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Cover Page Footnote

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Abstract

Integrated Science, Technology, Engineering and Mathematics (STEM) education is perceived to be the magic bullet for progressive and futuristic learning. It is widely touted as a way to develop 21st century competencies and scientific literacy. Despite the ubiquitous use of the term STEM, understanding of STEM education remains largely diffused. This study serves as a first in contributing a Singaporean narrative on perceptions of STEM education. To discern the diversity and prevalence of understanding of STEM education, 16 undergraduate preservice teachers (PST) responded to a series of questions. Out of the 16, nine PSTs were randomly selected for an interview to further elucidate their perceptions. Responses were coded and organized with respect to a validated conceptual lens. PSTs presented ideas that were similarly reported in other studies such as workforce readiness and making interdisciplinary connections, suggesting some perceptions are universal. New ideas such as STEM education transcending school contexts also emerged from the data. Further, PSTs could distinguish the epistemic practices of science and engineering to some extent. Their understanding of the knowledge-building processes in each discipline appeared to be emerging with generally accurate descriptions of certain epistemic practices. Some PSTs demonstrated ease in blending epistemic practices of both disciplines. However, PSTs harboured some potentially limiting conceptions of engineering such as a focus on physical products.

Keywords: STEM Education, Pre-service Teachers, Epistemic Practices, Perception

STEM, the acronym for Science, Technology, Engineering and Mathematics, has been a buzzword in recent times. STEM education is seen as a way to create a globally competitive workforce and to allow countries to maintain their economic competitiveness. This is particularly so in the United States (Reeve, 2015). Today, STEM education still possesses economic significance to prepare the workforce globally (Barakos, Lujan, & Strang 2012; R. Brown, J. Brown, Reardon, & Merrill, 2011; Cinar, Pirasa, & Sadoglu, 2016; Honey, Pearson, & Schweingruber, 2014; Lee, 2015). STEM education is also regarded as a means to develop scientific literacy (Barakos et al., 2012; Honey et al., 2014) — students' capability in utilising scientific knowledge to understand current social issues. Scientifically literate students could eventually become informed citizens who can make sound and informed judgements on the issues affecting society.

Beyond developing a competitive workforce and a scientifically literate society, STEM education is increasingly being regarded as a platform for students to learn and develop 21st century competencies (Bybee, 2010; Honey et al., 2014), such as teamwork and problem-solving. Development of these competencies are important for students in order for them to become effective workers in emerging industries. Indeed, Trilling and Fadel (2009) argued that one goal of education in the 21st century is to prepare students "to be able to quickly learn the core content of a field of knowledge while also mastering a broad portfolio of essential learning, innovation, technology, and career skills needed for work and life" (p.16). The urgency to help students attain the necessary skills to sustain the workforce of tomorrow is one of the reasons for the renewed emphasis on STEM education.

Currently, the understanding and knowledge of STEM education does not parallel the promised potential of STEM education. STEM education is generally not well understood by school administrators and teachers (Brown et al., 2011). This could be due to "few direct measures of integration…or of outcomes" and "absence of standardised measures of integrated learning" (Honey et al., 2014, p.63) thus preventing teachers from appreciating the value of STEM education. Additionally, different stakeholders may have a different take on what is considered STEM education (Breiner, Johnson, Harkness, & Koehler, 2012). This results in various definitions of STEM education that are inconsistent with one another (Siekmann, 2016). Without a common understanding of STEM education and integration, inconsistencies will arise in describing STEM programs and results (Honey et al., 2014). To design and conduct meaningful STEM lessons, teachers take reference from current literature and syllabus outlines. In the absence of a sound collective understanding of the characteristics and affordances of STEM education, educators and policy makers can misunderstand STEM education policies and outcomes (Tan et al., 2019).

There are various perspectives on how STEM education can be designed. The approaches toward STEM education can be regarded as a continuous spectrum (Barakos et al., 2012) ─ each discipline can be taught separately with no explicit integration to adopting a trans-disciplinary approach. Along the spectrum, there are multiple configurations in which the disciplines can be integrated. Bybee (2013) outlined nine different ways in which STEM integration is perceived and cautioned that there could be even more ways of perceiving STEM integration. With a myriad of choices available, confusion seems inevitable.

To better understand ideas about STEM education held by pre-service teachers (PSTs), we adopted a case-study approach to investigate the conceptions and ideas held by preservice teachers (PSTs) towards STEM education as both a construct and in context of Singapore's education system. The following research questions guide our inquiry:

1. What are the perceptions held by pre-service teachers (PSTs) towards STEM education?
2. How do PSTs compare and distinguish the epistemic practices of science and engineering?

Context

STEM Education in Singapore

Singapore has started in her efforts in STEM education although integration of STEM programmes into formal curriculum remains limited. Currently, STEM is a programme in school under the umbrella of Applied Learning Programme (ALP). ALP is a national initiative to enable students to find the relevance of academic knowledge in real-world contexts, increasing their motivation to learn the knowledge and skills in school (Ministry of Education, 2018). There were 68 schools running STEM as their ALP (Science Centre Singapore, 2018a). The Science Centre Singapore has a STEM focused unit called STEM Inc. that specialises in promoting STEM education in Singapore. It provides support to secondary schools in the running of STEM ALP programmes in school (Science Centre Singapore, 2018b) and conducts workshops on designing STEM education programmes for educators.

There are currently no integrated STEM courses in formal teacher preparation programme in Singapore (Teo & Ke, 2014). Consequently, there are formally no "STEM teachers" in Singapore who specialise in STEM education. Instead, teachers in Singapore usually specialise in two to three teaching subjects. Pedagogical courses are centred on those specified subjects. Interdisciplinary connections between subjects depend largely on course instructors. Given that pedagogical methods courses at pre-service levels are to impart basic pedagogical knowledge to PSTs, interdisciplinary connections may not be prioritised by instructors. Teachers rely on in-service courses or other external programmes by STEM organisations to learn about STEM programmes.

Importance of Perception

Perceptions of a teacher appear to hold considerable influence on the teacher's actions and approaches to teaching. The relationships between perception and actions of the teacher have been established in literature (Trigwell, Prosser, & Waterhouse, 1999; Wang, Moore, Roehrig, & Park, 2011). These intricate connections between perception, choice of teaching approaches used, and the ultimate quality of students' learning outcome is shown clearly by Cope and Ward (2002). This implied that teachers' perceptions of STEM education would likely have an impact on their students' understanding of STEM education as well as the outcomes their students can achieve from STEM education. Given the chain of effects that can originate from teachers' perception, it would be useful to elucidate the views held by teachers toward STEM education.

Importance of Understanding Epistemic Practices

Beyond elucidating ideas of STEM education, another important aspect is to understand PST's ideas of the different STEM disciplines and their epistemic practices. It is crucial to understand the different processes in which knowledge is constructed within each discipline in order to connect and integrate disciplines meaningfully. These discipline-specific processes of knowledge construction are termed epistemic practices (Kelly & Licona, 2018). Epistemic practices are "socially organised and interactionally accomplished ways that members of a group propose, communicate, evaluate, and legitimise knowledge claims" (Kelly & Licona 2018, p. 140). In this study, the use of this term epistemic practices refers to the knowledge building processes unique to each STEM discipline rather than STEM as a collective. These ways of knowing are useful and salient when connections are established between the different disciplines. Not only that, epistemic practices can outline the educational goals for the discipline and the rationale of the subject (Cunningham & Kelly, 2017). Depending on the extent to which these practices of the different disciplines synergise based on the learning task, the quality of the interdisciplinary connections can be strong, moderate or weak (Tan et al., 2019). Within a learning task, the integration can occur when one discipline e.g. engineering can used as a vehicle to drive learning of another discipline's concepts e.g. scientific concepts, with science and engineering being possible vehicles for one another (Purzer, Goldstein, Adams, Xie, & Nourian, 2015). In order for teachers to use disciplines to scaffold the learning of another discipline appropriately while retaining meaningful connections, their knowledge of epistemic practices must be sufficiently robust.

Among the four STEM disciplines, science and engineering are considered to be conceptually similar (Lewis, 2006; Cunningham & Kelly, 2017). In fact, science and engineering “intersect, mutually inform one another, and become less distinct” (Cunningham and Kelly 2017, p.489) and share several features such as engagement with problem-solving and the subsequent stages that follow (Schwarz, Passmore, & Reiser, 2017). The epistemic practices are extensive which would be difficult to explain all in this paper. The epistemic practices of science and engineering are explained in depth by Kelly and Licona (2018) as well as Cunningham and Kelly (2017) for each respective discipline. However, since engineering is not a subject in the formal curriculum, most teachers may not encounter engineering as a student. This lack of exposure to engineering may result in confusion related to differences and similarities between engineering and science (Blackley & Howell, 2015). This, coupled with conceptual similarity between science and engineering, might pose difficulty for teachers to design meaningful integrated tasks.

Literature Review

Studies on teachers’ perceptions of STEM education is not entirely new. In this section, we present the literature on definition of STEM education, teachers’ perceptions of STEM education, and the instruments that have been developed to measure these perceptions.

Unravelling STEM Education

STEM education itself remains a muddled concept. One major and recurring source of confusion is the level of integration. There are several proposed ways in which STEM education is conducted, ranging from teaching the four disciplines (1) in silos – each discipline is taught on its own with zero connection, (2) multidisciplinary approach – disciplines are taught with some form of conceptual or epistemic overlap being emphasised, to a transdisciplinary approach – concepts are taught in a holistic manner with boundaries between disciplines are disregarded (Bybee, 2013). One version of STEM education that is gaining popularity is integrated STEM education (Tan et al., 2019; Honey et al. 2014) in which the focus is on the epistemic connections between these disciplines and using these connections to problem-solve complex, extended and persistent problems. We believe that this shows the potential of STEM education and thus serves as our “definition” on STEM education for this study. Within this definition, the scale of integration among the four disciplines can vary. It is not necessary that knowledge and skills from all four disciplines must be used. It is possible that one discipline is the dominant one whose concepts and ideas are the main focus whilst the other disciplines provide skills or knowledge to support the learning of the concepts of the dominant discipline (Tan et al., 2019). As such, for this study, we focused on a version of integrated STEM education focusing on integrating science and engineering with mathematics and technology supporting the former two in terms of basic knowledge or skill application.

Teachers’ Perception of STEM Education

Research into teachers’ perceptions of STEM education have been carried out with either pre-service or in-service teachers. For example, Radloff and Guzey (2016) as well as Cinar et al. (2016) focused on pre-service teachers while others (Brown et al., 2011; Dare, Ellis, & Roehrig, 2018;

Nadelson et al., 2013; Ring, Dare, Crotty, & Roehrig, 2017; Srikoom, Hanuscin, & Faikhamta, 2017; Wang et al., 2011) focused on in-service teachers of varying subjects and/or grade levels. Apart from teachers, there has been research on STEM perceptions of university faculty (Breiner et al., 2012) and even policy makers (Wong, Dillon, & King, 2016). One study by Holmlund, Lesseig, and Slavit, (2018) had a wide-ranging group of participants as their intention was to assess the relationships between participants' work contexts and their perception of STEM education. Methods to collect and record these perceptions are diverse. Some research studies opted to focus on prior conceptions of participants (Cinar et al., 2016; Radloff & Guzey 2016; Srikoom et al., 2017) while others decided to analyse changes in conceptions of participants with certain intervention programmes (Holmlund et al., 2018; Nadelson et al., 2013; Ring et al., 2017; Wang et al., 2011). However, such perceptions are purely theoretical and their impact on the teacher's practice may not necessarily be present. The phenomenological study by Dare et al. (2018) revealed that teachers have trouble transferring theoretical concepts of integrated STEM education into their practice. This suggests that contexts influence the perceptions being studied.

The popularity of STEM education did not mean that all educators are aware of it. Brown et al. (2011) found that only half of the participants (teachers and school administrators) in the US could define the acronym STEM. Incorrect responses from participants included descriptions that were narrow such as "just integrating computer technology into a classroom" or misguided such as "a program for either students with disabilities or gifted students" (p.7). Srikoom et al. (2017) reported "limited awareness" (p.14) among in-service teachers in Thailand where 85% of the participants had not heard of STEM education. This lack of awareness is not specific to teachers. Even at the highest levels of learning and research, there are members who may not know STEM education. Breiner et al. (2012) reported 72.5% of university faculty participants were able to describe STEM with the remainder admitting to not knowing STEM. One cannot assume that every educator is aware of the term STEM education despite being in the education service. There also appears to be no connection between personal factors and experiences with a teacher's perception. There is little evidence to suggest a connection between the demography of the participants with their conceptions (Radloff & Guzey 2016; Srikoom et al., 2017). Besides personal factors, teachers with similar workplace roles and professional contexts hold different interpretations (Holmlund et al., 2018). Additionally, in an extensive meta-analysis by Margot and Kettler (2019), a lack of consistency between teaching experience and perceptions on STEM education was reported. This indicates that a teacher's perceptions of STEM education are not in any way influenced or dependent on their background.

The understanding of STEM education is also varied. For instance, Srikoom et al. (2017) showed the sheer variety of interpretations STEM education held by teachers. Descriptions include STEM education being an integrated program, a teaching approach, a science and mathematics focused approach or an inquiry-based approach. Srikoom et al. (2017) reported variation in in-service teachers' views towards integration of STEM, with a majority viewing STEM education as transdisciplinary. They also noted that the same individual could perceive STEM as "overlapping across disciplines" (p.14) despite saying STEM education to be transdisciplinary. Radloff and Guzey (2016) reported a diversity of definitions provided by teachers. Four themes emerged from their study ─ Instruction, Discipline, Exclusion and Integration ─ of which the authors reported a huge majority defined STEM education "from an instructional perspective" (p.765), which included problem-based learning or student-centred instruction. Radloff and Guzey (2016) also reported a high degree of "variation in the visual and textual conceptions of STEM education" (p.771). The most frequent visualisation was that of an interconnected nature where there are connections between the various STEM disciplines. In another study by Wang et al. (2011), teachers believed that the STEM disciplines are connected conceptually or through different processes. In particular, the process of problem-solving was picked out as a key factor in integrating disciplines. In the study by Cinar et al. (2016), they reported themes related to aspects of development, "learning process" as well as "interdisciplinary interaction" (p.1482). Ring et al. (2017) similarly reported practitioners holding various models of STEM integration but these conceptions were sensitive and are amenable with exposure to professional development experiences.

Another observation that researchers made about STEM education is that the importance of STEM education is not necessarily guaranteed. In the study by Brown et al. (2011), 75% of their participants agreed STEM education was important as they appreciate that it would be beneficial for students to learn the connections between disciplines and learn skills. The remainder who disagreed opined that STEM education was not suitable for all students. This prompted Brown et al. (2011) to investigate the existence of "universality of STEM education" (p.8). Participants who believed STEM education was for all students explained along the lines of problem-solving skills that STEM education was supposed to promote and the importance of such skills in society. For participants who did not believe it is for all students, they explained the "academic needs for STEM education" (p.8) prevents every student from benefiting from STEM education. The proportion of participants who support an equitable image of STEM education differ from study to study. Cinar et al. (2016) reported a sizeable number of the pre-service teachers expressed the STEM education is for any child "of any age" (p.1483) as they saw numerous benefits to students in developing competencies and "career guidance" (p.1483). On the other hand, Holmlund et al. (2018) mentioned a low proportion of their participants, who were educators, administrators or business stakeholders, thought STEM education was for all students. The value of STEM education appears to be context-specific and their valuation of STEM education could be some way dependent on the circumstances that they are in.

Adding onto research focussing on the conceptual understanding of STEM education, Nadelson et al. (2013) focused on teacher confidence and efficacy in teaching STEM and found positive correlation between knowledge of STEM with confidence and efficacy in teaching STEM. Self-efficacy is, in a way, a perception held by an individual specifically on their ability to do something. Studies on teacher self-efficacy is important as it affects the teacher's willingness to engage in STEM education (Margot & Kettler, 2019). Nadelson et al. (2013) also reported a lack of association between teaching experience with knowledge, confidence and efficacy in teaching STEM. This supports the idea that personal factors do not have a role in teachers' capacity in engaging STEM education, much like the findings of the other research (Radloff & Guzey, 2016; Srikoom et al., 2017).

Beyond conceptual understanding, value and challenges in implementation, perception studies also delve into the challenges and tensions teachers have with STEM education. Cinar et al. (2016) elicited issues related to infusing STEM education as part of the curriculum. These issues included supply of resources, time management and "definition directives" (p.1484) and were similarly highlighted by Margot and Kettler (2019) who classified them as curriculum and structural challenges. Other hurdles raised included pedagogies, student profile and the lack of assessment and content knowledge for STEM education. Collectively, there is a constellation of unique research on STEM education perceptions, each providing a unique view of STEM education. The findings in these research pieces would assist us in making sense of Singaporean PSTs' perceptions.

Instruments Measuring Teachers' Perceptions

To better understand teachers' ideas of integrated STEM education, various instruments were created. Most of the aforementioned studies took a more grounded approach, constructing general themes based on the data collected. Due to the subjectivity and dynamic nature of perception itself, it would be useful to apply validated instruments that can function as a "yardstick" to make better sense of the perceptions and provide a valid structure to other subsequent data. For this purpose, we performed a second search on literature that describe the validation of instruments.

A study by Mobley (2015) detailed the development of the SETIS instrument that measures self-efficacy of science teachers to teach science within an integrated STEM framework. Through the instrument, Mobley (2015) was able to construct a model made of three factors – social, personal and material – with each factor being further described by several constructs such as teaching experience, access resources and so on. The model could explain 62% of the variance. The author also reported the instrument to have acceptable validity using a series of statistical tests as well as acceptable reliability with Cronbach alpha values ranging from 0.878 to 0.917 for the three factors. These indicated the relationships between the constructs identified were at least not tenuous.

Smith, Rayfield and McKim (2015) also conducted a study based on self-efficacy and social cognitive theory, to investigate the perceptions and confidence levels of agricultural teachers towards integrating STEM education. They constructed a survey instrument which was validated by an expert panel and results were considered reliable as their Cronbach alpha's value was above 0.70. Findings from Smith et al. (2015) mainly focused on teacher's ranked importance of STEM disciplines, their perceived confidence in integrating and the type of instruction that they are likely to utilise.

T. Nguyen, V. Nguyen, P. Lin, J. Lin, and Chang (2020) investigated the perceptions of Vietnamese teachers towards STEM education. Nguyen et al. (2020) constructed their instrument on the premise that perceptions of teachers towards STEM education can be attributed to three key sources broadly named *STEM education*, *STEM competencies* and *STEM difficulties*. The authors reported these sources could account for 64.35% of total variance in their data as well as validated through a combination of statistical tests. They further found that these sources contribute to a teacher's perception through principal component analysis and "Varimax with a Kaiser normalisation rotation method" (p.1536). Furthermore, they reported their Cronbach alpha values for each construct to be 0.764, 0.919 and 0.774 respectively, which were within the acceptable range to consider the instrument as reliable.

Given the growing literature of perceptions on STEM education, the intention of this study is to supplement the existing literature with a Singaporean narrative. To our current knowledge, the perceptions of Singaporean PSTs regarding STEM education have not been researched. It would be meaningful to utilise an existing, validated framework to filter and organise the perceptions as well as to make comparisons of Singaporean PSTs against those mentioned in current literature. For this purpose, we utilised the structural framework presented by Nguyen et al. (2020). Their framework provided a very comprehensive overview of the possible constructs that contribute to the teachers' perceptions towards STEM education. The constructs covered not just the general, abstract conceptions about STEM education, but also the practical aspects of competencies and challenges associated with STEM education. These constructs are broad, which allows the constructs to be malleable and tailored to this study's purposes.

There are three key constructs identified by Nguyen et al. (2020) that have shown to contribute to a teacher's perception are *STEM education*, *STEM competencies* and *STEM difficulties*. Nguyen et al. (2020) did not precisely define these constructs, but described the question items that correspond to each construct. As such, we attempted to re-define these constructs by first outlining the ideas Nguyen et al. (2020) mentioned, before presenting with our description based on the former.

According to Nguyen et al. (2020), *STEM education* describes the theoretical bases of STEM education, namely: (1) teaching skills and knowledge related to STEM industries, (2) degree of integration of the four STEM disciplines and (3) scientific inquiry and engineering design are the two factors influencing STEM education. We concur with what was mentioned by Nguyen et al. (2020). The primary goal of STEM education was originally to prepare students to become part of the STEM workforce. Honey et al. (2014) noted this as a goal of STEM education, termed workforce readiness. We thus refine this aspect as *Workforce readiness*. A current issue with STEM education is the level of integration that is expected of STEM education. As mentioned, Bybee (2013) outlined a spectrum of possible configurations which introduces confusion to what STEM education means. Underlying these configurations is the establishment of meaningful connections between disciplines. This is another goal of STEM education, which is noted by Honey et al. (2014) as "the ability to make connections" (p.36). These connections ought to be meaningful in the sense that they enable improvement in learning experience and quality for the students (Honey et al., 2014). In light of this, we refine the second aspect as *Making connections*, which covers whether PSTs could recognise the act of connect ideas and process skills among the different disciplines in STEM education.

The third aspect of scientific inquiry and engineering design being factors of STEM education alludes to pedagogical frameworks to design lessons. Engineering design, scientific inquiry and problem-based learning have been used in various STEM education efforts over the years (Honey et al., 2014). For example, Tan et al., (2019) constructed a STEM model using engineering as the pedagogical backbone. However, details of this third aspect were not explored in detail by Nguyen et al. (2020). As this discussion of pedagogical frameworks of scientific inquiry and engineering design aligns towards our second research question, we aim to explore this aspect in terms of how PSTs understand disciplinary processes in knowledge construction as well as recognise and differentiate epistemic practices. As such, we re-framed this aspect as *Epistemic practices*. Finally, Nguyen et al. (2020) mentioned the boundaries of technology as a discipline by specifically asking whether technology is restricted to the tools used in the classroom. This is a very specific aspect of technology, which ultimately impacts the degree of interdisciplinary connection that can be established with technology. As such, we subsume this under *Making connections*. We summarised our descriptors in Table 1.

The second construct *STEM competencies* was described by Nguyen et al. (2020) to include (1) skills related to STEM industries, (2) critical thinking, (3) problem-solving skills, (4), collaboration and (5) engineering design. As mentioned, STEM education has been advocated as a platform for students to develop 21st century competencies (Bybee, 2010; Honey et al., 2014), making it a crucial construct that could influence how PSTs view STEM education. Competencies referred to "a blend of cognitive, inter-personal, and intrapersonal characteristics that may support deeper learning and knowledge transfer" (Honey et al., 2014, p.35). Some of these competencies include critical thinking, problem-solving and collaboration (Honey et al., 2014). As such, we re-grouped all of these traits under a single category *21st century competencies*. We disregarded the skills related to STEM industries since these aspects were accounted for under the construct *STEM education* as "teaching skills and knowledge related to STEM industries".

The third construct *STEM difficulties* was described by Nguyen et al. (2020) in terms of: (1) ideation, (2) "enhancing integrated knowledge beyond the major" (p.1537), (3) assessment, (4) curriculum issues and (5) materials and equipment.

This construct deals with the barriers to implement STEM education in schools or challenges teachers foresee in carrying out STEM education. Indeed, teachers saw lack of STEM-specific assessment, curriculum structure, knowledge of STEM disciplines and administrative issues such as timetabling as potential barriers to implement STEM education (Margot & Kettler, 2019). Without access to assessment that provides direct evidence of student learning, limited understanding of other disciplines, the tension with the existing curriculum outcomes and structure as well as the perceived lack of support by schools and districts were perceived as challenges that teachers might face in carrying out STEM education. As such, we have accepted these aspects, redefining them as *Lack of STEM-specific assessment, Limited knowledge, Tensions with curriculum outcomes and structure* and *Limited school support* as seen in Table 1.

It is noted that these aspects of *STEM difficulties* primarily refer to teachers and not about possible challenges faced by students. It was reported by Brown et al. (2011) that not all teachers and administrators believe that STEM education is for all types of students, with several justifications made by the former such as acquisition of certain competencies or knowledge. Whether students can engage in STEM education may pose as a challenge for teachers as it could persuade or dissuade them from implementing in the first place. To convey this aspect, we defined a new descriptor *Student readiness* under STEM difficulties. *Student readiness* covers any idea pertaining to whether students are able to learn in a STEM education lesson.

The other instruments by Mobley (2015) or Smith et al. (2015)) are meaningful in their own right. However, these instruments focused on a specific aspect of teacher perception – self-efficacy – or are based on a specific field – agricultural education. In our study, we adopt a broader, general lens that is unbounded by a specific theory to examine perceptions. Due to these fundamental differences, the instruments by Mobley and Smith et al. do not fit well into our purposes for this study.

Research Methods

This research adopts a qualitative case study whereby the boundary of the case is defined by the community of PSTs.

Participants

Sixteen PSTs enrolled in the four-year Bachelor of Science (Education) programme at the National Institute of Education (NIE) participated in the study. PSTs specialising in one of the sciences (biology, chemistry, physics) or mathematics were selected for this study. Such a selection was done as PSTs who are going to teach subjects as science and mathematics teachers would most likely be deployed for STEM education lessons compared to non-science or nonmathematics teachers. PSTs from both primary (seven participants) and secondary (nine participants) teaching tracks were involved in the study.

Table 1.
The three constructs highlighted by Nguyen et al. (2020) with the re-framed descriptors that comprises each construct.

Construct	Descriptor
STEM education	***Workforce readiness*** Preparing students for STEM workforce in terms of skills and knowledge
	Making interdisciplinary connections Recognising and connecting concepts and process skills among disciplines
	Epistemic practices Disciplinary processes in knowledge construction Recognising and differentiating respective epistemic practices of science and engineering
STEM competencies	***21st century competencies*** a blend of cognitive, inter-personal, and intrapersonal characteristics that may support deeper learning and knowledge transfer
STEM difficulties	***Lack of STEM-specific assessment*** Assessment is an obstacle in which it does not clearly illustrate student understanding
	Limited knowledge The level of knowledge of the other disciplines beyond one's own is not sufficiently deep
	Tensions with curriculum outcome and structure Mismatches between outcomes and lesson structures for STEM education and existing curriculum
	Limited school support Minimal or lack of resources, materials and support provided by the school for STEM education endeavours
	Student readiness Concerns regarding whether students are able to learn in STEM education lessons

Participants ranged from their second year to fourth year of undergraduate studies, possessing different levels of exposure to classroom teaching. Second-year PSTs had a two-week school experience in which they mainly observe school lessons. Third-year PSTs had completed the aforementioned school experience as well as a teaching assistantship in which they observe lessons and engage in co-teaching. Fourth-year PSTs would have completed all the above as well as at least one practicum in which they taught classes independently. The varying levels of exposure to teaching may influence the PSTs' views on STEM education and thus important to include a range of PSTs from the different years of study to uncover the repertoire of perceptions that might exist.

Data Collection

To elicit these opinions and glean their understanding, we first collected responses to several questions on various aspects of STEM education. After reviewing the responses, we narrowed to specific questions in accordance to the three constructs mentioned earlier. Table 2 below shows the alignment of the questions to each construct.

Table 2.
A list of questions that were narrowed down for closer analysis and aligned to each construct.

Construct	Questions
STEM education *STEM competencies*	• Can you describe what STEM education is about? • What do you think the objectives of STEM education are? • How important would you think STEM education would be to have it integrated into current curricula? • Which of these, would be a definition of STEM education? Why did you choose this definition? • What constitutes content for Science as a discipline? What ideas or concepts are taught under Science? • What constitutes content for Engineering as a discipline? What ideas or concepts are taught under Engineering? • In the following questions and statements, please determine whether the question is meant to promote thinking from a science perspective or engineering perspective. • Can you explain why you have chosen as such? • What is the difference between Science and Engineering? Or is there a similarity / resemblance between the two?
STEM difficulties	• Why do you think that STEM education is not prominent despite what is being mentioned in the preamble at the beginning of this section? • Is STEM education for ALL students?

To better understand the written responses, semi-structured interviews were used. The interviews primed PSTs to look inward into themselves on their understanding. PSTs had the platform to construct and share the reality that they allow researchers to have access to. This aided in identifying and reinforcing salient ideas as well as highlighting any inconsistencies in the PSTs' understanding.

There were three segments in the interview. Firstly, PSTs were asked to describe STEM education and the sources that they learn STEM education from. Secondly, PSTs were provided a selection of "definitions" (see Appendix 1) and were asked to select and explain the one that appealed the most to them. The discussion that followed provided ideas on features of STEM education that appeared salient to PSTs. Thirdly, PSTs were asked to describe their perceived differences and similarities between science and engineering. PSTs were subsequently provided with a list of statements (see Appendix 2) that describe some epistemic features and processes in science and engineering. PSTs were asked to identify and justify which statements they think belonged to science or engineering. Justifications provided by PSTs were used to validate the

PSTs' earlier conceptions as well as to identify additional ideas associated with epistemic practices that PSTs may have left out. Interviews were audio-recorded and transcribed for analysis.

Data Analysis

Although studies on PSTs' perceptions on STEM education have been conducted in other countries, differences in social and immediate school context may produce differing ideas and understanding about STEM education. As such, directed content analysis was our analytic procedure as the goal of this analytic framework is to extend conceptually to existing research on teachers' perceptions on STEM education (Hsieh & Shannon, 2005).

In directed content analysis, the first step is to identify "key concepts or variables" (Hsieh & Shannon, 2005, p.1281) from previous research to be used as initial coding categories. For this step, we used our aforementioned theoretical framework based on Nguyen et al. (2020). We have highlighted the three constructs and outlined several descriptors belonging to each construct. These descriptors form our starting set of coding categories. Codes generated from prior research or frameworks are known as provisional codes (Saldaña, 2013). The PSTs' responses to the questions and interviews were coded using the provisional codes by identifying words, phrases or short statements from the responses that relates to the same idea conveyed by the code. If there were codes that convey a new idea that cannot be subsumed under the existing categories, a new coding category would be created. This constitutes the first cycle of coding.

Next, we performed code-mapping (Saldaña, 2013) which was to re-organise the codes generated from the first cycle into preliminary provisional code categories and new categories that emerged from the responses. This was to structure the codes such that it would provide a brief glimpse in the themes that possibly exist in the data. Thereafter, we performed elaborative coding (Saldaña, 2013). Elaborative coding involves using theoretical constructs from previous studies and refines these constructs. As we have based our theoretical lens and the provisional codes from Nguyen et al. (2020), elaborative coding is relevant. As the name suggests, we attempted to expand the descriptions for each descriptor. To do this, we paid close attention to the ideas presented in the codes and further re-grouped the codes with similar ideas together to form a distinct idea for each descriptor. This is particularly important as the responses provided by the PSTs hold several ideas that can be classified under different categories in different constructs. By engaging in elaborative coding, it would "sharpen" the lens by providing further detail to each descriptor, thereby creating a much fuller picture of the teachers' perceptions on STEM education.

This process of re-grouping was also performed on the codes that did not belong under a provisional code during the first cycle of coding. In this case, the coding serves not to elaborate an existing provisional category, but to seek out a distinctive and salient concept held by these codes.

Findings

Prior Knowledge and Experiences with STEM Education

There were no formal STEM education courses for PSTs but 14 of the 16 PSTs have heard of the term STEM education. Only two revealed that they never heard of STEM education. For those who have heard of STEM education, they highlighted a diversity of sources from which they read about STEM education. This ranged from newspaper articles to journal articles. When asked to provide examples of STEM education in Singapore, PSTs suggested a variety of examples of varying sophistication. Some mentioned generic, if not stereotypical, examples such as *"Teaching students coding" (Erica)* or *"Robotics" (Sherry)*. One PST, Rene, gave irrelevant examples of "*Project based learning, cooperative learning, assessment for learning?"*. On the other hand, there were PSTs who provided very specific examples. For example, Penny mentioned *"Applied Learning Programme (ALP), Singapore Science and Engineering Fair (SSEF)"* while Stacy suggested *"school science competitions such as Elementz*". As mentioned, schools in Singapore could choose STEM education as their focus in their ALPs. The SSEF is a national competition jointly organised by several institutions in which students present science or engineering projects, with research topics spanning across the different areas of science and engineering (Science Centre Singapore, 2020). Elementz is a local competition that aims to "promote science, technology, engineering, and mathematics (STEM) culture for local and overseas students" (Anderson Serangoon Junior College, n.d.). At this point, it seems that there is a huge variation in terms of prior knowledge of PSTs, ranging from those who have faint or vague ideas to those who have more elevated understanding of STEM education.

The next aspect of PST's background that we looked into was their prior learning experiences involving STEM education. Margot and Kettler (2019) reported that teachers who have prior experiences with instructional methods used in STEM education initiatives facilitate success in STEM education efforts. These experiences allowed teachers to understand the cognitive processes involved in STEM education and the confidence to teach it. In this case, the prior experiences should also affect the PSTs' understanding of STEM education and thus, the quality of ideas they could offer. Understanding these prior experiences provides a context that allows us to better understand the sophistication of the ideas of the PSTs.

The majority of the PSTs in this study did not encounter any form of inter-disciplinary activities in both pre-university and tertiary classrooms. For those who have engaged in such activities, they were able to provide concrete examples. One PST, Yolanda, mentioned that "*Chemistry, biology and physics were integrated to teach the topic of kinetic theory of matter. This is was done in a research of a senior specialist whom I followed during my internship.*" Two PSTs, Aida and Cath, highlighted the explicit integration of two disciplines in their university courses. Aida said that *"Computer Analysis, which integrates Mathematics and Technology. This module teaches us how to do some basic coding, hence, we have to use both technological and Mathematical knowledge."* Cath said *"In biostats and ecology, we have to make use of our ecology knowledge and statistic knowledge."*. On the other hand, some PSTs suggested activities that sounded less related to STEM education. For example, the PST Glenda, mentioned *"A debate on the human genome project"* and the PST Stacy said "*I had to do problem-based solving in a humanities subject*". The experiences highlighted by these PSTs were either irrelevant or did not have obvious STEM elements. This, together with the majority of PSTs not having engaged in any inter-disciplinary activities, indicates a lack of rich experiences this group of PSTs has.

PSTs' Ideas on STEM Education

To address our first research question on the perceptions held by Singaporean PSTs towards STEM education, our analysis using a refined lens based on Nguyen et al. (2020) revealed ideas that supported the initial categories, which are summarised in Table 3. No initial categories were left completely untouched. This itself was rather interesting considering the fact that the PSTs only had superficial awareness of STEM education. Apart from the initial categories, new ideas for each construct had also emerged from the data. The evolution of the coding categories is documented in Table 4.

Table 3.
The initial set of categories that were pre-determined at the time of refining the framework prior to the coding process.

Construct	Initial set of categories

STEM education	Workforce readiness
	Making interdisciplinary connections
	Epistemic practices
	    Epistemic features
	    Objects of interest
	    Connections
	    Relationship with society

STEM competencies	21st century competencies
	    Problem-solving
	    Thinking deeper
	    Taking perspective

STEM difficulties	Assessment* Limited knowledge Tensions* Limited school support Student readiness

Note: The categories with an asterisk have their names altered gradually during coding analysis but its descriptor remains unchanged, if not, even broader than before.

STEM Education. The construct *STEM education* describes the broad theoretical aspects associated with STEM education. The initial set of categories were *Workforce readiness*, *Making interdisciplinary connections* and *Epistemic practices*, of which *Epistemic practices* would be discussed in a subsequent separate section.

Under *Workforce readiness*, PSTs did see that STEM education was to prepare students for the workforce, as how the PST Jodi, put it as to *"prepare students for careers in science and technology"*. This preparation naturally meant in terms of skills and knowledge, as articulated by the PSTs, Nora *("skills and knowledge needed for them to excel in the workforce"*) and Aida *("jobs in the world today requires one to be knowledgeable in these areas"*). This is very much in line with the earlier intentions of STEM education to prepare a workforce that can support STEM-related industries (Blackley & Howell, 2015; Honey et al., 2014; Reeve, 2015). PSTs seem to also suggest that it is precisely the emergence and increasing importance of STEM-related industries that STEM education is crucial in preparing students for work. As how the PST, Jeff, brilliantly explains STEM education *"prepares students for the real world…underpinned rather significantly by nascent and/or advanced fields under STEM"*. The existence of such an idea showed an awareness of the evolving demands of the economy, which then influences PSTs' understanding of STEM education.

PSTs also perceived that STEM education involves *Making interdisciplinary connections*. This category was the most identified in teacher responses from the study conducted by Holmlund et al. (2018). Therefore, it was not surprising that PSTs also suggested ideas relating to interdisciplinary connections. These connections were interpreted mainly in terms of combining or making links the different disciplines together (Danny – *"link the four components of STEM together"*; Cath – *"see the links between the different disciplines"*) or at least casting away boundaries between disciplines (Felicia – *"stop looking at different subjects in silos"*; Erica – *"Subjects should not be seen as independent"*). In a subsequent exploratory exercise where PSTs had to choose a definition on STEM education, *Making interdisciplinary connections* was an essential feature that PSTs picked out that defines STEM education to them. This line of thought was nicely demonstrated by Aida, who said "*because of the word "inter-disciplinary…which I think is umm, to me this is what I think STEM is*".

Honey et al. (2014) suggested that manifestations of such connections can come in the form of knowledge transfer, recognising or combining specific disciplinary knowledge or practices. Furthermore, the establishment of these connections among the four disciplines can exist in multiple configurations and can be designated as strong or weak (Tan et al., 2019). PSTs did not offer elaborations of these connections, highlighting the dearth in understanding the concept of interdisciplinary connections. Rather, there appears to be some confusion with the degree of integration. Some PSTs opined that interdisciplinary had similar meanings to multidisciplinary and integration (Yolanda – *"multi-disciplinary approach"*; Melissa – *"integrated manner"*; Jeff – *"cross- or interdisciplinary across some combinations"*). As outlined by Bybee (2013), integration exists as a spectrum. Interdisciplinary, multidisciplinary and integrated belong to different points and thus not exactly inter-changeable. Additionally, there were occasional interpretations of these connections to be between STEM disciplines with humanities or languages, as seen in Danny stating *"aspects of STEM may be used in humanities or linguistics"*.

There were a few new categories that emerged from the PSTs' responses, *namely STEM literacy, Pedagogical, Authenticity, Transcends school, Interest and engagement* and *Equal opportunity* (Table 4). There were two other categories that emerged but there were too few codes to make them substantial categories. *STEM literacy* is a high-level goal suggested by Honey et al. (2014), where it is "some combination of (1) awareness of the roles of science, technology, engineering, and mathematics in modern society, (2) familiarity with at least some of the fundamental concepts from each area, and (3) a basic level of *application fluency*" (p.34). The PST, Erica, suggested that STEM education *"broaden the perspectives of students about science, technology, engineering and mathematics"*. This is in line with point (1) as gaining awareness could come in the form of getting students develop more views about each STEM discipline. The more common idea raised by PSTs was on *Application fluency*. Examples of *Application fluency* are described by Honey et al. (2014) such as critically evaluating science material in news reports or utilising mathematical knowledge "relevant to daily life" (p.34). This idea of students transferring knowledge to make sense of real-world situations is commonly referred to by the PSTs. Statements such as *"applicable to the real world"* (Cath) and *"make applications of these subjects to real-life"* (Erica) illustrate this. Similar to *Making interdisciplinary connections category*, *Application fluency* was commonly picked out as an essential feature of STEM education or at least, what PSTs envisioned STEM education to have. On a separate note, while most kept mentioning the word "apply", one PST, Penny, had more progressive awareness by mentioning *"STEM thinking"*. STEM thinking was defined by Reeve (2015) as "purposely thinking about how STEM concepts, principles, and practices are connected to most of the products and systems we use in our daily lives" (p.8). With this, there appears to be varying levels of sophistication exhibited by PSTs.

As the codes for *Application fluency* were inspected further, another category *Authenticity*, which refers to the real-world contexts emerged. Statements by PSTs that illustrated this idea include *"through real world situations"* (Sherry) and *"related to our everyday lives"* (Cath). PSTs opined that STEM education is to be situated in a real-world context to enable application of knowledge to take place. In other words, there should be an authentic element to STEM education efforts. This was similar to teachers in the study by Holmlund et al. (2018) who highlighted real-world connections between school and out-of-school contexts as a common theme.

When we consider this *application fluency* and *authenticity*, it makes sense why PSTs also highlighted that STEM education *Transcends schools*. PSTs generally seem to disagree with definitions that suggest STEM education occurs at certain stages of schooling. For example, the definition provided by Gonzalez and Kuenzi (2013) used phrases such as "pre-school to post-doctorate", "formal" and "informal" while Brown et al. (2011) defined STEM education with the phrase "residing at the school level". PSTs pointed out that STEM education *"Doesn't have to be within-school context"* (Danny) and *"you can learn STEM even when it's like not educational activity"* (Penny). On the other end of the spectrum, there were considerations, albeit few, on *"how STEM can be applied for in your entire life"* (Hedi). Regardless, the general perception appears to be that STEM education operates within authentic contexts which would support transfer and application of knowledge and skills. Therefore, STEM education need not to be confined to only school programmes.

Pedagogical encompasses ideas relating to teaching and learning. PSTs saw STEM education as teaching students using and about the four STEM disciplines, as seen in statements such as *"Teaching students the four areas"* (Melissa) and *"teaching students"* (Glenda). One PST equated STEM education to *"hands-on learning"* (Hedi) while others perceived STEM education to *"provide(s) a challenge to students"* (Stacy) and *"deepen their understanding"* (Cath). The emergence of this theme is consistent with other perception studies mentioned earlier on (Cinar et al., 2016; Holmlund et al., 2018; Radloff & Guzey, 2016; Srikoom et al., 2017). Regardless, the *Pedagogical* category is a generic description. Although the study by Holmlund et al. (2018) had a theme Instructional practices that is similar to *Pedagogical*, theirs mentioned details about teacher decision-making, classroom discourse and so on. These were evidently missing from the codes here. Aside from the occasional mention of enhancing learning, it would seem that the majority of PSTs do not really know what STEM education entails. It might be plausible that because the PSTs are in training, considerations in classroom contexts may not be of concern for them compared to their relatively more experienced counterparts.

Some PSTs also perceived that STEM education bolsters students' interest in STEM-related subjects, as seen in statements such as *"increase students' interest in STEM fields"* (Penny) and *"spark student's interest"* (Danny), collectively placed under the category of *Interest and engagement*. Boosting interest and engagement has often been cited as a goal for STEM education with several projects reporting increased interests and confidence towards STEM (Honey et al., 2014). Margot and Kettler (2019) also found that in a number of published studies, there is a common view that STEM education itself is motivating, due to the problem-solving tasks associated with STEM education. Lastly, the category *Equal opportunity* describes whether or not all students should engage in STEM education. Brown et al. (2011) reported that with respect to this "universality" (p.8), there were varied responses. They illustrated that for those who believed STEM education is for all students were buying into the promise of developing skills in students. PSTs here also seem to believe that on the basis of skill development, STEM education is for every student. However, this was coupled with another idea in which STEM education is for everyone regardless of students' inclination to the sciences or arts. Just how as how one PST, Erica, put it *"Every student, no matter is an arts or science student, can all benefit as soft skills"*. This was interesting in which PSTs viewed the equal opportunities in terms of students of arts foray into the sciences. At the same time, another line of reasoning was simply adopting an egalitarian mindset as seen in PSTs' statements such as *"all students should be given the chance"* (Cath).

Epistemic Practices. PSTs saw differences between the two disciplines that could be classified in two broad categories, namely *Epistemic features* and *Objects of interest* (Table 3). The first category *Epistemic features* refer to the goals and processes that contribute to the knowledge-building in the discipline, which are further categorised into four sets of practices – propose, communicate, evaluate and legitimise (Kelly & Licona, 2018). PSTs were aware of a distinction between the epistemic processes involved in each discipline, as seen in statements such as *"thinking from the scientific point of view vs (versus) thinking from an engineering point of view"* (Penny).

For science, PSTs suggested that seeking explanations is a goal, as seen in statements such as *"science...It explains everyday phenomena"* (Hedi) or *"in terms of science, we are more focused on… figuring how like for example mmm molecules work"* (Yolanda). This goal of generating explanations was subsequently used as a distinguishing feature to identify statements describing epistemic statements that belong to science, as illustrated in statements like *"This is more of science because you are enquiring like how or why things work"* (Erica) or *"I put science 'cos again why is it beneficial so explain- explanation"* (Glenda). One noteworthy observation was from Penny, who elaborated on the nature of scientific problems. To her, *"a lot of scientists don't actually care about societal problems"* which highlights a relatively more advanced understanding of the knowledge construction processes in science.

In the process of identifying the epistemic practices, PSTs understood the goal of science to be that of discovery. While some PSTs merely mentioned *"discover new stuff"* (Danny) or *"I feel like is a lot about like discovering?"* (Melissa), others provided more information as seen in *"you find something that nobody had nobody understands"* (Penny) and *"you find the missing information that allows you to understand the entire concept"* (Erica). A possibility is that when PSTs mention discovery, it could be on the identification of missing linkages in explanations or theories, thereby alluding to the goal of seeking explanations.

Lastly, PSTs described the scientific method, as seen in statements such as *"scientists they describe, they observe, then they come up with a theory"* (Aida) *and "science would just be lab experiment. You get a certain result and that's it."* (Danny). PSTs outlined the steps of a typical scientific investigation, that serves as another distinguishing feature when compared to engineering. Collectively, these ideas are traced back to the features described by Kelly and Licona (2018) in the beginning epistemic practice for science – propose. As such, these ideas are subsumed under a larger category of *Propose*.

The PSTs provided more varied ideas that could constitute epistemic practices for engineering. In terms of the goal for engineering, PSTs perceived that there were three possibilities – problem-solving, product design and understanding how things work. The first two were highlighted by teachers as crucial components of engineering, or what constitutes as engineering (Thatcher & Meyer, 2017). PSTs readily pointed out problem-solving is a feature of engineering, as Aida puts it *"for engineering right is to solve some problem or fix something."* Problem-solving was repeated as justification of epistemic practice statements belonging to engineering (*"the product is trying to solve like trying to meet a requirement of like the society or something"* – (Glenda)). Given that problem-solving is indeed a feature characteristic of engineering (Cunningham & Kelly, 2017), this was a positive find. As for product design, PSTs suggested that a purpose of engineering is to create something, often a product or tool that addresses a certain problem. This is illustrated in statements such as *"for engineering, you do things to create an end-product"* (Felicia) and *"engineering is more of the applying or to create something or like a product"* (Glenda).

Similar to problem-solving, product design was used by PSTs to identify epistemic practices belonging to engineering as seen in Melissa's justification *"like engineering 'cos…like cycles of trials and errors like suggest like you're making a product again"*. However, product design is merely one feature of engineering as a more important aspect of the product is whether the product has met the constraints and client needs (Cunningham & Kelly, 2017). The third goal of engineering identified was understanding how things work. As how Yolanda put it, *"engineering is more of making things work"*. This presents a conceptually different understanding of engineering where the focus is on understanding the mechanisms, which could but not necessarily lead to the successful design of a product. Lastly, in some ways parallel to the scientific method category, PSTs suggested an approach that is unique to engineering in their justification of epistemic practice statements that belong to engineering. This is seen in statements such as *"engineering is quite specific and maybe there're specific actions they need to take"* (Erica) or *"it shows like something needs to be done like there's an action to do things"* (Melissa). This approach appears to be methodical or step-wise. It might be possible that these PSTs are alluding to systems thinking (Cunningham & Kelly, 2017).

PSTs identified differences between two disciplines largely by their content. The content refers to the knowledge, the very objects that epistemic practices produce. To the PSTs, the nature of the knowledge constructed in science is inherently distinct from that in engineering (Cunningham & Kelly, 2017). For science, PSTs were fixated on the knowledge being theoretical where *"Science is more towards the theory"* (Felicia). This theoretical aspect was also frequently mentioned by PSTs, such as *"for science to be successful, it has to be grounded in theore-theory"* (Yolanda) or *"I put it as science maybe because of the theory part"* (Danny), when justifying which statements contained epistemic practices of science. As such, PSTs perceived that the nature of scientific knowledge as more abstract.

For the knowledge in engineering, PSTs understood that the knowledge incorporates or involves some scientific concepts or principles, as seen in *"engineering a bit bigger? Like...is definitely not just physics. It has chemistry, bio and everything"* (Hedi) and *"engineers don't have to exactly understand like the whole scientific theory. But they only need to understand the part that like is applicable to them"* (Penny). Perhaps due to the science-theory association mentioned earlier, PSTs might have perceived that theory plays a role in engineering as well because engineering involved science. This would explain justifications such as *"engineering is very like a must, like have to meet this criteria, it has to satisfy the theories"* (Danny). On the other hand, there were PSTs who were cognisant that scientific or theoretical knowledge is not necessary in knowledge construction for engineering as seen in statements such as *"engineers are not that concerned about err about the theory"* (Penny) or *"for engineering, you could, you could have no theoretical knowledge and play around with things and see if it works"* (Yolanda). Much as how knowledge constructed in science is labelled as theoretical by PSTs, knowledge in engineering was seen as more application-heavy and thus more procedural, evident from how PSTs describe engineering as *"more of like a specialised applied skills of science"* (Erica) or *"is more of the applying or to create something or like a product"* (Glenda). However, this knowledge is apparently not unique to engineering. Rather, PSTs saw the knowledge applied in engineering, was from science. This is seen in statements such as *"I feel I want to say engineering is more application-based so is science"* (Aida) and *"engineering is more of like a specialised applied skills of science"* (Erica). In general, these ideas relate to engineering's epistemic practice to propose (Kelly & Licona, 2018), thus enabling them to be placed in the larger category of *Propose.*

The practices of evaluating and legitimising knowledge claims were not suggested explicitly by the PSTs, but the sorting of the statements (Appendix 2) revealed an understanding of these practices. It was difficult to identify ideas from PSTs related to the evaluation of scientific knowledge claims. The evaluation process in science is an "assessment of merits of a scientific claim, evidence or model" and "considering alternative explanations" (Kelly & Licona, 2018, p.19). This often involves debates between the constructors and critiquers of knowledge claims (Ford & Forman, 2006). Yet, this was not particularly evident in the PSTs' responses, with the closest being *"I don't think science would think of the benefits or umm improving in a certain way"* (Erica). As for engineering's form of evaluation, PSTs could pick out that it could manifest as optimisation. PSTs seem well aware that engineering evaluates solutions that has been optimised with respect to the constraints, as seen in statements such *as "more engineering 'cos is like some- to make something more effective"* (Melissa) or *"engineers might think like ok so how can we do this better?"* (Aida). Some PSTs were aware of the importance placed on the clients (*"engineers try to optimise for the user right?"* – (Penny)) and the constraints (*"Cos it talk about cost"* – (Glenda)). However, not all PSTs were clear of these distinctions (*"if you're talking about increasing the efficiency, it might not necessarily require engineering"* – (Erica)).

PSTs generally displayed a clear understanding of the legitimisation process that occurs in science, albeit upon being prompted by the statements presented to them. Most seemed aware, but not necessarily able to articulate, that scientific claims need to be recognised by practitioners of the scientific community or "relevant epistemic community" (Kelly & Licona, 2018), which need not include the masses. This exclusive conferment of legitimisation is captured in Penny's statement *"it has to get you have to gain acknowledgement from that specific society. Even if the layman agree with you, it doesn't work".* On the other hand, there were PSTs who were confused and unclear with these practices. For example, PSTs questioned the legitimisation of claims to be conferred only by science practitioners, as illustrated in *"why it has to be accepted by a specific community. Why can't it be everyone?"* (Erica) and *"if a lot of people agree on it it can like people would follow that as a scientific fact"* (Glenda). One PST went even further to assert that in science *"there's no such thing as successful or not successful"* (Felicia).

The category *Objects of interest* was a surprising find. PSTs found a difference between the two disciplines in terms of the things that the disciplines are focused on. For science, the focus seemed to be on natural objects or bodies as seen in this statement *"It can be in your body. It can be in the way you walk or like even in the sun"* (Hedi). For engineering, PSTs describe that *"engineering can talk about lightbulbs"* (Yolanda), *"engineering because I think of oh the man-made things that for example machines"* (Felicia) and *"mechanical and technical things"* (Aida). The PSTs emphasized the idea that engineering focus on man-made, inorganic objects. It is uncertain if the PSTs are fully aware of the fact that specialised fields such as bioengineering and chemical engineering are, in fact, part of the engineering discipline. This category reveals a rather superficial and somewhat stereotypical understanding of the disciplines, particularly more so for engineering.

Apart from differences, ideas regarding similarities between the disciplines were also sought from the PSTs. This yielded some interesting findings, of which one is the category *Connections.* The category *Connections* comprises ideas relating to some knowledge-related connection between the two disciplines. As how the PST, Felicia, put it, *"Engineering and science share a connection"*. Although PSTs were asked to seek similarities, it was strange that they viewed how the disciplines were connected to each other as a similarity.

From the PSTs' responses, emerged three types of connections. Firstly, PSTs saw that (1) engineering depends on science, in which scientific concepts provides a foundation for the engineering discipline. PSTs highlight this somewhat hierarchical dependence in statements such as *"Like Science pave the way for engineering"* (Penny) and *"engineering requires science"* (Yolanda). Although applying concepts and principles from other disciplines is an epistemic practice of engineering, engineering also constructs knowledge and solutions in its own way (Cunningham & Kelly, 2017). While PSTs had pinpointed accurately an epistemic practice of engineering, it remains uncertain whether PSTs are aware of knowledge in engineering can be independently constructed.

The second type of connections is simply (2) overlaps, in which concepts and principles of science and engineering seem to blend and merge together. This produces confusing conceptions of both disciplines. Statements such as *"engineering seems like a subset of science"* (Erica) and *"I used to think engineering would be within science...it used to be because it's physics"* (Danny) suggest that some PSTs see the overlap is so great because engineering is based off on one type of science – another point of confusion – that engineering is basically subsumed under science. On the other hand, PSTs also perceived that the engineering-specific epistemic practices are also found in science. For example, the idea of constraints is associated with engineering in which solutions have to be created under limited conditions. Yet, this idea apparently is an epistemic feature of science where *"GMO for example then what kind of constraints you think you face if you were to create like a GMO crop"* (Erica). Another example is optimisation, another unique feature to engineering, which is also somewhat present in science, as described by Yolanda where *"in science, sometimes you have to think about how to make things more effective"*. Interestingly, PSTs majoring in chemistry seem to blend the epistemic practices of science and engineering seamlessly. Examples of such blending include *"I had to optimise my conditions for yeah. Like my reaction conditions"* (Melissa) or *"for chem, err when you synthesise something, you always want to synthesise at a higher yield"* (Penny). Reynante, Selbach-Allen and Pimentel (2020) noted that in practice, the boundaries between disciplines are less defined and more dynamic, giving the example of theoretical physics as a field where the fields of mathematics and science seem to meld together. In our case, certain branches of science might adopt engineering practices more readily, which results practitioners, or students, of those branches to have a more blended understanding of epistemic practices.

The third type of connection is a (3) mutual relationship where science and engineering are seen as equals to one another. Statements illustrating this idea includes *"Science informs engineering. Engineering informs science"* (Yolanda) and *"(Engineering) Is very close to science"* (Danny). For this type of connection, the transmission of knowledge and tools is bi-directional between both disciplines. Neither discipline is wholly dependent on the other.

Collectively, the *Connections* category shows variants of a connection between science and engineering.

The category *Relationship with society* was an interesting find, albeit it did not directly emerge as a difference or similarity. When it comes to advantages/disadvantages or benefits/harm, some PSTs seem to equate them to be discussing society. For example, Erica said *"in terms of wha umm more of a soc- societal concern, then err...Then it would involve science"* while Yolanda *"science, we always look at whether, like for example discoveries help to benefit or cause…I mean, it can benefit or it can cause potential harm."*

STEM Competencies. In this construct, the competencies being referred to are 21st century competencies. PSTs picked out the development of such competencies as an essential feature of STEM education. This was evident when PSTs mentioned statements such as *"I really like the third one (definition) also 'cos it also talks about 21st century skills which I think is very important"* (Melissa) or *"21st century skills kinda of like overlap with STEM"* (Penny). Based on the responses, three specific competencies could be gleaned, which are termed *Problem-solving*, *Thinking deeper* and *Taking perspective* (Table 3). In *Problem-solving*, PSTs perceived that STEM education is a platform for students to somehow transfer the knowledge learnt into generating a solution, as seen in this statement *"everything they learn, they can apply to the same things to solve something"* (Felicia). PSTs mentioned *"solve complex problems in the 21st century"* (Aida), *"solve problems using the four areas"* (Melissa) or *"solve problems in the 21st century"* (Stacy). The second competency, *Thinking deeper*, revolves developing thinking processes of students such it is more flexible and critical. PSTs readily offer complex terms when describing how students' thinking would be developed. Examples to illustrate include *"hone students' critical thinking, logical thinking, adaptability and innovation skills"* (Erica) or *"honing students' creativity and critical thinking skills"* (Stacy). The third category, *Taking perspective*, revolves around guiding students to adopt different viewpoints, as seen in statements such as *"see a situation from different perspectives"* (Penny) and *"looking at it from different perspectives"* (Nora). One PST, Aida, went further and envisioned that with STEM education allowing students to develop multiple perspectives, one can hope that it *"will raise awareness about such global issues"*, *"shape pupils' attitude towards them"* and embrace their *"role as a global citizen"*.

There were some generic, if not superficial, descriptions that suggested the outcomes of developing these competencies. Such outcomes were making the students *"wholesome"* (Felicia), implying a holistic development of the student or equipping students *"with skills rather than knowledge"* (Hedi). Collectively, there is a disparity in the level of sophistication in the PSTs' thinking.

STEM Difficulties. Codes could be found for all initial categories under the construct of *STEM difficulties* (Table 3), which two categories, *Assessment* and *Tensions*, were revised in view of the PSTs' responses. Originally, the *Assessment* category intended to cover ideas of a dearth of assessment that can sufficiently test for students' learning in integrated STEM education programmes. This was revised to include attitudes towards assessment as well. Honey et al. (2014) had highlighted the problem of assessments that can accurately test the outcomes of integrated STEM education, highlighting the historical format of assessments often focus on single disciplines with insufficient attention paid to the practices characteristic to the discipline. This was an issue highlighted by teachers (Margot & Kettler, 2019). PSTs also had highlighted this mismatch between STEM education and assessment. Assessment becomes an obstacle when it *"does not allow students to see the different aspects as an integrated unit"* (Felicia) or it forces compartmentalisation of knowledge with *"students only need(ing) to master the knowledge learnt from one subject for a particular examination"* (Glenda). One PST articulated that *"problem-solving is a complex skill, knowing about real world issues and current world trends is also not that simple"* (Aida). This highlights another issue of the complexity of the skills or processes, a central feature of integrated STEM education, that assessments would need to grapple with and it would not be easy to test them with standard pen-and-paper formats.

The PSTs provided an interesting point that was not reported in other studies, which was the overt focus on examinations and grades. In Singapore, examinations and results are important for accountability. PSTs have articulated that *"schools who are focused on grades, may not have the motivation"* (Aida), or that the *"Exam focus is too strong"* (Hedi) with the concern to *"prepare students for the major examinations"* (Danny). The larger concern expressed by PSTs related to accountability – whether STEM teaching could result in good examination outcomes for students. At this point, it is apparent that PSTs do see that STEM education is something wholly separate.

Tensions is another category was revised as the PSTs responses focused mainly on the curriculum rather than outcomes. Rather than focussing on possible tensions between curriculum or their individual subject requirements and integrated STEM education (Holmlund et al., 2018; Margot & Kettler, 2019), the PSTs were concerned with time and coverage of content. PSTs seemed to suggest that there is insufficient time to implement such STEM education programmes, as seen in *"eats up the curriculum time"* (Penny) or *"lack the curriculum time"* (Sherry). PSTs saw time as a constraint as they need to cover concepts stipulated in the syllabus. Due to the presence of *"whole lots of content"* (Cath) need to *"cover the graded content"* (Penny), STEM education becomes a competing need for the already crowded curricular space and time. The concerns of lack of curricular time was different from what Margot and Kettler (2019) reported — the teachers in their study were concerned with the lack of time due to a greater workload in terms of planning and coordinating STEM education projects.

The category *Student readiness* contains ideas relating to the suitability of students, either in terms of skills and academic progress, to handle the cognitive demands of STEM education. Teachers in several studies reviewed by Margot and Kettler (2019) do not think their students are able to handle the demands of STEM education. Responses from the PSTs mirror this lack of confidence as they considered the student's individual progress. This is seen in the statements such as *"Not all students would be able to do it"* (Felicia) and *"Depending on the abilities of each student"* (Jodi). There were two main ideas that PSTs presented that account for *Student readiness* to be an obstacle. The first is the concern with lack of mastery in the basic concepts or fundamentals. As Aida opined, *"STEM is not for weaker pupils...struggling with their subjects in silos"*. PSTs expressed fear that academically weaker students who have yet to master the basics would not be able to engage in STEM education. This fear could be in terms of students struggling as suggested in statements such as *"does not sound easy for students who struggle with basic subject knowledge"* (Glenda) or *"requires a certain level of mastery over basic concepts"* (Stacy). This indicates that PSTs prioritise concept mastery of each discipline.

A second finding was PSTs' perception of integration as an advanced skill. Just as how action verbs are ranked hierarchically in Bloom's taxonomy, PSTs viewed the action of integration is a higher-order skill which would be cognitively challenging for students. The skill is difficult to understand such as implied by Aida in *"pupils may not know how to integrate"*. Alternatively, the skill has pre-requisites in the form of basic foundational knowledge, as suggested by Stacy in *"If students struggle to grasp basic concepts, then it would be difficult for them to integrate"*. Rightly so, Honey et al. (2014) noted that knowledge of individual disciplines can impede an individual's ability to establish connections between different disciplines and thus recommend integrative experiences to take account of the students' knowledge of the individual disciplines. Looking at these ideas under *Student readiness* as a whole, student's content mastery seems to be a key determinant for a PST to decide to engage in STEM education.

The category *Limited school support* describes the possible ways schools could support STEM education initiatives and how these ways could be limited. PSTs highlighted that STEM education could *"require a lot of planning and resources"* (Aida) which may dissuade schools from implementing STEM education. In statements such as *"education in Singapore very rigid"* (Jodi) and *"amount of change that different stakeholders have to embrace"* (Rene), school support could be limited if the existing structures and the accompanying mindsets are not receptive to new changes, leaving little space for STEM education initiatives to take root. This is similar to what was found by Margot and Kettler (2019) who reported several studies mentioned school structuring and relevant support are crucial factors (or obstacles) in implementing STEM education. The category *Limited knowledge* describes ideas involving the lack of understanding about STEM education. The first idea presented by PSTs was a lack of understanding on the pedagogical skill sets specific to STEM education. They pointed out that *"teachers are not as skilled at STEM education"* (Melissa) and that *"may not know how to strategically infuse STEM into the students' learning"* (Cath). On the other hand, the lack of knowledge made PSTs perceive STEM education as something obscure where *"not very well understood"* (Penny) and *"not many people know"* (Rene). Due to this obscurity, there could be *"fear / rejection"* (Jeff), becoming an obstacle to implementing STEM education. This notion of a STEM specific pedagogy and the lack of understanding was also reported even among experienced teachers who were less confident and comfortable with STEM education (Margot & Kettler, 2019). Interestingly, one PST was cognisant of how prior experiences influence her teaching practice when she mentioned "*not taught with this approach*" (Rene). This idea was mirrored by other teachers who believed having experienced the instructional methods used for STEM education would enable them to implement STEM education (Margot & Kettler, 2019). These ideas point out the importance of pedagogical content knowledge unique to STEM education. Teacher require more professional development in translating what they have understood about STEM education and integration into actual classroom practice (Dare et al., 2018).

Value was a new category that emerged from the responses (Table 4) and it describes the importance and utility of STEM education ascribed by both students and teachers. PSTs suggested that the students may not value or view STEM education as relevant to them, so *"not all students are interested"* (Jodi). As seen previously, PSTs had categorised students' preferences either towards the sciences or arts. Students who are arts-inclined may not value STEM education as much, which is a barrier to successful STEM education. This idea can be seen in these statements *"students who may not be interested in any of the 4 disciplines and may be more interested in pursuing the arts"* (Nora) and *"some students may be more inclined towards arts education"* (Sherry). The PSTs are also aware that the value of STEM education may be perceived differently by different stakeholders. Margot and Kettler (2019) had reported that the value attributed by teachers affects the willingness to be involved in STEM education efforts. Statements from PSTs such as *"not seen as an essential aspect"* (Penny) and *"not feel the compelling need"* (Glenda) suggests that the unclear value of STEM education does not help to encourage teachers or stakeholders to participate in STEM education efforts. PSTs further mentioned that it is *"hard to change whatever that was already established"* (Rene) or *"inertia"* (Jeff), suggesting a reluctance to try if the value is not clear.

Table 4.
The finalized categories elucidated from the coding process.

Construct	Initial set of categories	Newly added categories
STEM education	Workforce readiness Making interdisciplinary connections Epistemic practices Epistemic features Objects of interest Connections Relationship with society	STEM literacy Pedagogical Authenticity Interest and Engagement Transcends school Equal opportunity
STEM competencies	21st century competencies Problem-solving Thinking deeper Taking perspective	
STEM difficulties	Assessment* Limited knowledge Tensions* Limited school support Student readiness	*Value

Note: The initial set of categories were pre-determined at the time of refining the framework. Categories with an asterisk (*) are those whose names have been altered. Newly added categories are those that emerged from the coding process.

Concluding Remarks

STEM education has been gaining prominence for the various outcomes it is supposed to attain. A large part of STEM education efforts being successful relies on the teacher's implementation in the classroom. Various studies have shown different conceptions of teachers regarding STEM education as well as highlighting the challenges that comes with it. This study adds to this narrative by providing a Singaporean context. Our combined experiences as a practicing science teacher and a science educator researcher provides both a practitioner as well as researcher insights into our interpretation and analysis of the data. It is the first such study to investigate the perceptions held by PSTs towards STEM education through a validated lens.

Our study has revealed that the original ideas under the three constructs *of STEM education*, *STEM competencies* and *STEM difficulties* were observed in the responses of the PSTs. Some of these ideas, such as *making interdisciplinary connections*, come more naturally to PSTs. Furthermore, new categories such as *Pedagogical, Transcends school* and *Value*, aids in expanding our understanding of how STEM education could be perceived. Both initial and new categories had been similarly reported in other studies, suggesting some universal perceptions of STEM education that are independent of social and cultural context. Separately, this study also showed that Singaporean PSTs do have an emerging level of awareness, where they are not entirely unfamiliar with STEM education and its concepts. It also does raise a question of how these PSTs arrive at this level of awareness, which merits further investigation.

Our study also attempted to investigate how well PSTs could differentiate science and engineering in terms of epistemic practices. At a broader level, PSTs offered ideas that could be mapped to epistemic practices described by Kelly and Licona (2018). PSTs, particularly those majoring in chemistry, could connect or blend epistemic practices of both disciplines, demonstrating some semblance of epistemic fluency (Reynante et al., 2020). However, PSTs do harbour some limiting conceptions of engineering, such as the focus on physical products. Further investigation could be done to ascertain whether Singaporean PSTs have any other, limited, if not stereotypical notions of engineering.

One limitation of this study is that the perceptions of in-service teachers who are already teaching in schools were not captured. Nguyen et al. (2020) reported differences in the perceptions and enthusiasm between novice and more experienced teachers where novice teachers perceived STEM education as more valuable while experienced teachers were less receptive to newer innovations. In this study, there were some aspects such as the issues regarding curriculum implementation that were not raised by PSTs, which could have been attributed to the lack of prolonged experience in school settings. Thus, the next step could be to understand and compare the perceptions of in-service teachers. A second limitation is the limited number of participants. As 16 PSTs were selected, the findings may not be generalised to the larger population of PSTs as a whole yet. Further, we have considered all the PSTs across different years of study as a single group based on the assumption that they have enrolled in the same programme and hence have similar exposure to the actual school system and similar professional knowledge related to STEM. There could be differences between the quality of perceptions between PSTs depending on their level of exposure to STEM education. This can be investigated further in future studies. Nevertheless, this study is the first in detailing the perceptions of STEM education in Singapore and could serve to support the design of STEM education training programmes in the future.

Declarations

Availability of Data

The data used and analysed during the current study are available from the corresponding author on reasonable request.

Conflict of Interest

The authors declare that they have no conflict of interest.

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Ethics Approval

This study has been approved by the Institutional Review Board of Nanyang Technological University (reference number: IRB-2018-08-026).

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APPENDIX A

"DEFINITIONS" AS EXTRACTED FROM INTERVIEW SEGMENT

Definition #1
"teaching and learning in the fields of science, technology, engineering and mathematics. It typically includes educational activities – from pre-school to post-doctorate – in both formal (e.g. classrooms) and informal (e.g. afterschool programs) settings"

Definition #2
"a standards-based, meta-discipline residing at the school level where all teachers, especially science, technology, engineering, and mathematics (STEM) teachers, teach an integrated approach to teaching and learning, where discipline-specific content is not divided, but addressed and treated as one dynamic, fluid study."

Definition #3
"educational approach in which science, technology, engineering and mathematics are integrated, and these disciplines are linked to everyday life and supported by the 21st century skills."

Definition #4
STEM is a curriculum based on the idea of educating students in four specific disciplines — science, technology, engineering and mathematics — in an interdisciplinary and applied approach. Rather than teach the four disciplines as separate and discrete subjects, STEM integrates them into a cohesive learning paradigm based on real-world applications.

Definitions taken from:

#1 Gonzalez, H. B., & Kuenzi, J. J. (2013). Science, technology, engineering, and mathematics (STEM) education: A primer. In N. Lemoine (Ed.), *Science, technology, engineering and math (STEM) education: Elements, considerations and federal strategy* (pp. 1–35). New York, NY: Nova Science Publishers, Inc.
#2 Brown, R., Brown, J., Reardon, K., & Merrill, C. (2011). Understanding STEM: Current perceptions. *Technology and Engineering Teacher, 70*(6), 5-9.
#3 Yıldırım, B. & Türk, C. (2018). Opinions of secondary school science and mathematics teachers on STEM education. *World Journal on Educational Technology: Current Issues. 10*(1), 52-60.
#4 Hom, E. J. (2014). What is STEM education? *LiveScience*. Retrieved August 9, 2018 from https://www.livescience.com/43296-what-is-stem-education.html

APPENDIX B:

LIST OF STATEMENTS DESCRIBING SCIENCE OR ENGINEERING EPISTEMIC PRACTICES

1. Does genetically modified corn grow better than wild corn?
2. In country X, there is an intention by the agricultural ministry to increase profits by cutting costs in production of corn, how should the corn be modified such that costs can be reduced?
3. It is deemed successful because a specific set of criteria has been fulfilled.
4. It is deemed successful because there is alignment with existing theoretical thought.
5. To achieve this goal, what sort of constraints would you think you would face?
6. Does this explanation correspond well with what I have been taught or learnt?
7. What are the advantages or disadvantages of this?
8. Does this thing answer the need or requirement?
9. Why or how does this thing work?
10. How do I go about to make this more effective?
11. I am ultimately trying to generate an explanation, an answer that fulfils a gap in current knowledge.
12. I am ultimately trying to generate a solution to a societal problem.
13. Why is it beneficial for plants to cross-pollinate?
14. In what ways can we increase the efficiency of cross-pollination of the pea plant?
15. To be successful, it has to be accepted by a specific community sharing the same common knowledge.
16. To be successful, its acceptance does not exclude anyone without relevant knowledge.
17. Many cycles of trial and error are needed for optimisation.