligned lessons. In many cases, teachers are the recipients of education policies who shoulder most of the pressure to implement changes that they do not accept or fully understand (Pearson & Rao, 2006). They have a high demand for professional development and support during educational reform (Aithal & Aithal, 2019; Kirkpatrick & Bui, 2016; Milne, 2017; Ogunyinka et al., 2015). Thus, there is a gap between policy goals and the practical guidance of implementation that further promotes teachers' inadequacy and confusion (Mausethagen & Granlund, 2012).

One important way to improve teachers' willingness to change is to involve them in policymaking and design processes. However, in top-down education systems such as China, the policymaking process relies on those in positions of authority and power to decide what policies and how they should be implemented (Matland, 1995). Individual teachers' self-interest and beliefs are ignored. Research has shown that failing to recognize teachers' wellbeing and needs leads to ineffective policy implementation in many countries (Dimmock et al., 2021; Karkouti et al., 2022).

Teachers' Understanding of and Practices in STEM Education

As stated above, teachers' practice of policies is largely influenced by how they interpret the policies and how much relevant support they receive. STEM education has been a popular trend around the world. A variety of policies, standards, curricula, and strategies were proposed for teachers to implement. It is important to know how the teachers responded to the trend. This section presents a review of the current teachers' understanding of, practices in, and challenges that they face in STEM education.

STEM education has been practiced in a variety of ways in educational settings. In formal school settings, it is used as a complement to traditional curricula, while informal programs tend to place the primary focus on one of the disciplines (e.g., science) and use other disciplines to complement it (e.g., mathematics is used to complement science). A national study in the U.S. shows that a few programs were fully or deeply integrated into all four disciplines (Heil et al., 2013). The role of STEM as a complement to single-discipline learning also exists in many countries since no integrated national STEM curriculum exists. For instance, Malaysia integrated STEM education with an applicable curriculum (Ramli & Talib, 2017); Hong Kong went a step further by reforming its previous education curriculum to implement STEM education (Hong Kong Education Bureau, 2016); South Korea has been promoting the integration of science, technology, engineering, arts, and mathematics education since the issue of a nationwide policy agenda in 2011 (Kang, 2019); and the U.K. also put forth a similar education policy agenda (Hoyle, 2016).

Although STEM education is widely implemented, there is no agreement and unified understanding of it among researchers, educators, and teachers. Researchers have different ideas of the meaning of STEM, especially whether the four disciplines should be dealt with individually or as an integrated group (Bybee, 2013). Martín-Páez et al. (2019) reviewed the educational literature and summarized five perspectives about STEM education: integration (Sanders, 2009), transdisciplinarity (Hoffmann ‑ Riem et al., 2007), interdisciplinarity (Klein, 1990), supradisciplinarity (Balsiger, 2004), and multidisciplinarity (Tress et al., 2005).

Classroom teachers in different disciplines have various perceptions about STEM integration, leading to different classroom practices (Wang et al., 2011). Preservice and in-service teachers show a highly diverse understanding of STEM education (Radloff & Guzey, 2016). Even teachers from the same discipline are likely to have different views on STEM education. For instance, Dare et al. (2019) interviewed 37 K-12 science teachers on their perceptions of eight STEM education models and found that although all participant teachers taught science and were clear about what STEM education was, they did not agree with the same conception of STEM education. In addition, teachers participating in the same programs could develop various ideas about what STEM is (Ring et al., 2017). Bybee (2013) concludes that STEM practitioners can hold nine possible visualizations of STEM education, ranging from viewing it as a single subject to viewing it as completely transdisciplinary or more associated with real-world applications.

It is noted that a lack of teacher knowledge, skills, and experience is a major constraint in implementing integrated STEM programs (Heil et al., 2013). Teachers often feel that STEM education is challenging and have been unprepared for implementing it in the classroom with students (Nadelson and Seifert, 2017). For instance, El-Deghaidy and Mansour (2015) found that pioneering middle school teachers in Saudi Arabia believed that hardware (technology) is the core element of STEM integration, and they all felt underprepared to implement STEM education in the classroom. Jiang et al. (2021) argue that STEM teachers have various emotions in response to Chinese STEM educational reform; these emotions play crucial roles in developing STEM teachers' professional identities. Moreover, although preservice teachers are often required to plan and implement STEM lessons, they are confused about STEM education and are not confident about their practices (Ryu et al., 2019; Bartels et al., 2019).

With these views in mind, this study highlights a continuing need to investigate teachers' understanding of and practices in STEM education, especially under educational reforms and policies, and how the reforms and policies eventually manifest in STEM teaching and learning.

Reserach Questions

With the gap and need identified, this study investigates the key stakeholders of the STEM policies: the pioneering STEM educators—specifically their understanding of STEM education and how it is reflected in their teaching practices. In addition, this study investigated their knowledge of STEM policies and how they influenced their practices. The research questions are as follows:

(1) What are the pioneering educators' understandings of STEM education?
(2) How do they practice STEM education in their teaching routines in local contexts?
(3) What is their understanding of STEM policies, and how have their practices been influenced by them?

The results of this study will inform educators, researchers, and policymakers about the current educators' understanding of and practices in STEM education under educational reform and a series of policies. They can provide a reference for policymakers to analyze whether the educators' understanding and practices are going in the direction they expected. While this study focuses on Chinese educators, it can provide useful information to other countries regarding the effectiveness of policies in encouraging the development of STEM education, especially those whose education systems are also content intensive and exam oriented.

Methods

This study takes an interpretivist approach to investigate the understanding and practices of eight pioneering Chinese STEM educators and their knowledge of STEM policies. In fact, interpretivism assumes that knowledge is socially constructed by individuals, groups, and cultures. An interpretivist approach aims to thoroughly document the perspectives being investigated (Schwandt, 1994). It meets this study's purposes because it allows the researchers to "build rich local understandings of the life-world experiences of teachers and students and of the cultures of classrooms, schools and the communities they serve" (Taylor & Medina, 2011, P. 5). The knowledge produced by the interpretivist approach in this study is based on the intersubjective knowledge construction of the researchers and pioneering educators (Taylor & Medina, 2011). Therefore, the researchers' subjectivity is important in building the trustworthiness and authenticity of this study (Taylor & Settelmaier, 2003).

In other words, the researchers' experiences of immersing themselves in the fields, environments, and cultures they investigated should be reflected in interpreting the pioneering educators. The first and second authors are native Chinese, have experienced the traditional education system, have taught in China, and are studying in the U.S. When interacting with the pioneering educators, the language used was Chinese Mandarin, which increases the likelihood of accurate communication and understanding. The researchers admit that subjective bias still occurred and that it is impossible to fully understand the participating educators' experiences. However, with the shared culture, life experience, language, and understanding of the Chinese education system, the researchers believe this study is reliable in providing insights into the Chinese pioneering STEM educators' understanding of and practices in STEM education with trustworthiness and authenticity.

Within the epistemological paradigm of interpretivism, interviews were used to investigate the pioneering educators' STEM knowledge and practices. The interview with each participant was semistructured with three topics: (1) educators' general understanding of STEM education, (2) their routine practices in STEM education in the local context, and (3) their understanding of STEM education policies. Each topic included several guiding questions, and the researchers adjusted the questions according to the actual interviews. The interview protocol can be found in the Appendix.

Participants

The participants in this study were eight pioneering STEM educators with various backgrounds, professional positions, disciplines, and geographies (see Table 1). The researchers recruited some of the educators by sending emails according to the name lists of STEM Seed teachers and STEM Pathfinder, Seed, and Pilot schools issued by the National Institute of Education Science (2018). Others were recruited based on the recommendations of the enrolled STEM educators. The researchers counted them as STEM pioneering educators because (1) they were officially accredited as STEM Seed teachers by Chinese education institutes, (2) they were principals from STEM Pathfinder or Seed schools, or (3) their STEM projects were awarded in STEM education conferences, demonstrations, or competitions by national or local education bureaus. All of the pioneering educators were either leading teachers or had many years of teaching experience when this study was conducted. Except for Superintendent Z, who was not teaching in the classroom during this study, all seven other educators, including the principals, were still actively teaching while also shouldering administrative responsibilities.

Table 1

Background Information of the Pioneering STEM Educators

Educator Pseudonym	Background
Superintendent Z	He is the district STEM education superintendent in an urban area that has more than 40 schools. He and his colleagues work with local schools to explore how to implement STEM education. Since 2017, a variety of STEM education events, such as seminars, meetings, project demonstrations, and teaching competitions, have been hosted for local teachers and schools to explore STEM education. He used to be a science teacher for 21 years before he moved into the position of district superintendent for STEM education.
Principal X	She is the principal of a STEM Seed public school in an urban area. Her school was accredited as a STEM Seed school in 2019 by the National Education Institute. As the principal of the school, she supports and works with teachers to explore how to implement STEM education. She has 30 years of teaching experience, of which 20 years were dedicated to science teaching.
Principal T	He is the principal of an urban public primary school. He is passionate about STEM education and works with teachers in his school to explore how to engage students at different grade levels in STEM projects. Many STEM projects in his school were awarded at the national, provincial, or local levels. He has 18 years of experience as a science teacher.
Vice Principal M	She is the vice principal of an urban public primary school. She was accredited as the Master Teacher of mathematics and was funded by the local government to conduct regular professional development workshops to help other teachers in their district. She is interested in and specializes in project-based learning and STEM in mathematics education. She has 20 years of experience as a mathematics teacher.
Teacher S1	He is a science teacher at a rural public primary school in the Tibetan Minority Autonomous Region. He was accredited as the Master Teacher of science and a STEM Seed teacher at the provincial level and was funded by the local government to conduct professional development workshops for other science teachers nationwide. Before and during the pandemic, he uploaded and livestreamed his science and STEM classes online, which made him an internet celebrity and attracted thousands of fans. He has 28 years of experience as a science teacher.
Teacher S2	He is a science teacher at an urban public primary school. He is interested in maker education and problem-based learning in science education. He is the director of a maker education center in the local city. Currently, he is funded by the National Education Institute to study STEM and conduct workshops for other teachers in his school. He has 30 years of teaching experience.
Teacher C	He is a computer science teacher at a rural village primary school. He is interested in makers and STEM education, especially in the electronics area. He teaches maker classes in school during extracurricular activities. Since 2008, 20 of his student projects have been accredited with national patents. He has 23 years of teaching experience in computer science.
Teacher A	He is an art teacher at an international private STEM pilot school in an urban area. He has experience teaching art and STEAM to students from kindergarten to high school. Apart from teaching, he designs the STEM curriculum for the school and works with students on their projects. He has 15 years of teaching experience.

Data Collection and Analysis

Each pioneering educator was interviewed at least once during the study. Interview 1 was semistructured by the protocol (see Appendix) and lasted 60–90 minutes. The interview questions were designed based on the research purpose, which aimed to understand these pioneering educators' interpretations of and practices in STEM education and their knowledge of STEM policies. The researchers designed and conducted the interviews by following Patton's work (2014). Their guiding principle was to build on conversations for the interviewees to provide a comprehensive description of their living experiences as the main topic. The first author tested the interview questions with several STEM educators, following which she presented this feedback and discussed revisions with the other authors. The first and third authors agreed on the interview questions after several rounds of discussion. After the first interviews were reviewed by the researchers, follow-up interviews (the second round) were conducted to acquire supplementary information and enrich the researchers' understanding of the educators' experiences. No specific protocols were created for the second interview; the questions were generated from the information provided in the first interview. For instance, the educators may have mentioned in the first interview that they had the experience of visiting STEM schools in other countries but had not received the opportunity to elaborate on how these experiences affected their STEM education's understanding and practices. Thus, in the second interview, the researchers asked the educators to provide more details about their understanding and experiences. After the researchers reviewed the results of the first interview, they found that they needed more details from four of the participants. They then invited them to the second interview so that they could elaborate on their responses to some of the questions from the first interview. The researchers had approximately 15 hours of audio interview recordings from eight educators.

Following this, the data were analyzed using an open-coding method based on grounded theory (Strauss & Corbin, 1997). The first researcher went through the interview transcripts and analyzed the data by inductively focusing on capturing the educators' narrations related to their understanding of STEM education, their routine practices in STEM education, and their knowledge of STEM education policies. The themes emerged directly from the data. The researchers met regularly to discuss the themes that were found in the data, and coding was revised throughout the process. After the first author completed the initial data analysis, the second author went through the results and provided validation and other feedback, such as regarding the accuracy of the translation of educators' ideas from Chinese to English. The final results were revised based on the discussion between the first and second authors.

Findings

Pioneering STEM Educators' Understandings of STEM Education

All of the pioneering educators emphasized that STEM is an educational philosophy. Although the definitions they presented varied to some extent, four common themes were identified: integration and real life were most frequently mentioned, followed by project-based and a new way of education. They had different ideas about which element from STEM should be at the center of STEM education. In fact, five out of eight educators indicated that there was no specific discipline at the center. Different disciplines in STEM education are always combined to meet the aim of solving the problem that the students identified. However, the educators also indicated that in practice, engineering was more often at the center of STEM education. All pioneering educators indicated that one of the important goals for STEM education was to develop students' problem-solving abilities. In the process of solving real-life problems, students will also foster creativity and other comprehensive abilities such as teamwork and communication skills.

All of the pioneering educators indicated that STEM classes could not replace but coexisted with the traditional single-discipline classes. They preferred students learning basic content knowledge before participating in STEM projects or activities. They indicated that single-discipline classes were the foundation for engaging in STEM inquiries and projects. However, this did not mean that the students needed to know everything before the project. The educators emphasized that some basic content knowledge and skills were necessary, while deeper learning could happen during the project. Specifically, in the first interview, Teacher S1 commented that STEM education was not perfect and had its drawbacks:

> I don't think there is such a thing in the world that is perfect in every way. Even though we know there are many problems in the traditional way of learning, we should not discard it entirely. STEM education is good for students' comprehensive learning, but the shortcoming is that it takes a long time. While single subject learning is hard to cultivate students' well-rounded ability, its advantage is that it needs less time to acquire the knowledge. So, I think they should coexist in the education system and are equally important.

All of the pioneering educators agreed that STEM education for Chinese students was meant to compensate for the disadvantages of single-discipline learning. By combining STEM education and traditional education, students have better opportunities to learn in a well-rounded way. The educators expressed that practicing STEM education in regular single-discipline classes is beneficial but not realistic. The constraints include time issues and high requirements for teachers. More importantly, as Principal T highlighted, it is more difficult to integrate STEM into some disciplines than others. For instance, his school held successful try-outs in integrating STEM into science classes. However, teachers who taught other disciplines, such as literature and art, faced more challenges in integrating STEM into their teaching. If the discipline's curriculum has many project-based learning techniques, such as science, it would be easier for teachers to integrate STEM. However, if the discipline's curriculum does not have integrated learning opportunities, such as literature, the teachers would find it difficult to integrate STEM.

Pioneering Educators' STEM Practices

In the Chinese compulsory public education system, there was no official STEM class through K-12. The ways in which the educators practiced STEM education varied depending on multiple factors, including their academic backgrounds, administration roles, school environments, and personal abilities and interests. Four of the pioneering educators, who did not have administrative positions in schools, practiced STEM education by using their own classes or extracurricular activity time. The focus of the educators' STEM classes was related to their academic backgrounds. For instance, Teacher S1 and Teacher S2's STEM classes or projects were related to science topics, while in Teacher C's STEM classes, more focus was placed on computer science and electronics. Two educators, who are school principals, practiced STEM education by designing large STEM events that were usually at the whole-school level and could involve most of the students in the schools. Principal T admitted, “I have more resources and power than an ordinary teacher. So, it is important for the school leaders to know about STEM and provide support in developing STEM education.” Only one educator, Teacher A, regularly scheduled STEM classes because he works at a private international school and thus has some autonomy and flexibility in determining the curricula for his students. In his school, STEM classes were taught in STEM classrooms twice a week.

All of the pioneering educators held a positive attitude toward STEM education. The most important benefit of practicing STEM was that students showed great interest and passion in learning. Teacher S1 described in his class that “some students won’t even waste the 10 minutes [*sic*] break to go to the bathroom because they were [*sic*] so engaged in their projects.” The educators indicated that all the STEM project ideas were inspired by real life and were identified by the students themselves; therefore, the students had great interest in and motivation to participate. In addition, STEM education contributes novelty to the relationship between students and teachers. During STEM activities, teachers’ authorities were decentralized and the students showed more agency. In the first interview, Superintendent Z observed the following:

> We have textbooks and standards in traditional teaching. Teachers know what to teach next and how to teach it. However, in STEM projects, many problems are raised and generated during the class when students and teachers need to interact, communicate and discuss. Thus, the learning style is different from the traditional way [*sic*]. Teachers and students have closer relationships.

Engaging in STEM education also empowered other teachers. Teacher S1 shared that when other teachers observed his STEM classes, they admired him for being able to effectively engage students. Some teachers expressed their desire to learn how to implement STEM education from him. However, the biggest challenge in practicing STEM is in designing activities. Vice Principal M shared, “It is not easy to find the relevant topic because STEM classes need to meet many purposes. I saw many STEM classes which were more like handcrafting activities. The kids liked them, but I don’t see many educational purposes.” Even for the STEM activities that have been practiced, the educators said that the connections between different STEM activities were highly loose, and there was a need to turn them into a learning system or a curriculum. Principal T, who was very proud of his school’s STEM practice in terms of engaging all students and teachers in large STEM projects every year, highlighted the drawbacks of such practices: “We need to think about how to make the big STEM projects into [*sic*] many small ones and integrate them into students’ daily learning.” He wanted STEM education to be more systematic and normalized in students’ daily learning. Principal X added that some real-life problems were identified and solved in the first year and could not be used again in the next year. Therefore, every year, they needed to develop new STEM projects by guiding the students to identify new problems, which was extremely difficult. In addition, there were few resources that the educators could use when designing STEM projects compared with traditional single disciplines. Indeed, it takes a significant amount of energy and time to develop a STEM project.

Pioneering STEM Educators' Knowledge of STEM Policies

The pioneering educators showed limited knowledge of STEM policies. Most educators could name some STEM policies at the national and local levels; however, they were unfamiliar with the content of those policies. However, the educators shared a similar understanding of the purpose of the STEM policies: most aimed to encourage educators to explore different STEM practices. They indicated that there was no policy to specifically indicate how to practically implement STEM education. The policies are more about educational needs, such as practicing interdisciplinarity and developing students' abilities, rather than specific strategies and details of what and how to implement STEM practices. Principal T thought that the reason for this was that China is a big country in which different areas have various contexts in terms of developing STEM; it is therefore impossible to specify how to implement STEM education in a unified way.

All of the pioneering educators expressed the need to know about an authoritative or authentic way of implementing STEM education. They expressed uncertainties over their own STEM practices and were unsure whether they were on the right track. However, at the same time, they were also aware that the methods of implementing STEM education were highly dependent on the local context. Indeed, it is impossible to imitate other educators' STEM practices in their own contexts. In the first interview, Principal X shared his experiences of visiting schools in the U.S. and Finland:

> We hoped we could bring some of their STEM practices into China, but it turned out [to be] impossible. Everything is different. The students, teachers, resources, and even the classroom arrangement and sizes. Their STEM practices won't work in our classes in China.

The other pioneering educators also showed such conflicting feelings. To elaborate, Teacher A used an old Chinese adage to describe their exploration of STEM education as "wading across the river by feeling the stones. Every step is uncertain, and you have to make your own way because everyone's path would be different."

STEM education policies encourage the educators to try new practices; however, they have no influence on how they practice STEM education. Teacher S1 said, "The policy made me feel that what I am doing and what I am passionate about is [*sic*] the right thing. With the encouragement, I feel I can go further in this route." However, Teacher C and Teacher A indicated that the policies did not have much influence on their practice: "A lot of STEM policies are about giving funding, which is the main way to encourage educators to explore STEM practices. However, there is no policy that tells you how to do it."

The educators indicated that whether the policies had an influence on the school's STEM practices depended largely on the school principals—e.g., in the second interview, Principal T said, "If the principal is a literature teacher, he/she might not want to do the STEM [*sic*]. His/her background knowledge will influence his/her decision about what their school would focus on." In addition, STEM policies do not have much influence on the teacher's professional promotion systems and thus do not influence their practices at all. Many educators indicated that their passion for STEM education did not align with their personal interests. All the educators expressed that they felt no pressure in their STEM practices because implementing STEM education was an option, not a requirement, according to their understanding of STEM policies. However, most of them expressed that being named a pioneering STEM educator was pressurizing since they were supposed to show how to implement STEM education to other teachers.

Policies Needed to Support Educators' STEM Practices

Including STEM in the Education Assessment System.

The Chinese education system is highly dependent on established standard tests and college entrance examinations that are not compatible with STEM education. The assessment system in the Chinese education system works similar to a baton in a symphony orchestra: it determines what and how students learn in classrooms. In the first interview, Superintendent X indicated that "in high school and college entrance exams, we could start to include questions that are [*sic*] related to STEM activities and project-based learning. In this way, our teachers would gradually include these new ways of teaching into their classes."

Including STEM in the National Curricula System.

All of the pioneering educators expressed that there was a need to accord an official status to STEM education in the National Curricula System. Although the overall environment of STEM education was highly encouraging, the pioneering educators felt several uncertainties over their STEM practices. The educators' STEM practices were mainly self-guided because there were no curriculum, guidelines, standards, or class hours in the timetables for STEM education. Essentially, there was no stable platform for it in regular schooling. With so many difficulties and uncertainties, the pioneering educators expressed that they had no pressure to implement STEM education because it was only an option. Nevertheless, they hoped STEM would be included in the National Curricula System so they could at least understand the directions of implementing STEM education. They stated that, although they were willing to try and practice STEM, they realized that it required team effort. There should be systematic cooperation from different institutes in the education system and support from society as a whole.

Including STEM in the Teachers' Professional Development and Promotion System.

All of the pioneering educators indicated that there were not enough teachers who knew STEM and who could teach it in China. There is a need for policies to support in-service teachers' STEM practices. The coverage and content of the present STEM professional development program cannot meet the needs of the educators from different areas. For instance, Teacher C, who is from a village school, said that STEM professional development opportunities for teachers like him were rare and that most of what he had attended was not helpful. In addition, all of the pioneering educators hoped that policies would be implemented to include STEM education in the Teacher Professional Promotion System, which directly impacts their income. Although there have been many STEM events for teachers to participate in in recent years, the number of events that would benefit teachers' promotion was low. In the second interview, Teacher C further explained the following:

> For myself, I am not expecting material benefits from doing STEM. I am just interested in doing it. However, I know doing STEM is time and energy consuming. For other teachers, if they commit themselves into [*sic*] doing it, I think they should have some returns. I hope the returns would make them think what they are doing is worthwhile and valued.

Apart from motivating more teachers to learn to implement and practice STEM education, teachers who have better expertise in STEM education should be accredited and receive rewards.

Establishing Stable and Long-Term Funding for STEM Education.

All of the pioneering educators expressed that, although there are policies at different levels to encourage schools and teachers to use funding to practice STEM education, there should be policies to guarantee a stable budget in implementing it every year. Since developing STEM education is a long-term project and the progress is slow, stability and enough funding would definitely be helpful. Teacher S2 made the following comment in the first interview:

> It is teamwork, takes time, and needs money. You need to build the room, buy the materials, develop technology, etc. You cannot just suddenly go to a fifth-grade classroom and say, 'Let's have a STEM class,' which is impossible. It is a gradual process.

He further explained that all STEM practices needed money, including designing and implementing STEM projects and teacher professional development. Therefore, instead of applying and getting funding piecemeal, which depends on when the relevant policy is released, educators prefer a long-term funding plan to better support their STEM practices.

Discussion

In Viennet and Pont's (2017) education policy implementation framework, inclusive stakeholder engagement is identified as one of the four crucial determinants of successful policy implementation. There are three key aspects to consider when integrating stakeholders into effective policy implementation: (1) stakeholders' beliefs, interests, and motivations; (2) their capacities; and (3) their responses and reactions to the policy. This study investigated eight Chinese pioneering STEM educators' understanding of and practices in STEM education and their knowledge of STEM policies. The following sections utilize this framework to discuss how these educators engage with each aspect in the implementation of STEM education policies.

Educators' Beliefs, Interests, and Motivations

Stakeholders' beliefs, interests, and motivations determine whether and to what extent they desire to engage in the policy implementation process (Viennet & Pont, 2017). One important factor for successful policy implementation is determining whether the stakeholders agree with the policy goals and buy-in to solve the problem (Bybee, 2013; Ntho-Ntho & Nieuwenhuis, 2016). This study found that the pioneering educators showed a common understanding that STEM education can be a promising national strategy for cultivating talents. The pioneering educators all agreed that (1) the traditional education system is not beneficial for cultivating students' real-life problem-solving abilities, creativity, and innovation; (2) integration is key to implementing STEM education; and (3) engineering is the most frequently used discipline that cultivates problem-solving skills. They also showed a highly similar understanding of how STEM should be practiced in China, which is as follows: (1) STEM classes need to coexist with traditional single-discipline classes; (2) students need content knowledge before participating in STEM activities; and (3) STEM education is an effective method of engaging students in learning.

Educators' Capacities

Stakeholders exhibit autonomy in their interpretation of policies and enact them in their daily activities (Viennet & Pont, 2017). They have the potential to impact various factors that hinder the implementation process. Hence, a crucial aspect to evaluate is their capacity to influence a particular policy. This influence is gauged by their resources, including prestige, networks, and personal qualities, as well as their determination to utilize these resources effectively for political influence. When translating the policy into practice, teachers' practices are inevitably affected by institutional and social contexts as well as personal capacities (Jones & Barkhuizen, 2011; McLaughlin, 1998). In this study, although the pioneering educators demonstrated a similar understanding of STEM education, their STEM practices were diverse and influenced by their academic backgrounds, administration roles, school environments, available resources, and personal abilities and interests. The educators in different roles had different visions, powers, and resources for implementing the different levels of STEM projects. In addition, they focused on different aspects of STEM education based on their own local contexts and needs (Johnson, 2012).

Educators' Responses and Reactions

Collectively, stakeholders' interests and capabilities determine their response to a policy (Viennet & Pont, 2017). In this study, all of the pioneering educators showed passion and motivation for STEM education and a shared understanding of its meaning and how STEM should be practiced. However, they exhibited a variety of STEM practices influenced by their capacities in different school contexts. They called for additional policies to guide STEM practices.

Previous research has emphasized the significance of providing support to teachers for their practices even when they agree with policy goals and values (Johnson, 2012). This study further supports the importance of including teachers' ownership and agency in STEM policy implementation. As shown in the findings, the pioneering educators experienced tension and confusion over their own STEM practices. On the one hand, they all expressed the need to know the authoritative way of implementing STEM education. On the other hand, they realized that STEM practices were highly dependent on the local context and the individual teachers. This tension may stem from the conflicts between the top-down centralized policy operation system and the new education systems needed to implement STEM education (Sharma & Yarlagadda, 2018).

In the top-down Chinese education system, teachers are used to following the commands and guidance of their department's deans. The centralized education system makes teachers dependent on the authorities who can guide their teaching (Aithal & Aithal, 2019). However, in STEM education, education systems are decentralized (Johnson, 2012; Thomas & Watters, 2015). Teachers are expected to determine how to practice STEM education, depending on their own teaching methods, without highly specific guidance. Furthermore, STEM classes are decentralized from teachers to students because many STEM activities need to be generated from students' own ideas and life experiences (Johnson, 2012; Thomas & Watters, 2015). Failing to recognize the bottom-up nature of STEM education in policies leads to confusion and uncertainty among educators.

Limitations

While this study focuses on Chinese STEM educators, it may provide lessons for other countries, especially those that are also using policies to promote STEM education at different levels. For instance, many Asian countries consider STEM education a tool to improve learning outcomes for students, such as developing problem-solving skills, creativity, and innovation (Wahono et al., 2020). However, this study has its own limitations. First, although the interviews were designed with different content in mind, they were the only sources of data. This study included class videos in the second interview; however, they were not analyzed as data sources due to their main purpose of prompting participant responses to the interview questions. Furthermore, the first author was the main person coding the data. The limitations of this decision were recognized, and multiple meetings were conducted with the second author for validation.

Implications for STEM Education Policy Implementation

In top-down systems, education policies are imposed by the authorities on stakeholders who are required to implement them (Aithal & Aithal, 2019). How stakeholders interpret, modify, and implement the policies may vary depending on their values, knowledge levels, supporting environments, and available resources (Aithal & Aithal, 2019; Ntho-Ntho & Nieuwenhuis, 2016). The pioneering STEM educators showed passion and willingness to explore STEM practices, as encouraged by the policies. However, they all demonstrated confusion and uncertainty over their knowledge and practice in STEM education. They expressed a desire for official guidance on whether their understanding of and practices in STEM were on the right track. This implies the need to include educators' ownership and agency in defining STEM education in the policy.

As Bybee (2013) argues, while researchers can provide a crude definition of STEM education, the most accurate one(s) comes from one's personal context and needs. The results agreed with Das and Adams' (2019) critical argument that STEM education should be based on the local context and the knowledge of learners and educators. When drafting STEM policies, this knowledge should be considered and encouraged.

In fact, education policy implementation is a complex process that requires cooperation from many stakeholders (Aithal & Aithal, 2019; Bybee, 2013; Ntho-Ntho & Nieuwenhuis, 2016). Although all the educators in this study were pioneering STEM educators and had already gained many achievements in STEM education fields, they expressed the need for not only more professional development programs and better promotion systems but also a broader range of educators who are not mathematics or science teachers—especially those who have administrative roles. The barriers to developing STEM education and implementing policies are related to not only time, money, and competing agendas but also the stakeholders and partners without the learning opportunity to develop a common vision and strategies before the implementation of STEM education (Johnson, 2012). As shown in this study, educators with leadership roles have more power and resources than educators who do not; thus, they are capable of creating a larger impact on their school's STEM practice.

Conclusion

Motivated to use STEM education to boost the economy by cultivating more future talents, the Chinese education system issued a series of policies to encourage educators to explore STEM education (An et al., 2020). This study analyzed eight pioneering Chinese STEM educators' understanding of, practices in, and knowledge of the policies. It offered insights into the factors impacting these educators' practices following STEM policies and the support needed to develop better practices. Although they were all passionate STEM practitioners and were accredited as experts in STEM practices, they all demonstrated uncertainty and confusion over their practices. This tension arises from the conflicts between the top-down system and the place-based nature of STEM education. The researchers believe that respecting teachers' ownership and agency while defining STEM education is necessary in policy implementation.

While the eight educators cannot represent all Chinese STEM educators, this study has the potential to inform education policymakers about the current educators' STEM understanding and practices under the influence of related policies. As it provides an in-depth understanding in specific contexts, this study can help education leaders and policymakers evaluate whether there is a gap between the current educators' practices and the direction they hope to take. Additionally, it provides a snapshot of how educators tried to make sense of these new policies before the educational rollout across one of the largest countries. Thus, better STEM policies for supporting STEM educators can be designed in the future.

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Appendix

Interview 1: Guiding Questions (Around 60 Mins)

Part 1 (Teacher's General Understanding of STEM Education)

(1) What is your understanding of STEM education?
(2) What is your understanding of the relationship between S, T, E, M? Any letter is capital? Why?
(3) What is the relationship between STEM classes and other science and/or technology classes such as math, physics, chemistry, computer sciences and so on?
(4) What are the goals in STEM classes? Why is China promoting STEM education?
(5) Is it necessary to teach students content knowledge before doing STEM projects? Which way do you prefer? Learning content knowledge before doing projects or providing content knowledge while doing the projects?
(6) What is the future STEM education development direction?

Part 2 (How Their Schools' STEM Education Looks Like)

(1) How many classes each week for STEM classes? In what way? STEM class or using STEM to teach science or art?
(2) What are the successful aspects of your STEM classes?
(3) What are the challenges of the STEM classes?
(4) What do you think about where we are right now in terms of developing STEM education? Or how's your local school's STEM education development?
(5) What kind of support do you need and challenges you are facing in developing STEM in your local school?

Part 3 (Their Views on STEM Policies)

(1) Are there any policies on STEM education nationally or locally?
(2) How do those policies impact your teaching?
(3) Do you have any challenges in implementing the policy in your teaching?
(4) Do you need any support for your teaching in order to align with the policies?

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