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Developing Undergraduate Student Teachers' Competence in Integrative STEM Teaching

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Developing students' literacy in Science, Technology, Engineering, and Mathematics (STEM) has been a major education issue since the 1990s. STEM education aims to support students to make informed decisions on social issues and become global citizens. In contrast with the interdisciplinary nature of STEM, initial teacher training usually focuses on teaching discrete subject disciplines. Novice teachers may also lack the relevant training in design and engineering to foster the practices in the classrooms. This article reports an initiative of preparing 25 pre-service teachers for integrative STEM teaching. The 24-h course combined the learning of design concepts and teaching inquiry within teaching the science content. Lesson activities of STEM classrooms engaged the novice teachers as "students"; and then they were prompted to reflect metacognitively on how they could support the "students" as teachers. Results from the questionnaires and focus group interviews indicated the importance of engaging the novices both as learners and future teachers of STEM education.

Keywords: teacher education, integrative STEM education, novice teachers, teacher competence, cognition and metacognition

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INTRODUCTION

STEM (Science, Technology, Engineering, and Mathematics) education advocates an integrative approach (Sanders, 2009) to help students better understand concepts, acquire the 21st century skills such as problem-solving (e.g., National Science Foundation, 1996), and become more able to tackle real-life problems. Nevertheless the ways of how integrative approach can be adopted in classroom has remained uncertain. A lack of integrative approach also exists in teacher education programs. Initial teacher training often focuses on discrete subject disciplines (Blackley and Howell, 2015). Novice teachers may also lack comprehensive training in scientific inquiry, technology, design, and engineering to teach the relevant practices proficiently.

To address this concern, a pre-service teacher course was introduced to advance STEM literacy (Bybee, 2010), and prepare them to teach the students within science lessons in an integrated manner. The design of the course integrated scientific inquiry and design concepts (Sanders, 2009) within the context of science teaching (Moore and Smith, 2014). The course involved 25 participants to play the role as their future students engaged in STEM learning activities for primary and secondary schools. The pre-service teachers could argue for their product designs with STEM principles in a cognitive manner (Chi and Wylie, 2014). Follow-up reflection and discussions on the pedagogies, as modeled by the course instructor in the activities, aimed to facilitate the participants to reflect metacognitively on how their students could be prompted to suggest creative solutions for daily-life problems. The discussions were extended to several cycles of reviewing the pre-service teachers' own STEM lesson plans, which further enhanced their understanding and enactment of teaching STEM in classrooms.

The usefulness of this initiative was reviewed by listening to the voices of the course participants. Results indicated the importance of engaging them both as learners and teachers of STEM education. The course activities provided a platform for the pre-service teachers to review what they knew, what they didn't know and identify the possible ways to achieve the learning goals. Timely feedback from their peers was important for the course participants to understand the how interdisciplinary education would be possible in teaching a single discipline, i.e., science in this case.

STEM LITERACY AND STEM EDUCATION

The acronym STEM (Science, Technology, Engineering, and Mathematics) represents the four closely related and yet independent fields of study. As early as in 2010, many researchers have already pointed out a lack of understanding about this acronym among the STEM-related professionals (Keefe, 2010). STEM seems to be more related to science and mathematics, while the importance of technology and engineering are usually undermined. The interconnection between the four fields should be strengthened in education for the sake of developing STEM literacy (Bybee, 2010).

Similar to STEM, STEM literacy is difficult to be defined. According to Zollman (2012), different professional organizations give multiple definitions to scientific literacy, engineering literacy, technology literacy and mathematical literacy. Achieving literacy in these four domains does not necessarily lead to STEM literacy. For example, learning the crosscutting concepts and practices in science and engineering (National Research Council [NRC], 2013) would mean learning the concepts, skills, processes, metacognitive capabilities and dispositions of the two domains at the same time. In addition, STEM literacy is dynamic as there is continuous development in the four domains. STEM literacy is also dependent on the social, cultural and environmental contexts. As a result, STEM literacy remains as a broad and ambiguous notion.

The interdisciplinary nature of STEM naturally advocates integrative instructional approaches. Sanders (2009) pointed out that these are "approaches that explore teaching and learning between/among any two or more of the STEM subject areas, and/or between a STEM subject and one or more other school subjects" (p. 21). Other educators focus on how to develop students' practices to tackle real-world problems with the application of STEM (Breiner et al., 2012). Since STEM education emphasizes a lot on developing skills (e.g., Morrison, 2006) and connecting students to the real-world situations (e.g., Zeidler, 2016), it is important to involve two or more STEM disciplines in teaching and learning.

Integrating science and mathematics has been common in STEM classrooms (Watanabe and Huntley, 1998; Koirala and Bowman, 2003). According to a meta-analysis of 98 studies on integrative STEM approach (Becker and Park, 2011), a majority of 36% studies integrated mathematics and science. The other types of integration (e.g., engineering and science) remained 18% or below. Results from previous studies show that such integration usually had positive effects on the affective domain of student learning (Gutherie et al., 2000) and student achievement (Hurley, 2001; Fortus et al., 2005). As a result, it is common for teacher professional development courses to combine science and mathematics for integrative STEM teaching (e.g., Berlin and Lee, 2005).

CHALLENGES OF INTEGRATIVE STEM INSTRUCTION

With such a complex nature of STEM literacy and STEM education, teachers undoubtedly experience great challenges in preparing the students to become STEM literates. Therefore a lack of integration of STEM education from K-12 has been identified (English, 2016). Meaningful connections between the four STEM disciplines have been consistently missing in the curricula (e.g., Dickerson et al., 2016). Although there have been calls for including technology and engineering in classroom teaching, the response rate has always been slow (Bybee, 2010). The competency of teachers can be a major reason.

Proficient teachers require specific subject matter knowledge and practical knowledge to teach well. The education background (Pang and Good, 2000; Kennedy and Odell, 2014) and teaching experience (Verloop et al., 2001) of individual teachers would have strong influence on the integrative approach they would develop. If teachers have already got deficits in their subject matter knowledge, it would be very likely for them to experience new knowledge gaps and challenges in implementing integrative STEM education (Stinson et al., 2009).

The challenge for novice teachers to adopt interdisiciplinary teaching can be doubled. Pre-service teacher training often focuses on discrete disciplines such as science and mathematics (Blackley and Howell, 2015). In a study carried out for 119 Australian pre-service teachers with STEM-related educational background, STEM was regarded by the novices as an important component of teacher education (Kurup et al., 2019). They needed training to develop their understanding, skills and dispositions to teach STEM. However, the pre-service teachers reported that they had not been well-prepared by the courses and professional practicum. In summary, pre-service STEM teacher education is still developing; and a lot of initiatives are essential to successfully implement integrative STEM instruction.

DEVELOPING PRE-SERVICE TEACHERS' COMPETENCE FOR INTEGRATIVE STEM INSTRUCTION

Quality STEM teacher education should first aim at improving the conceptual understanding of the teachers. A comprehensive coverage on the key learning theories such as design thinking, computation thinking and scientific inquiry (Kelley and Knowles, 2016) is necessary. Relevant pedagogical approaches such as problem-based learning should be introduced so that the awareness of teachers can be raised. Since initial teacher training is usually more discipline-focused, there have been very few empirical studies on the professional development of pre-service *integrative* STEM teachers (Brown, 2012), particularly for teaching more than two disciplines other than science and mathematics.

Berlin and White (2010) presented how different components of a master of education program could integrate the four disciplines in teaching. The program reinforced content knowledge and pedagogy of integrative STEM teaching. Pre-service teachers had to produce teaching packages, carry out action research and attend examination to fulfill the program requirements. Results indicated that pre-service teachers valued the integrative approach of STEM at the end of the program. Nevertheless they also reported that integration sounded to be more challenging than they had anticipated before. Therefore the two researchers suggested that STEM teacher preparation should *address the participants' perceived difficulties*, for instance by providing *authentic examples* of integrative STEM instruction in the program.

Other than developing a whole program, reforming part of a teacher preparation curriculum can still be useful for initial training. Rinke et al. (2016) presented how a new 6-credit STEM block could prepare the primary pre-service teachers in teaching STEM. The block emphasized on the subject matter knowledge and the related pedagogical knowledge and practices. *Processes of technology and engineering such as design thinking* that are usually neglected in classroom teaching were introduced. At the end of the course, the student teachers showed significant increase in the content integration of their lesson planning, made better use of engineering and design concepts, and were more confident to teach STEM.

In another study, Radloff and Guzey (2017) introduced authentic examples of STEM teaching to the pre-service teachers through the use of videos. A video-based intervention was carried out within a semester to engage the pre-service STEM teachers to observe, analyze and reflect upon STEM classroom instructional practices. The research suggested that the video-based approach could enhance their conceptions of integrative instruction, for which this understanding could be quite different from that of not having the intervention.

The limited number of studies indicates the difficulties of integrating the four fields in teacher education. Due to the small number and coverage of these studies, the useful instructional approaches of integrative STEM teacher preparation programs have been marginally touched upon. This article reports on an initiative for developing pre-service teachers' competence in integrative STEM education. An examination of the effects of particular instructional approaches to improve their conceptual understanding of integrative STEM instruction and their subsequent readiness can provide insights for teacher educators to better prepare the novice teachers.

TEACHING AND LEARNING STEM

STEM education was first emphasized in Hong Kong by the Chief Executive in the 2015 policy address (Census ang Statistics Government of Hong Kong, 2015). A later policy document of the Education Bureau (2016) reformed the Science, Technology, and Mathematics key learning areas to include STEM teaching. To meet a call for having proficient STEM teachers, the researcher of this study (also the course instructor) reformed a year three major methods core course of a five-year undergraduate science education program. The course aimed to illustrate the connections among the four disciplines. It neither presented S-T-E-M as discrete subjects nor put the T-E-M components subsidiary to science teaching.

The course was designed based on two principles: (1) having close resemblance to effective STEM education programs at schools; (2) fostering pre-service teachers' cognitive and metacognitive development for integrative STEM education. A total of 24 h, made up by 12 two-hour sessions, were included in this course held within a semester. Equal amount of lesson time was spent on student teachers' hands-on activities (an example will be provided in later discussion) and the instruction on the theories and practices of STEM teachings. Student teachers also occasionally had take-home tasks to prepare for the later lessons.

Close Resemblance to Effective STEM Education Programs at Schools

The course incorporated the process of "Introduction to related STEM and pedagogical *concepts – Hands-on activities – Reflect critically – Debriefing* to bridge theory and practice" in most of the lessons. It adopted an experiential learning approach for the novices to experience the learning and teaching activities similar to their students in the future. As discussed before, student teachers might have limited prior experience to learn about the four subjects in an integrated manner. Therefore the experiential learning approach emphasizing on "the process whereby knowledge is created through the transformation of experience." (Kolb, 1984) would be useful. The novices' understanding can be improved by active participation in the hands-on activities and continuous reflection on this personal experience. It also echoed with the notion of having lots of "hands-on activities" in STEM education.

The learning activities of this teacher preparation course included common examples found in K-12 classrooms (Berlin and White, 2010). They were designed according to the model of high quality STEM education programs for schools (Kennedy and Odell, 2014). The course design was guided by the following features of the model:

- Include technology and engineering into science and mathematics curricula – In one of the sessions, the pre-service teachers were involved in a paper plane design activity that are common in primary and secondary STEM teaching. The pre-service teachers learned about concepts such as aerodynamics, mathematical calculations and design thinking. They were asked to adopt inquiry learning to search for scientific concepts related to the designs of airplanes, for example thrust, drag and air resistance that would affect its proper functioning. Then they were introduced to the design thinking cycle that has five stages: empathize with the people/environment in need – identify the problem – ideate and identify the solutions – develop prototype – test and revise. The course participants had to make up paper planes with A4-sized paper so that these could fly with a particular propeller in a horizontal manner and as far as possible. After trial testing and calculating the average distances, the pre-service teachers were required to explain the effectiveness of their designs based on scientific principles. Promote inquiry, engineering design and problem solving – Based on the above activity, the course participants carried out active inquiry to identify the factors affecting the planes flying for a long distance. They had to solve many problems to make sure that fair tests would be carried out. In addition, they had to account for the efficiency and effectiveness of their designs that might train their reasoning and argumentation (Chi and Wylie, 2014).

- Hands-on, minds-on and collaborative approaches to learning – Pre-service teachers worked in groups during the hands-on activities.
- Incorporate appropriate technologies to enhance learning – For example, the participants were asked to produce short video clips to promote their products.

Fostering Cognitive and Metacognitive Development

Knowledge building is an iterative process that involves critical reflection from time-to-time. The course did not only emphasize on developing student teachers' conceptual understanding of how integrative STEM teaching would be possible, but also facilitated them to be more metacongitive. According to Flavell (1976), metacognition is "knowing about knowing, thinking about thinking." Schraw and Moshman (1995) further divided metacognition into metacognitive knowledge – the knowledge about cognition – and the regulation of cognitive activities. Developing students' metacognitive capacities is an important part of STEM literacy (Zollman, 2012). In the course, student teachers were guided to reflect on the qualities of being scientists, mathematicians, technologists and engineers so that they would be able to identify the common practices in the four disciplines. They were invited to comment on the instructional strategies such as questioning that were modeled by the course instructor in the learning activities. After every activity, the pre-service teachers were prompted to take up the role as teachers to reflect individually upon their learning experience. They also discussed about their learning within the groups with the guidance of the course instructor. Through inquiring and reflecting on their learning experience, the course participants might develop the capabilities to transfer their learning to new contexts and develop new curriculum in the future.

Inviting pre-service teachers to reflect critically on the features of STEM teaching was another important component of the course. Before they had to prepare a STEM activity as a group assignment, the novices were asked to make individual STEM activity plans. In two 2-hour workshops that were held later, the pre-service teachers drew up a list of key features by revisiting their prior conceptions of STEM learning, carrying out online research, holding in-depth discussions and reaching an agreement within the class. Based on the list, the student teachers were asked to select the best individual activity plan for developing the group assignment. Then the class carried out peer reviews on the group plans so that they could clarify their understanding, as well as reflect and revise the plans. Lesson materials were then prepared for the final microteaching and presentation session. It was hoped that course participants could have better understanding of integrative instruction at the end.

METHOD

This study adopts a qualitative approach (Merriam, 2015) to investigate how the conceptual understanding and readiness of Hong Kong pre-service teachers *changed* after attending the 24-h major methods core course. The study does not focus on what their conceptions were and whether their understanding was accurate. Rather it focuses on student teachers' self-evaluations on their own understanding of STEM education and their perceptions about the usefulness of the course. Some data was collected from the pre-course and post-course questionnaires that were completed by the 25 course participants. The questionnaires used open-ended questions to prompt into their conceptions about STEM education, such as what STEM education is and how effective STEM education looks like. The post-questionnaire focused more the student teachers on the possible changes of their understanding by comparing the data they had given before the course. They were asked to rate their understanding based on Likert scale and explain the reasons if changes had occurred. The self-report would possibly open a window for the novices to reflect on their learning journey in a metacognitive way. Their readiness to teach STEM in an integrative manner was also documented through this post-questionnaire.

All the research data were collected by a research assistant alone. The researcher carried out a preliminary analysis on the anonymized questionnaire data after the course assessment results had been announced. This review helped to identify five student teachers for a subsequent focus group interview. They were selected according to whether they had minimal and great changes in the ratings of their understanding, as well as their readiness to teach STEM. The questions mainly inquired into the sources of the changes (if any), particularly those related to the course. They were invited to provide feedback on how to improve the course.

Basic qualitative techniques were used to analyze the questionnaires and interviews (Patton, 2002). Each data set was first coded openly and themes were generated by axial coding.

Comparison was made constantly so that patterns could be identified from the two data sources (Corbin and Strauss, 2008).

FINDINGS AND DISCUSSION

In this section, the changes of pre-service teachers' understanding of STEM education are discussed. From their reports on the possible sources of giving such changes, we can examine whether and how the instructional designs of the course could facilitate the development of their understanding. Then the discussion extends to whether the understanding would be adequate to support these novices in becoming more ready to teach STEM.

Perceived Understanding of STEM Education

The post-course questionnaire shows that the novice teachers had significant increase in their perceived understanding of STEM education (**Table 1**). With a Likert scale of five (5 as very good understanding; 1 as very poor understanding), 76% of participants gave a rating of 4 or above. This represents a 72% increase of perceived understanding that was above 4 points. The percentage of having average or below understanding (three or below) significantly decreased to only 12%.

The pre-service teachers had the opportunity to review their responses given in the pre-course questionnaire when they completed the post-questionnaire. At the end of the course, 19 pre-service teachers (out of a class of 25; 76%) reported changes in their understanding of STEM education; while the rest either missed out the question (four "nil" responses) or simply wrote "no change" (two responses). For these 24 percent giving "nil" responses or "no change," all of them actually reported increases of rating for at least one point (e.g., from a rating of two to three) in another question. Examination of these six participants' answers in the remaining questions confirmed that they actually had improvement in their understanding. For example, two of the course participants could tell what they had learned from the course (all names used are pseudonyms):

We learned about different stages of STEM teaching, how to plan a STEM activity and the criteria to evaluate if the activity is good. (Chris, post-questionnaire)

TABLE 1 | Understanding of STEM education before and after the course.

Perceived understanding of STEM education	Before studying the course (%)	After studying the course (%)	Percentage change
5	0	4	+4
4	4	72	+68
3	20	12	−8
2	56	0	−56
1	8	0	−8

N = 25.

The course provided examples of STEM activities that helped me understand the integration of STEM education. (Julia, post-questionnaire)

Among the 76% pre-service teachers who reported changes in their understanding, the changes ranged from one to two point(s). The five students selected for the interview also reported one to two point(s) of increase in their rating (**Table 2**).

Further analysis of their answers can review what the changes were and how they arrived at the understanding. For example, a course participant, Lucas who reported improved understanding from two to four points, wrote this in his post-questionnaire:

STEM education has to nurture students' problem-solving skills; and students may have to do some measurement and calculation. (Lucas, post-questionnaire)

In the pre-questionnaire, Lucas had simply regarded STEM as interdisciplinary and useful for nurturing generic skills. When compared with the above excerpt, he initially had not reported anything as concrete as to develop students' particular skills such as problem-solving; neither he had been able to provide clear examples of linking S-T-E with mathematical calculations (M). In the post-course interview, Lucas also elaborated on the other goals of STEM education. This implies he had better understanding of STEM teaching after taking the course.

STEM education should nurture the creativity of students and invite them to take risks in daily life.

(Lucas, post-course interview)

Similar to Lucas, another novice teacher Leanne had provided a simple description of STEM education before studying the course:

STEM education refers to teach science, technology, engineering and mathematics together and facilitate learning of certain concepts. (Leanne, pre-questionnaire)

In this excerpt, Leanne had stressed on the interdisciplinarity of STEM education. She had pointed out a "knowledge" objective of STEM teaching, but not yet provided explanation on what the "concepts" actually meant. This is similar to Lucas's pre-questionnaire response that specific examples and details had been missing. In this case, Leanne might actually have similar level of initial understanding as Lucas. After the course, she gave a clear report on what she learned:

My understanding about STEM education is *deepened*. I know more about how to design a STEM learning task or a lesson, the assessment criteria of the task and the relevant pedagogical content knowledge and skills. (Leanne, post-course interview)

By explaining what was meant by "deepened understanding," Leanne shared more details on the characteristics of STEM tasks or lessons. One of the characteristics discussed in the course was about achieving objectives in the domains of "knowledge" and "skills." After taking the course, Leanne's final understanding might be similar to Lucas (four points) as she also stressed on "creativity."

STEM teachers have to be creative. They can make use of STEM activities to teach students the relevant concepts while nurturing students' creativity and curiosity. (Leanne, post-course interview)

In the post-course interview, Leanne mentioned that she was able to classify whether a lesson can be STEM based on some

TABLE 2 | Understanding of STEM education of the interviewees before and after the course.

Student	Rating before studying the course	Rating after studying the course	Increase in point(s)
Leanne	3	4	1
Lucas	2	4	2
Mandy	2	4	2
Wilson	2	3	1
Helen	1	3	2

"assessment criteria." Her classmate Mandy suggested what these assessment criteria can be in the post-course interview.

I understand more about the *criteria to evaluate* whether an activity can be regarded as STEM. At the very beginning, I somehow *mixed up* STEM with experiments in science classroom. I couldn't really tell how they are different. But now I can tell *STEM is more than* just an experiment. It's transdisciplinary. It aims to solve authentic problems that are related to the daily life, and has a linkage with the society and environment. It aims to cultivate skills such as creativity and attitudes, instead of merely to help students understand the scientific knowledge through it. (Many, post-course interview)

The evaluation criteria mentioned by Mandy and Leanne are actually the features of STEM tasks. Examples of the features include making the tasks interdisciplinary, involving students to solve authentic problems and fostering collaboration and peer learning. These features were identified by revisiting their prior conceptions, doing online research and extensive discussions in the two 2-hour workshops of the course. Since the discussions were at depth, both the course instructor and the participants agreed to use the same criteria in assessing the group work at the end.

Another point worth noting from Mandy's response was her changing conception about STEM education. When she wrote "I somehow *mixed up* STEM with experiments in science classroom," this indicates that Mandy initially had confused about how to integrate science teaching with STEM-related activities and/or curriculum. This confusion had been evident from her response in the pre-questionnaire:

In STEM lessons, students should have hands-on activities and learn *scientific knowledge*. (Mandy, pre-questionnaire)

This initial response indicated that Mandy had focused a lot – if not only – on science learning. Although science activities do not necessarily involve experiments, at the beginning Mandy could not point out that whether STEM can include scientific experiments, or vice versa. More importantly, this reflects that Mandy had got problems in identifying the similarities and differences of the nature of STEM and science education. The integration of science teaching with teaching other subject disciplines was a challenge to her. As a novice teacher with science education and science background but limited training on technology and engineering, it was natural for Mandy to have the confusion. This also corroborates with the findings of a previous study (Yip and Chan, 2019). At the end when she said "but now I can tell STEM is more than just an experiment...," she clearly illustrated the features/criteria of STEM activities she had learned from the course. The usefulness of the course was evident from her response.

Factors Facilitating the Conceptual Changes of STEM Education

Most of the pre-service teachers who indicated changes in their perceived understanding attributed their improved understanding to the course content and activities (70%; first three columns shaded in gray in **Table 3**). The connection between STEM and self-directed learning was taught in one of the lessons, and hence can be regarded as part of the course content. Thirty percent recognized the assignments and related workshops in the course were useful.

The course participants provided the possible factors supporting their learning in the post-questionnaire and subsequent interview. For example, Leanne who claimed to have deeper understanding of STEM education after the course:

The *interactive* lessons had different learning activities or tasks, such as designing the STEM lesson. They helped me apply the knowledge of STEM into real case so that I can know more about how should a STEM lesson be designed and carried out. (Leanne, post-course interview)

Leanne's description on "interactive" lessons points out an important dimension of the course, that is, the lesson activities had high resemblance to the actual STEM classrooms locally and internationally. In the lessons teaching design thinking, pre-service teachers were given STEM teaching examples ranging from primary to senior secondary levels. Each lesson had at least one hands-on session to help the pre-service teachers in experiencing the STEM activities similar to the students they would teach in the future. One of these examples – the paper plane activity – was provided in the previous discussion. Based on the design of "theory – hands-on practices – reflection (as students and teachers) – bridging theory and practice," the lessons focused pre-service teachers on particular teaching strategies, for example, how open-ended questions would be useful to prompt their students in making the designs. Other than theories, they had the opportunities to develop, implement, reflect and evaluate their questioning skills. As a result, most novice teachers who indicated conceptual changes of STEM education found the course content and activities useful.

TABLE 3 | Possible sources of having conceptual changes in STEM education.

Possible sources	Percentage of students (%)
STEM workshops, guest lecture, examples of STEM activities	40
Lesson content (e.g., theories) and materials provided	25
Explaining the linkage between self-directed learning and STEM	5
Designing STEM activities	15
Finding and reviewing resources to prepare for the STEM activities	15

N = 19.

The group assignment asking the novice teachers to design STEM events collaboratively was another major source of learning. Echoed with the later part of Leanne's explanation (see the excerpt above), Mandy further elaborated on a specific aspect of the group work that supported her to better understand STEM education:

The possible sources (of my learning) may be the group STEM activity project plan, as well as the lecture content. *Throughout the selection (of STEM activity)* in our group, we were able to *make judgment and select with the criteria* developed in our workshops. We got exact examples to *distinguish* which activity is more STEM-related and how it can be *modified* to become a more STEM alike. (Mandy, post-course interview)

As discussed before, Mandy had confused STEM instruction with science teaching. The group assignment required the pre-service teachers to prepare individual STEM activity plans and select the "best one" based on the agreed criteria. The selection process was crucial for Mandy for two reasons. First, such *inquiry* into the nature of STEM instruction was useful for Mandy to clarify the "misconceptions" of STEM teaching, which was on the cognitive side. In a deeper sense, Mandy was prompted by the "selection and making judgment" process to *reflect critically* on her conceptual understanding, and hence became more able to apply such knowledge in revising the work. The thinking process of "knowing about knowing" (Flavell, 1976) and finding the ways to progress indicates that Mandy had developed *metacognitively* as well.

In a similar vein to Mandy's idea, the *collaboration* fostered by the group assignment was equally important to other course participants.

From the *peers' feedback* of the workshops, I *understand* how STEM education *really* functions. (Lucas, post-course questionnaire)

The peer feedback gathered from the selection process of the "best plan" within a group, and the later feedback on the group plan by their peers, comprise the formative assessment in the instructional design of the course. Pre-service teachers collaborated to improve their understanding by getting critical comments from their peers. This facilitated their reflection and improving their work. By saying "I understand how STEM education really functions," Lucas echoed strongly with the cognitive and metacognitive development as in Mandy's case.

The novice teachers were further asked about their readiness to teach STEM after taking the course. Seventy-two percent reported that they had the confidence in developing STEM instructional projects and preparing guiding questions for the instruction. The experience of being a student and a teacher from the course was the most important factor. A student who reported a one-point increase in his understanding of STEM education gave the following explanation:

When we were (primary and secondary) students, STEM had not been a hot topic and *we had never experienced these activities*. Therefore it is essential for us to experience (as a student). (Wilson, post-course interview)

By saying "we had never experienced such activities," Wilson pointed out a characteristic of the course for looking after their prior knowledge of STEM education, as well as their capabilities and difficulties for integrating multiple disciplines in teaching. Since most of them had only science and mathematics background, it was unlikely for them to teach STEM well without good understanding of STEM education. Therefore the course started with fundamental concepts of integrative STEM teaching, for instance, on what design thinking is, and slowly immersed the students in activities adopting design thinking, scientific inquiry and mathematical thinking in the lessons. The immersion was situated in the context of STEM and science teaching (Moore and Smith, 2014). Based on what they had experienced in the activities, the novice teachers were guided to identify the instructional approaches adopted in the debriefing. The course instructor then made use of think aloud technique to further illustrate the techniques used in the lessons. Throughout the whole process, student teachers were given ample chances to reflect *metacognitively* on how they could learn and teach STEM. Another student, Helen (rating increased from one to three), highly regarded this "theory – hands-on practices – reflection (as students and teachers) – bridging theory and practice" approach:

I *really appreciate* that we can look from both students' and teachers' perspectives in experiencing STEM activities. I *learned about my role* as the teacher in carrying out STEM education. Therefore, I know how STEM education can be incorporated into science teaching. (Helen, post-course interview)

For novice teachers like Helen and her classmates without much understanding of engineering and technology, it was essential for educators to equip them with the concepts and skills to teach STEM so that the novices would have more positive self-efficacy (Stohlmann et al., 2012). It might take a long time for pre-service teachers to value and apprehend STEM education, and then actively teach STEM education no matter in a single subject or in multiple disciplines. From Helen's response, a short course on STEM education with careful design might create long-term impacts in the affective domain of teacher professional development.

Limitations of the Course in Preparing Novice Teachers

Based on the self-reports of the pre-service teachers on their understanding of STEM education, there was an increase in the percentages of novices giving ratings of four or five and a drop in the average or low ratings (**Table 1**). Nevertheless, some student teachers such as Leanne and Wilson might report only one point increase in their perceived understanding, rather than two to three points. This could be partly explained by the limited time given by a course held within a semester. As a short course itself, the pre-service teachers could not practice or enact too much on what they had learned in authentic STEM classrooms. In the post-course questionnaire and interview, the course participants suggested a lot of extended activities to support them continue their learning journey. For instance, Wilson would like to observe STEM lessons in primary and secondary schools as part of the course requirements. Another student Diana (rating increased from two to four) indicated in her post-questionnaire that she wished to have more microteaching opportunities within the course. For moving beyond the course, a student suggested to make holding STEM activities or workshops compulsory in their professional practicum at schools. To enact the understanding, Helen would like to join more school-based and community-based STEM education programs so that she could connect with the broader STEM communities (Kennedy and Odell, 2014).

This course was part of a science education program to develop student teachers to teach science. In other words, the instructor was a science educator with specific training on science teaching. As pointed out by Auerbach and Andrews (2018), teacher educators with different disciplinary background can possess diversified pedagogical knowledge of STEM education. Therefore before the course was implemented, the course instructor had had to collect information about various local and international practices of STEM education, critically reflect on these practices and disseminate through the course. Nevertheless it was unavoidable that the instructor might deliver pedagogical practices more related to science education, and less on those advocated by the experts in mathematics, engineering and technology education. This would likely to be an important factor to shape the student teachers' understanding of and attitudes to STEM education.

CONCLUSION

This study examines how a STEM education course would possibly facilitate student teachers' development of conceptual understanding of, attitudes toward and readiness for STEM education. It was situated in a science education program to support the novices to teach STEM in a single discipline or in integrative STEM lessons. According to the pre-service teachers' reports, the course was regarded as useful to develop their understanding of STEM education. It looked after the prior understanding and difficulties of student teachers with only science and mathematics background to teach S-T-E-M in a holistic manner. The integration was made explicit to them through introducing concepts such as design thinking and technological literacy. As reported by Leanne, student teachers were engaged in interactive STEM teaching activities as their students in the future. The process "theory – hands-on practices – reflection – bridging theory and practice" was meaningful to them. The connections between the nature of the four disciplines, scientific investigation, argumentations and product making were made clear. When the student teachers had to work on various design tasks, they were approaching their students to solve real-life challenges. Through inquiring into the learning experience and continuous reflection (e.g., what Mandy demonstrated in her excerpt), pre-service teachers did not only develop better understanding of how effective STEM teaching should look like (the cognitive side), but also supported them develop metacognitively so that they were able to modify their plans. Finally, the assignments played important role in effective use of assessment. In particular, the group activity to plan for a STEM activity allowed them to collaborate actively and evaluate on the quality of their work. In summary, the effective practices of integrative STEM instruction for school students as described by Kennedy and Odell (2014) can be further extended to effective practices of *integrative preparation for STEM teachers*.

Future studies adopting similar instructional approaches can develop measures to examine the changes of teachers' conceptual understanding, capabilities and attitudes toward integrative STEM education. An investigation can be carried out on whether these approaches would be useful for developing the competence of pre-service and in-service teachers with mathematics, engineering and technology background to teach STEM. This would further address the needs of teachers for becoming interdisciplinary in teaching. Another direction for research may focus on the possible link between teacher education program adopting similar approach with the subsequent STEM classroom instruction. The support necessary for putting theories into classroom practices would worth a thorough examination. Studies on the perspectives of students toward integrative STEM instruction, for instance on their understanding and attitudes toward STEM, can provide more information on how STEM education can move onward.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/supplementary material.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Human Research Ethics Committee, Research Services, The University of Hong Kong. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

This manuscript discusses about how novice teachers could learn cognitively and metacognitively about STEM education in an undergraduate course. This is related to teacher preparation and the learning of their students. Upon the graduation of these novices, they will have the capability to teach STEM in an integrative manner, which is an important concern of global education reform.

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Conflict of Interest: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.