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STEM Teachers' Private Theories and Their Learning Design in International Schools in Hong Kong

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ABSTRACT

This paper reports on the study of private theories of Science, Technology, Engineering and Technology ("STEM") teachers and their learning design practices at International Schools in Hong Kong. The literature emphasises that teachers are the key to successfully implementing STEM education. However, most are unprepared and ill-equipped for the task of preparing students for a sound STEM education. Teachers' thinking is critical for their learning design, decision-making and implementation of STEM. This decision-making is underpinned by a set of private theories. Using the methodology of a qualitative multi-case study, this research focuses on five participants teaching STEM in International Schools in Hong Kong. The private theories of the cases were identified and observed for any change with the use of a learning design model for STEM education. The learning design is introduced using a novel methodology of intervention. An observable change occurs in the majority of cases after the intervention, however certain private theories remained an obstacle to the effective implementation of STEM education. To overcome the remaining private theories in effective implementation of STEM education, the study proposes a novel framework incorporating both learning design and collaboration to mediate teachers' thinking in the context of STEM learning design.

Keywords: STEM education, private theories, learning design, RASE, collaborative professionalism

CURRENT STATE OF STEM EDUCATION

The acronym STEM (Science, Technology, Engineering and Mathematics) has gained substantial traction in education around the globe in the last decade. The expectation is that STEM education will boost students' interest and achievement and that pursuing STEM studies will enhance their employability (van Driel et al., 2018). The second decade of the 21st century has seen governments and industry intensify their focus on STEM as a vehicle for future economic prosperity (Barkatsas et al., 2018). However, international research (Marginson et al., 2013) has demonstrated that STEM subjects are often taught in ways that fail to engage young people. Indeed, student interest and participation in STEM learning is declining, particularly in western countries and more prosperous Asian nations (Bøe et al., 2011; Kennedy and Odell, 2014; Thomas and Watters, 2015). This decline has led governments to develop policy that promotes reform and more significant investment in new initiatives for STEM-related education. Despite a sense of urgency to improve K-12 STEM education (kindergarten to Grade 12) at the federal, state and local levels in the USA (Forman et al., 2015) and elsewhere (Ritz and Fan, 2015), there remains a sense of vagueness concerning the nature and conceptualisation of STEM education, not only among educators, but also other stakeholders, including students, educational leaders and policymakers (Breiner et al., 2012; Sanders, 2009; Williams, 2011).

Teachers have a significant influence on student interest in and understanding of STEM educational pathways and careers (Autenrieth et al., 2017; Brophy et al., 2008). It is recognised in the literature that "success is brought about by extraordinary teachers who overcome a variety of challenges that stand between vision and reality" (National Research Council, 2011: 19). STEM education is an educational innovation that involves solving real world problems and novel curricular and instructional approaches (Nadelson et al., 2015). This requires teachers to focus more on student-centred learning and other related innovations and less on knowledge conveyance (Nadelson and Seifert, 2013). STEM teachers often have specialised training in one of the subject disciplines of STEM and are passionate about teaching STEM. However, classroom teachers with limited background knowledge, confidence and efficacy in teaching STEM may hamper STEM learning in their students (Nadelson and Seifert, 2013).

For STEM teachers to be effective in their practice, they must first have deep knowledge of the content they teach (Darling-Hammond and Sykes, 1999; Munby et al., 2001; Shulman, 1987; Wilson, 2011). Additionally, they must also have specialised knowledge of how to teach STEM to students, i.e., pedagogical content knowledge (Shulman, 1987). The research shows that many STEM teachers believe in STEM integration and see it as constituting the use of all four disciplines, but they have no clear understanding of how integration might be effectively enacted (Breiner et al., 2012). According to Kelley and Knowles (2016), educators and schools lack a cohesive understanding of the practice of STEM education, and yet teachers of STEM education are seen as the means to achieving the results that will ensure their students are able to learn and apply crosscutting concepts from different disciplines to solve problems (Bybee, 2010; NGSS Lead States, 2013; NRC, 2009, 2014).

All teachers hold beliefs, preconceptions and private theories (also referred to as private beliefs and the terms are interchangeable) that affect how they interpret experiences and guide their thinking as they make instructional decisions (Pajares, 1992). Vartuli (2005) stresses the importance of analysing teachers' beliefs, arguing that "beliefs are the heart of teaching," and are not merely theoretical understandings but serve to guide teachers' behaviour and decisions in the classroom. Teachers' private beliefs influence their choices regarding what and how to teach, and when, as well as how best to deal with students' problems. Their ability to implement their beliefs may also be subject to factors such as the school culture and institutional constraints (Zanzali, 2003; Cimbricz, 2002), which also play a critical role in their decision-making process when integrating technology into their classroom practices (Churchill and Wang, 2014). Hence, teachers' beliefs have drawn increased attention in education, particularly in the sciences (De Jong, 2007).

As teachers gain experience over time, so will their private theories change and alter, progressing their cognitive development (Howard et al., 2000). According to Churchill (2006), when a teacher is led to become aware of their private theories, these theories can be transformed such that there is a change in those that are dominant; this in turn leads to a change in the instructional decisions of the teacher. Churchill also articulates that it is essential to effective teaching for teachers to examine their private theories after they alter, modify or shift their thinking in any way.

A learning design is a cognitive structure that enables students to understand new information and engage in specific disciplinary thinking, problem-solving and further learning (Churchill et al., 2016). The RASE (Resource, Evaluation, Support and Evaluation) learning design framework is built on the concept that resources are insufficient for the full achievement of learning outcomes (Churchill et al., 2016), as seen in **Figure 1**, and that activity, support and evaluation are critical for teachers to ensure that learning outcomes are achieved. The RASE framework builds upon theoretical concepts such as constructivist learning environments (Jonassen and Henning, 1999), problem solving (Jonassen, 2000), engaged learning (Dwyer et al., 1985-1998), problem based learning (Savery and Duffy, 1995), rich environments for active learning (Grabinger, 1996), technology based learning environments (Vosniadou, 1995), interactive learning environments (Harper and Hedberg, 1997; Oliver, 1999), collaborative knowledge building (Bereiter and Scardamalia, 2003), Quest Atlantis (Barab et al., 2005), situated learning (Brown et al., 1989), MicroLessons (Divaharan and Wong, 2003; Churchill, 2006), and WebQuest (Dodge, 1995). It is critical to understand how teachers use and implement the learning design model in the STEM classroom to support them in teaching outside their area(s) of expertise. The RASE model focuses on what is considered essential for ensuring quality in teaching and learning and can be used in almost every program and course (Churchill et al., 2013).

Central to RASE is the emphasis on the design of activities in which students engage, using resources and producing artefacts that demonstrate learning (Churchill et al., 2013). Practically, this learning design enables teachers to develop more effective programs for their students, increasing engagement, giving students greater autonomy over their learning, and creating opportunities for deeper learning leading to the achievement of the intended learning outcomes.

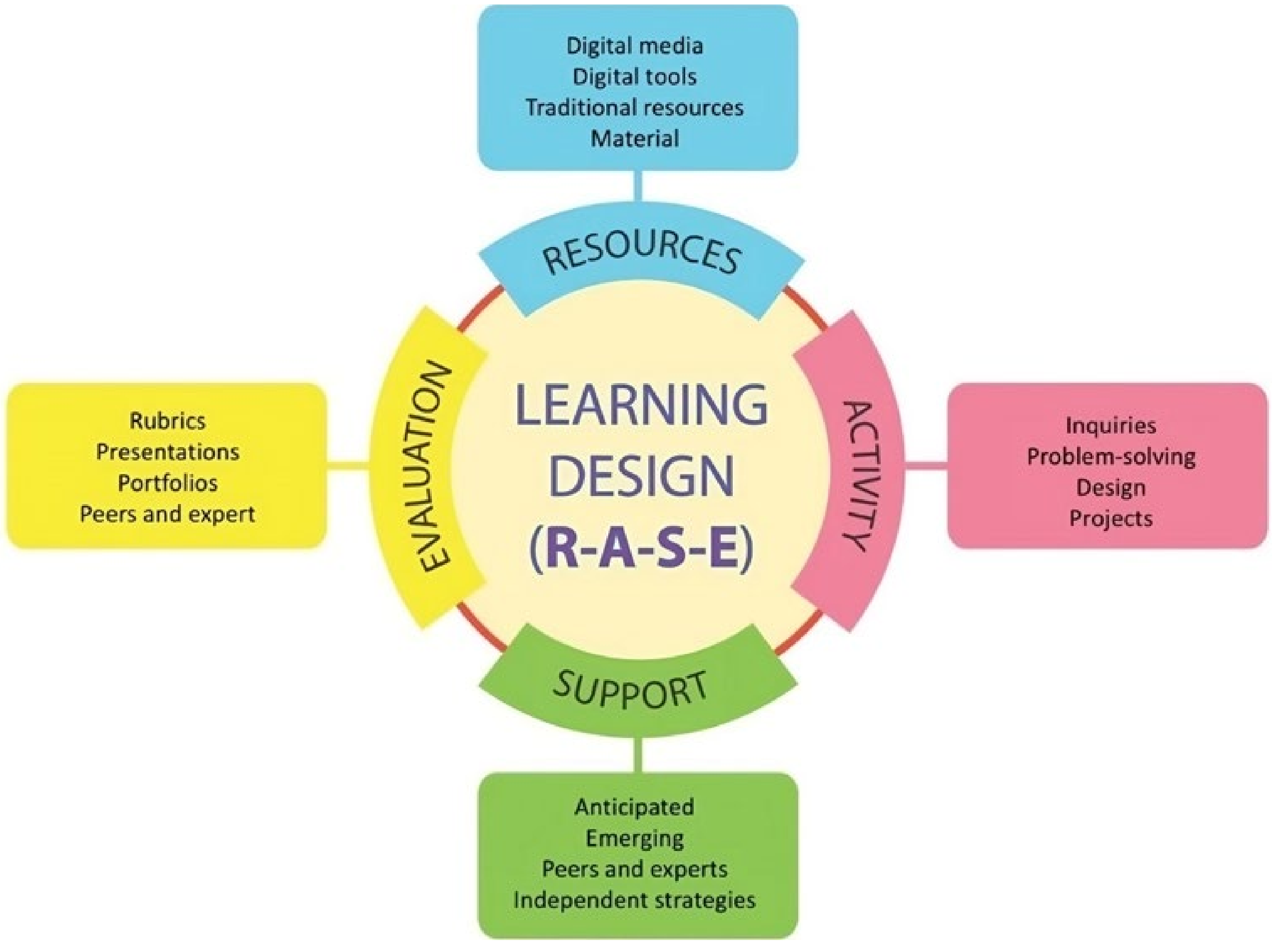

Figure 1. RASE learning design framework

METHODOLOGY AND APPROACH

The study seeks to address the following question:

How does a learning design model impact STEM teachers' private theories and approaches to learning design? In this context learning design means a strategy for transforming teachers' practices from teacher-centered to student-centered, which engages students to be more active in their learning, improved critical thinking and problem-solving skills.

Three sub-questions follow this:

(i) What private theories of the participating STEM teachers inform their instructional planning?
(ii) How do participating teachers' private theories change as they adopt a learning design framework?
(iii) What participating teachers' private theories continue to present barriers to effective implementation of a learning design for STEM education?

To answer these questions, the procedure used was guided by the recommendations from Merriam (1998), Yin (2009) and Stake (2006) and their approaches to qualitative, multi-case studies. This was essential to understand each of the case studies in-depth, exploring complex issues in a naturalistic, real-life setting. According to Yin (2009), case studies can be used to explain, describe, or explore events or phenomena in the everyday contexts in which they occur and help us to understand and explain causal links and pathways; these in turn should lead to new policy initiatives. The way this study has been approached is with an interpretivist approach to understand each of the individual cases in three stages.

During the recruitment process, the world was experiencing peak disruption from the COVID-19 pandemic. Schools ceased face-to-face lessons and replaced them with online teaching. Social distancing and the increased workload for teachers made it very difficult to gain access to potential cases to conduct selection interviews. Adding to the difficulties, classroom observations were curtailed because STEM teachers could not run their regular STEM courses or allow visitors into classrooms when face-to-face teaching was taking place. Ultimately five cases joined the study in this context and their backgrounds are summarised in **Table 1**.

Table 1. Background of the cases selected

Case	Gender	Age range	Teaching specialisation	Experience teaching STEM (years)
Bernie	Male	30-35	Design & technology, engineering	6
Moses	Female	40-45	Mathematics	6
Bridget	Female	25-30	Science	3
Milou	Male	40-45	Science	12
Freddy	Male	45-50	Science	3

Procedure

The data collection for this study was completed within a single academic year. This was significant as it provided consistency in the classes and programs, and the documentation collected. The relevant period was the northern hemisphere 2021-22 academic year.

Data collected during pre-intervention includes a semi structured interview, lesson observations and artifacts. The data collected included the teaching background of each case and findings on how the individual participants incorporated STEM education in the classroom, and how private theories impacted their teaching. The cases reported how they became involved in STEM teaching, their definition of STEM education, how STEM is implemented into their school curriculum, and the impact of their private theories on their teaching of STEM. For example, an interview question was, "When you plan a lesson what is the first thing you take into account?" During lessons, the researcher observed, amongst other things, the focus of teacher from a pedagogical perspective, and part of the review of artifacts included considering the objective of the lesson.

At the second phase of data collection, the intervention program was developed in a workshop format to provide training on the RASE learning design model, including implementing it in a unit and the classroom. The RASE learning design model according to Churchill et al. (2013) is a practical, evidenced-based learning design model with applications of technology to improve student learning outcomes and satisfaction. The program also included discussion on the challenges of STEM teaching and potential opportunities to improve their delivery. Following the pre-intervention data collection, all cases attended the workshop at The University of Hong Kong. It included a presentation by an MTR Academy representative on industry demand for STEM graduates in Hong Kong. The cases were provided with instruction on using the RASE learning design framework. Data was collected from the intervention via an open question and answer forum, which evolved organically into a participant-centred discussion on unit development for STEM education and associated challenges, primarily due to institutional constraints.

The third data collection phase was a follow-up survey individualised for each case and sent after they had had sufficient time to include the RASE learning design in a STEM unit of study. The survey's purpose was to determine whether their private theories and reflections had changed since the intervention in respect to their learning design for STEM education, and whether they considered any of their private theories an obstacle to effectively using the RASE learning design model.

RASE Learning Design Framework

The RASE learning design is practical and aims to improve student learning outcomes with an evidence-based learning design model (Churchill et al., 2013). The RASE model focuses on what is considered essential for ensuring quality in teaching and learning and can be used in almost every program and course (Churchill et al., 2013). The RASE model is suitable for STEM education due to it is practical student-centered and problem-based approach to teaching.

Central to RASE is the emphasis on the design of activities in which students engage, using resources and producing artefacts that demonstrate learning (Churchill et al., 2013). Practically, this learning design enables teachers to develop more effective programs for their students, increasing engagement, giving students greater autonomy over their learning, and creating opportunities for deeper learning leading to the achievement of the intended learning outcomes.

Analysis

Using a qualitative approach to content analysis, areas of private theories were identified in the literature and then compared with the private theories explicated in this study for each of the participating cases. Patterns and themes were identified for each case and confirmed through reference to the literature. The private belief were identified through interviews with each case and confirmed with lesson observations and documented artifacts. The researcher had to identify the private theory in every one of the three sources (interview, lesson observations and artifact) in order it to be confirmed. Investigation of patterns and themes through cross-case analysis indicated that the cases' private theories transformed after they were exposed to the RASE learning design.

Table 2. Private theories and their codes (Xue and Churchill, 2019)

Area of private theories	Code
Teacher	• Teachers' roles in a technology-based environment • Their perceptions of the affordances of technology • Their ways and experiences of using technology • Their capabilities and confidence in using technology • Their perceptions of their own professional identity
Teacher knowledge	• Teachers' content and technological knowledge • Their pedagogical knowledge about technology integration • Their own definitions of technology integration
Students	• Students' backgrounds and characteristics • The role they play in teaching and learning • Their ability in using technology for learning, and way of doing so
Learning	• How knowledge of an academic discipline is acquired • Useful teaching and learning strategies • Ways learning can be evaluated
Design	• Selection criteria for topics • Design of technology-based learning
Technology	• Relevance of technology to learning • Efficiency and limitations of technology on learning • Benefits of technology for learning • The roles of technology in students' lives
Institutional influences	• Relevance of technology to learning • Efficiency and limitations of technology on learning • Benefits of technology for learning • The roles of technology in students' lives
Educational changes	• Changes in society and their implications for education • Ways in which such changes impact teachers and students • Tendencies in technological development

Analysis was conducted from the first round of interviews which were transcribed and read by the participants and validated. Lesson observations and documents served triangulation. The data from the transcripts was then used to identified key themes in conjunction with Worksheet 2 developed by Stake (2006) and recorded. To add validity member checking (Merriam, 1998) between researchers was done. Any discrepancies that arose were discussed with a resolution reached.

According to Xue and Churchill (2019) there are key private theories held by teachers that impact their learning design. These are included in Table 2 and were used in this as the basis of identifying the key private theories under the headings as well as the option for the identification of new theories from the cases that participated. Cross-case analysis occurred using Stake's worksheet No 4.

RESULTS: THE TRANSFORMATION OF STEM TEACHERS' PRIVATE THEORIES IN THE STUDY

Each of the cases were selected from international schools in Hong Kong. International schools were selected because they provided English language instruction and were accessible to the researcher during the COVID- 19 pandemic. Each of the schools were currently running a STEM program that had been incorporated into their curriculum.

All cases are identified with a pseudonym to protect their privacy.

Case One: Bernie

Bernie had been teaching Design & Technology (D.T.) in the United Kingdom for five years followed by seven years at an international school in Hong Kong. He commenced teaching STEM when this school introduced a non-assessable programme for students in years 9, 10 and 11. Bernie's initial tertiary qualification was a bachelor's degree in engineering at a university in the U.K..

In pre-intervention interviews Bernie identified the key private theories as 'students', 'teacher', and 'institutional influences'. He recognised that students wanting the latest technologies and innovations to support their experience solving real-world problems played a critical role in the forming of teachers' private theories. This was evident in the practical lessons and lesson plans collected from Bernie. The aim for his lesson was for students to solve problems through collaboration to create a vertical indoor hydroponic garden using the latest technology. Bernie identified the teacher was central to introduce technologies, since without these students would not receive the necessary exposure. The institution instructed the curriculum and did not encourage collaboration between faculties of the STEM subjects.

Post-implementation of the RASE learning design, Bernie identified that despite his background in Engineering and Design & Technology, a full teaching load made it very difficult to invest sufficient time in following technology trends, thus confirming 'teacher knowledge' as a continuing private theory. In addition, 'institutional influences' were evident as his institution continued to restrict STEM education to elective courses for middle school years rather than integrate with its International Baccalaureate (I.B.) curriculum. The IB is an international educational curriculum that offers a framework for students aged 3–19 years. This program is recognised worldwide and aims to develop students with strong academic, social and emotional characteristics.

Case Two: Moses

Moses has taught for eleven years, with initial training as a Bachelor of Arts majoring in Architecture. He had worked as an architect for ten years before retraining as a Science and Mathematics teacher. Moses has taught STEM for three years, currently to middle school students aged 11 to 13.

Pre-intervention data collection identified the critical private theories of 'student', 'learning', 'design' and 'educational changes'. Lessons were planned around students working on an in-class project in groups to learn from and help each other. This need for the teacher to ensure student involvement was a critical factor in how Moses decided what unit of work he would choose for students. Students were challenged with new skills outside their regular learning. The project design was explicitly planned and organised to facilitate the students learning how the final device works and the best design for high performance. It was observed that many students needed help understanding the names and purpose of the parts and were guided by an example of a completed project shown in class. The unit was adapted to teach online due to COVID-19; students could design using CAD software on their laptop computers and send to the school for printing.

Post-implementation, the private theory 'teacher knowledge' remained an obstacle for Moses as he continued to question his knowledge and understanding within the STEM disciplines. The impact of 'institutional influences' remained evident from lack of support for teachers and insufficient financial support provided for resources. The broad range of abilities in the class meant 'students' continued to be a challenge.

Case Three: Bridget

Bridget's initial training was in primary school; however she subsequently completed a Bachelor of Education in Science and Mathematics. STEM is compulsory in her school as part of its I.B. curriculum. She teaches STEM to Grades 6, 7 and 8 students.

The critical private theories that were dominant pre-intervention were 'learning', 'technology' and 'design'. Bridget's students were learning how to use a new form of technology, adapt its use in the design process, and improve their designs and ideas for possible future application. The role of the teacher was critical in this lesson; while it was a student-centred class, there were crucial instances in which the case had to lead and direct the students to enhance their understanding of what to do and how to do it.

The vital private theories that were observed to be obstacles for Bridget post her use of the RASE learning design in her STEM teaching were 'teacher', 'institutional influences' and 'educational changes'. Bridget acknowledged that while her current school was well resourced, her sense of inadequacy when teaching STEM persisted. She recognised that while her knowledge had increased, further development was still required for the STEM disciplines in which she did not have teaching experience. The institutional expectation was that Bridget would be part of additional teams within the school community, creating additional demands on her time. It also prohibited collaboration with STEM teachers from other institutions. Bridget identified the need for more connection and consistency between the STEM curriculums of the elementary and secondary schools.

Case Four: Milou

Milou has sixteen years of teaching experience, twelve of which involve teaching STEM. Her initial training was an undergraduate degree in Mathematics (Canada), followed by a Master of Science in Information Technology at the University of Hong Kong. Milou commenced teaching in Hong Kong as an English teacher, later switching to Mathematics due to personal interest and her previous training. STEM is a compulsory subject in Milou's school.

Table 3. Categories of private theories that are an obstacle (pre-intervention)

Private theories	Bernie	Moses	Bridget	Milou	Freddy
Theme 1 – Teacher	X			X	
Theme 2 – Teacher knowledge					
Theme 3 – Students	X	X		X	X
Theme 4 – Learning		X	X		
Theme 5 – Design		X	X		
Theme 6 – Technology			X		X
Theme 7 – Institutional influences	X				
Theme 8 – Educational changes		X			

The ‘teacher’ and ‘students’ were the critical private theories that played a dominant role in observed lessons pre-intervention. Milou identified the teacher as playing a pivotal role in how the STEM course is taught. She identified that students play a crucial role in her private theories and the implementation of STEM education.

However post-implementation Milou identified the impact of ‘institutional influences’. She felt frustrated with reductions by the institution of STEM planning time but did acknowledge that COVID-19 had played a role in the decision. She was hopeful that the time allotted to STEM would increase when face-to-face lessons resumed. As she also continued to emphasis the teacher’s role in implementing lessons appropriately, ‘teacher’ remained an obstacle whilst ‘Catestudents’ was no longer considered to be one.

Case Five: Freddy

Freddy trained as a Physics teacher and has more than twenty years of teaching experience in that subject area; he has been teaching at his current school for the past seven years. For the past three years he has been incorporating STEM education into Physics lessons at the school’s request. He has no formal training in STEM education and sought professional support by joining the STEM Teachers Association, a worldwide association of teachers sharing materials and project ideas.

The researcher concluded that the fundamental private theories that informed Freddy’s teaching of STEM were ‘students’ and ‘technology’. He believed student interest to be a key factor in the topics he chose to study with his class and their ability to use technology. The students are at the centre of his planning and implementation of the STEM curriculum. Technology has helped keep students engaged, especially during online lessons.

Freddy identified that ‘technology’, ‘students’, ‘educational changes’ and ‘institutional influences’ were the key obstacles for him post-intervention. He highlighted the inclusion of technology with the use of the RASE learning design as an area he wished to explore since he had not recognised the lack of a learning design model as a limiting factor in his teaching. Students and their abilities were crucial factors in implementing STEM education more effectively in the classroom. Freddy was keen to keep up with innovation in education, however he felt a lack of time due to his current workload and school expectations prevented this. The expected workload for teachers in this institution is high, which resulted in a lack of time to plan STEM lessons, and this impacted the quality of teaching and opportunities to collaborate with teachers from the STEM disciplines.

CROSS-CASE RESULTS

Private Theories That Impact the Cases Pre-Intervention

The results are synthesised from each of the participating cases’ integration of the RASE learning design, private theories identified pre- and post-intervention, how these transformed and which remained an obstacle despite the use of the learning design. Following Stake (1995), the cross-analysis allows for comparing patterns and differences between each of the cases. According to the data, the private theories of Moses and Bridget underwent the most significant transformation with the application of RASE. The private theories of Milou, one of the most experienced teachers in the study, transformed least, as observed post-intervention.

Tables developed from Stake’s (2006) worksheet three were used to identify each of the participating case’s private theories pre-intervention and how they changed. Table 3 summarises the private theories of the cases when teaching STEM education pre-intervention, i.e., before use of the RASE learning design.

Results from pre-intervention data show all cases had confidence in their ability to teach STEM education no matter their experience or qualifications – that is, none identified ‘teacher knowledge’ as a private theory impacting their teaching of STEM education; all expressed the view during pre-intervention interviews that they had enough knowledge to confidently teach students even when teaching outside their area of expertise. Four cases identified ‘students’ as a private theory; all stated in their interviews (confirmed in lesson observations and documentation), that students’ abilities and interests heavily influenced what was taught and how it was delivered.

Table 4. Categories of private theories that are an obstacle (post-intervention)

Private theories	**Bernie**	**Moses**	**Bridget**	**Milou**	**Freddy**
Theme 1 – Teacher			X	X	
Theme 2 – Teacher knowledge	X	X	X		X
Theme 3 – Students		X			X
Theme 4 – Learning					
Theme 5 – Design					
Theme 6 – Technology					
Theme 7 – Institutional influences	X	X	X	X	X
Theme 8 – Educational changes			X		X

Table 5. Institutional issues identified by cases

Case	**Institutional issues**
Bernie	• Restriction on how many years students could elect to study STEM
Moses	• Restricted by timetabling • Restricted by yearly changes in total face-to-face teaching allocated to STEM
Bridget	• Access to limited resources • Room shortages leading to STEM being taught in a regular classroom
Milou	• Institutional expectations • Academic achievements for students • Restricted by yearly changes in total face-to-face teaching allocated to STEM
Freddy	• Institutional expectations Academic achievements for students • Restricted by yearly changes in total face-to-face teaching allocated to STEM

The critical private theories of 'educational changes' and 'institutional influences' were each selected by just one of the cases studies. The researcher concluded these private theories were rarely identified because most cases had sufficiently flexibility rather than follow a strict curriculum to implement STEM education.

Private Theories That Remain an Obstacle

Post-intervention, the cases' private theories had transformed except for Case Study 4. This is attributed to her being a very experienced teacher who was already delivering STEM curriculum through organised collaboration between STEM disciplines within her school. The data revealed that all cases had fundamental private theories that continued to inform and instruct their teaching of STEM education. **Table 4** summarises which private theories remained an obstacle post the RASE learning design intervention.

'Institutional influences' was identified as a private theory by only one case pre-intervention; however, post-intervention, all the cases realised that their institution was a more significant critical factor than initially thought. Cases shared that the institution impacted how they implemented STEM, their access to relevant professional development, and their ability to collaborate with teachers at other schools. This last issue was quickly identified as being due to the institutions, all international schools in Hong Kong, competing against each other for students, and thus restricting teachers through their contracts from sharing resources. The 'institutional influences' had not been a prominent factor for most cases as they were more focused on students and not mindful of how their institution was restricting what and how they could teach. **Table 5** summarises the specific restrictive issues identified by each case within their respective institutions.

Another private theory identified in the data as a critical obstacle was 'teacher knowledge', impacting all of the cases. While pre-intervention all cases had acknowledged challenges in maintaining and developing STEM knowledge, none had self-selected 'teacher knowledge' as a critical private theory. However, post-intervention, four cases stated that they often felt out of their depth with their knowledge when teaching outside their area of specialisation. While the cases felt more confident collaborating with other teachers when using the learning design model, they became more aware of their knowledge gaps in the new units they developed. Despite feeling more uncertain and stretched, a few of the cases expressed a desire to expand on their current curriculum by collaborating with other teachers in their school in STEM disciplines in which they are not experts.

DISCUSSION OF RESULTS AND RECOMMENDATIONS

The research results show that 'institutional influences' impacted all cases in various ways, including the approach adopted to incorporating STEM education into the school curriculum, funding and resources and support or lack of it for STEM education. The results also highlighted that 'teacher knowledge' was a key private

Table 6. Distribution of the private theories that remain an obstacle

Private theory	Distribution
Institutional influences	Lack of oversight and support from the administration Limited time given to teach STEM Structure within the school Competition between schools Insufficient resources and time for curriculum development Lack of training and development from the institution
Teacher knowledge	Lack of experience and qualification Finding real world problems Student engagement Implementing STEM in curriculum Connecting STEM disciplines within the school

belief impacting all of the case studies with limited out-of-field training in the STEM disciplines. Table 6 summarises how these private theories are distributed.

Institutional Influences

STEM education in Hong Kong international schools could be improved by opening up opportunities for more teacher collaboration on developing a set cross-school curriculum. While widely evident in the pre-intervention interviews, by the post-intervention stage all cases identified 'institutional influences' as a private theory that impacted the inclusion of STEM education in a variety of ways. Of those identified, the most prevalent were lack of oversight and support from senior leadership on programming, timetabling resulting in reduced time with students.

Teacher Knowledge

It was evident in four case studies' results that the private theory of 'teacher 'knowledge' directly impacted on student engagement. While all the case studies were keen to teach STEM, some admitted post-intervention that their knowledge, or lack of it, limited their ability to visualise and incorporate a broader STEM curriculum for their students. Therefore, appropriate 'teacher knowledge' is a key requirement for the STEM teacher. In particular, teachers' lack of experience and qualification and finding real world problems were those which presented the most often across cases.

Reflections

We propose a new education model for STEM teachers to use to assist in modifying or removing the private theories that remain an obstacle to successful STEM teaching. It is a combination of the RASE learning design and Andy Hargreaves' collaborative professionalism model by Hargreaves and O'Connor (2018). The results of this study demonstrate conclusively that with the adoption of a RASE learning design framework by STEM teachers, a significant proportion of their initially obstructive private theories end up being no longer an issue. However, in this study two key private theories persisted notwithstanding the use of the learning design – 'institutional influences' and 'teacher knowledge'. The main objective in using the RASE learning design is to compensate for the knowledge gaps of the STEM teacher. It is unrealistic to require them to be specialised in all STEM disciplines; therefore, teachers who do not have the support of a learning design model like RASE may be unable to put workaround measures in place to bridge gaps in their subject knowledge that will risk compromising their students' depth of knowledge and understanding of related learning material.

STEM education aims to develop students' capability and inclination to identify questions and solve problems associated with STEM-related issues and the natural and designed world (Bybee, 2013). From the study it can be reasonably extrapolated, based on the evidence gathered, that in international schools in Hong Kong (and reasonably likely elsewhere) there needs to be greater emphasis from institutions on increasing the quality of STEM teaching. An approach needs to be adopted that will recognise, change, and transform the teachers' obstructive private theories. International schools in Hong Kong strongly aspire to being leading institutions with effective and comprehensive STEM education programs. To achieve this, they need to recognise the barriers in implementation and ensure there is a framework with a carefully planned strategic approach to overcoming the obstacle of teachers' private theories. It is evident from this study that a formalised framework assists in improving the quality of STEM programs and the teaching of those delivering them, thus advancing the cause of building and bridging gaps in student knowledge and understanding.

Selection of curriculum content from each of the individual disciplines of STEM requires knowledge of multiple sub-disciplines. Developing a STEM education program that delivers holistic and intensive learning requires focused planning and collaboration between specialised subject teachers. Planning how to fit a modern and more inclusive version of STEM into an already crowded curriculum is an ongoing challenge (Lloyd, 2013). The formalisation and inclusion of teacher collaboration is an important part of the equation for achieving this since it will dilute if not negate the impact of STEM teachers' persistently obstructive private theories. In researching collaborative professionalism, Hargreaves and O'Connor (2018) contends that the evidence that professional collaboration benefits both the student and the teacher is undeniable. He views collaborative professionalism as a deeper and more rigorous form of professional collaboration. The results of this study have shown that the use of the RASE learning design model was effective in transforming the cases' private theories and thus removing some of the obstacles associated with them whilst the two obstructive theories of 'institutional influences' and 'teacher knowledge' could not be overcome solely through use of the RASE learning design. However, it is proposed they could be overcome with the inclusion of professional collaboration. The lack of formalisation of collaboration manifested in a broad range of degrees of collaboration occurring with all the cases, only one instance of which was organised and structured. However, the inclusion of collaborative professionalism in the RASE learning design creates a deliberate, committed and professional practice of collaboration between teachers. Hargreaves and O'Connor's (2018) definitive elaboration on collaborative professionalism is relevant here.

In combining the learning design with ten tenets of collaborative professionalism the former is the foundational framework. Collaborative professionalism is a secondary step to ensure the implementation of collaboration is formalised and agreed upon by the participating teachers and embedded in each aspect of the learning design in order to remove any remaining obstacles attributable to teachers' private theories. As part of the intervention, there was a collaboration that occurred, and it did help in this respect. However, it needed to go further to entirely remove private theory-related obstacles. The researcher believes that a formalised structure of collaborative professionalism will effectively counter the obstructive effects of private theories, such as 'institutional influences' and 'teacher knowledge'.

Summary and Recommendations for Further Studies

This study contributes to the literature by investigating different approaches to effectively incorporated STEM in the classroom. Its results show that the use of the learning design model can positively transform private theories and diminish associated elements that were initially identified as STEM teaching barriers. Nevertheless, for the cases some private theories remain an obstacle, namely those of 'institutional influences' and 'teacher knowledge'. The influence of institutions did not seem to be affected by the experience or capability of the teacher in this study, with variations in nature of influence attributable to the institution itself. Gaps in teacher's knowledge appeared surmountable in one case due to a deeply experienced case utilising a form of structured collaboration, with less experienced teachers acknowledging the benefits of collaborating. The researcher proposes that the use of the RASE learning design model combined with collaborative professionalism (**Figure 1**) will remove these obstacles and enhance the ability of the STEM teacher to provide meaningful and in-depth learning experiences for students. Further, through application of this proposed combination of RASE and collaborative professionalism, the STEM teacher will have greater support and confidence in teaching STEM across the subject disciplines when working with material outside their area of specialisation and training.

The combination of the RASE learning design model with collaborative professionalism provides scaffolding for STEM teachers when teaching outside their area of training or specialisation, regardless of their teaching experience. It also incorporates a deliberate and formalised structure that can remove private theories that remain an obstacle when teaching across STEM disciplines.

Based on this study, it is recommended that the STEM teacher have specialised training in a minimum of two of the STEM disciplines. The literature highlights that current Science teachers lack an understanding of the nature of engineering, limiting their ability to effectively integrate engineering into their Science instruction (Cunningham and Carlsen, 2014). Lack of specialised subject knowledge across the STEM subject disciplines hinders students in gaining the full breadth and depth of knowledge that STEM education should provide. The use of the learning design model reduces the gap arising from 'teacher knowledge' and increases understanding of the possibilities of implementing STEM education. Still, the institution's election of the STEM teacher should seek to identify those with multiple areas of specialisation of the STEM subject disciplines in order to provide a holistic curriculum and the best opportunity for students.

Collaboration within the institution between the STEM teacher and specialist teachers of the STEM disciplines is essential to reducing the STEM teacher's knowledge gaps. Careful planning of units will ensure that students not only acquire relevant knowledge and understanding, but that they will be able to apply it to solving real-world problems in the classroom. The recognition of the need for teachers to collaborate with others paves the way to enriching and transforming the STEM teacher's ability to provide a richer learning experience for their students.

Whilst Hong Kong international schools have autonomy in how they implement their STEM curriculum, these schools must adopt a practical and proactive approach to provide the best education for their students; leadership must ensure the selection of the right STEM program and teacher, embrace collaboration between silo departments and ensure that time is allocated for this to occur. With this approach, the institution can ensure that STEM can be effectively implemented into the school and will deliver the desired results for students.

A broader study could include investigating how local schools in Hong Kong adopt and implement STEM education in their curriculum. A component of further research could also be determining how many students want to pursue a STEM career after being exposed to STEM in their formal education, and which elements of their STEM education were most influential in steering them in this career direction.

It is clear from this study that the institution is a critical private theory that impacts the STEM teacher, and there is therefore a clear need to further research the roles of institutions in improving STEM education through teacher development and support.

Future research needs to investigate further the private theories of local teachers in Hong Kong teaching STEM education. The impact of their private theories, and then a cross-case analysis between local and international schoolteachers of STEM education.

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