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Investigating Affordances and Tensions in STEM Applied Learning Programme from Practitioners' Sensemaking

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ABSTRACT: The key role of teachers has been widely acknowledged in education reform and pedagogical innovation, and there is no exception in STEM education. This paper documents affordances and tensions in the implementation of STEM applied learning programme (ALP) through investigating school leaders and teachers' sensemaking of the new approach. Attending to both the individual processing and the social interactive work with issues of coherence, sensemaking theory provides a theoretical framework for analysing school culture and resources and connections between actions and understandings of school leaders and teachers in the programme. In this qualitative case study, semi-structured interviews and focus group discussions were conducted with three school leaders and three teachers from two Singapore secondary schools to identify their prior understandings, shared interaction and interpretations during the practice. The findings provide some insights into implementations of STEM in schools and professional development.

Keywords: STEM education, Applied learning, Sensemaking, Teacher professional development

1. Introduction

In response to the rapid advancement of new technologies permeating almost every sector of society, Singapore launched a lifelong learning campaign, advocating for lifelong learning, continuous education and skills mastery for all citizens in Singapore (Sung & Freebody, 2017). Aligned with this national initiative, the Ministry of Education launches the Science, Technology, Engineering and Mathematics (STEM) Applied Learning Programme (ALP), which aims to support an innovative 21st century learning environment in Singapore schools and encourage the application of academic knowledge learnt in class to real-world contexts (Wu & He, 2018).

STEM education receives tremendous attention in education reform and the key role of teachers is widely acknowledged (Al Salami et al., 2017; Cavlazoglu & Stuessy 2017; Lee, Chai & Hong, 2019). For the positive change in STEM education, teachers have the biggest role to play, as ultimately, they are the ones who will be the implementers of the lessons (Wells, 2008). The driving force of the pedagogical shift lies in the hands of teachers, as they will be driving the inquiry and facilitating the lessons (Margot & Kettler, 2019). While increasing teachers' proficiency levels in content knowledge is important, their pedagogical content knowledge is vital for the pedagogical shift to materialise (Milner-Bolotin, 2018; Wells, 2008).

Majority of existing STEM research on the teacher's role either focused on teachers' self-efficacy (e.g., Lee & Houseal, 2003) or training needs (e.g., Garet, Porter, Desimone, Birman, & Yoon, 2001; Margot & Kettler, 2019). However, there are few studies on how the larger system goals influence practitioners' perceptions and enactment while implementing education reform guidelines (Ganon-Shilon & Schechter, 2018; Gawlik, 2015). Investigating teachers' sensemaking of education policies or instructional approaches is important to their implementation in that usually, teachers' interpretations of their contexts vary widely and diverge from policymakers' interpretations (Penuel et al., 2009). Innovation and implementation also require that school leaders make sense of policies and bridge the gap between internal and external demands (Ganon-Shilon & Schechter, 2018; Weick, 2009). Sensemaking provides a means to analyse how practitioners wrestle with issues of coherence, that emerge from interactions within the practice, associated with curriculum materials, with colleagues and school leaders (Allen & Penuel, 2015). Therefore, drawn from sensemaking theory, this paper documents affordances and tensions in the implementation of STEM ALP in two Singapore secondary schools and aims to provide some insights into the implementation of STEM in schools and professional development.

2. Theoretical framework

Sensemaking describes the ways that active agents "structure the unknown" (Waterman, 1990, p. 41) within organisational settings such as schools (Allen & Penuel, 2015). It involves a noticing of change or difference but includes the potential for integrating difference into one's practice for decision making (Clough et al., 2009;

Dervin, 1992). According to Allen and Penuel (2015), in the process of sensemaking, agents are actively engaged to resolve ambiguity and manage uncertainty within their environment and make retrospective and prospective sense of change. Sensemaking is grounded in both individual and social activity in that it has been a durable tension in the human condition (Weick, 1995). Therefore, teacher sensemaking about instructional innovation or reforms is not an individual matter, but it is influenced by the school environment he or she interacts with.

The sensemaking theory has been used by educational researchers to interpret teachers' responses to new policies or programmes. Drawing primarily on instructional and sensemaking theory, Coburn (2001) puts forth a model of collective sensemaking that focuses on the ways teachers co-construct understandings of policy messages, make decisions about which message to pursue in their classrooms, and negotiate details of implementation in discussion with their colleagues. The findings of the study also highlight the role of school leaders in shaping the sensemaking process. In her subsequent studies, she further investigates how principals influence teachers in learning and enacting new policies (2005). Within the framework of sensemaking, it is also highlighted by Ganon-Shilon and Schechter (2018) that principals' perceptions may contribute to the practice of the complex leadership role in reforms. In short, school-level leadership has been brought into the teacher sensemaking equation. Furthermore, it has been suggested that school culture, routines, and structure are the results of how teachers and leaders in the school notice or select information, make meaning of that information and act on those interpretations to develop culture over time (Gawlik, 2015). Allen and Penuel (2015) call attention to the role of teacher plays in sensemaking by wider contextual factors, such as examination demands and curricular constraints, in influencing or affecting the ways in which a teacher expresses or enacts beliefs or understandings in classroom practice. Their study suggests the need for professional development to engage teachers in sustained sensemaking activity around issues of perceived incoherence to improve the likelihood of implementing instructional practices aligned to standards.

In STEM education, based on the proposition of sensemaking, Holmlund, Lesseig and Slavit (2018) investigate how various stakeholders conceptualise new curricular or instructional ideas that can inform the conversation needed to support teachers' professional development and alleviate challenges to education reform. They indicate that sensemaking can provide a useful framework for considering the influence of institutional and professional contexts in shaping each practitioner's construction of a plausible story of STEM education. In their earlier study, teachers' collective sensemaking of STEM-based instruction in specific learning environments has been underscored (Slavit, Holmlund & Lesseig, 2016). Additionally, in terms of the findings suggested by Gherardi's study (2017), a teacher sensemaking process is often decoupled from his/her actions in regards to classroom technology, but teacher's mindset and cohesion between stated values, policy messaging, policy implementation, and administrator actions appeared to contribute to this process.

Therefore, in this study, sensemaking is adopted to provide a lens to document and analyse how school leaders and teachers perceive and enact their implementation role in the STEM ALP programme. The study follows a qualitative approach to explore school culture and resources and connections between school leaders' and teachers' actions and understanding in the programme, by addressing the overall question: how school leaders and teachers perceive and enact their implementation role in the programme. The study seeks to provide suggestions in the implementation of STEM in schools and teachers' professional development.

3. Method

This study adopted a qualitative case study to document the ways school leaders and teachers make sense of the STEM ALP programme. The cases selected for this study using purposeful unique sampling, for it is an effective type of sampling that provides "rare attributes or occurrences of the phenomenon of interest" (Merriam & Tisdell, 2015, p. 97). We investigated two Singapore secondary schools which implemented the STEM ALP programme. The two case schools that were selected were based on their involvement in the programme and have emphasised the importance of making centred activities or hands-on learning in their schools. In both the schools, STEM lessons were conducted for 3 periods over 2 weeks for 6 months. Within the cases, the selection of interview samples depended on the school leaders and teachers who had been involved in the programme.

3.1. Research context

Since the early 2000s, the Singapore education ministry has tried to broaden the notion of success beyond good academic results (Ng, 2003). Although the need of change from a result-oriented system to one that stimulates creativity and innovation has been supported by the government, schools and students still find themselves stuck in a pressurised exam-driven culture where the primary emphasis is still on students' exam results (Wu & He, 2018). The ministry has highlighted that success in education should not be measured by academic results alone and that more opportunities and multiple skills-based progression pathways should be available to all students of varying abilities.

STEM ALP was introduced in 2013, as a programme to provide authentic learning based on real-world situations in STEM learning (Teo, 2019). The programme draws out content from STEM disciplines that are relevant to existing and projected trends and needs of Singapore's economy (Teo, 2019). In this study, the two schools involved focused on robotics, to highlight how Science and Engineering could work in tandem. The delivery of the STEM ALP programme shared similar objectives with the pedagogy of making in its intention of helping students understand the relevance of what they learn in class to the real world through interactive and hands-on experiences. This programme used educational technologies and hands-on activities that integrate conceptual understanding within the curriculum to applications of real-world scenarios in a non-formal context. STEM ALPs are organised by schools and conducted after formal curriculum time, and students are not formally assessed. It is a big shift away from the examination-dominant culture Singapore is commonly associated with.

Two STEM educators, trained by the Science Centre, were assigned to each school. The STEM educators helped to customise the programme to the school and help with the facilitation of the lessons. After two years, the Science Centre would pull out the STEM educators from the school and the teachers would have to facilitate the lessons on their own. In this study, the Arduino, an open-source electronics platform, was utilised as a tool to control the sea perch. The Arduino platform enabled students to build, program and control electronics. The user would ideally need some basic understanding of electronics and programming although it was not absolutely necessary, as the main idea behind it was that the user would start learning how to use the platform by doing and by experimentation. Most of the teachers did not have prior experience. Yet teachers were encouraged to look for training on their own. There was a budget set aside for teachers to go for external training, but they were required to get approval from their school.

3.2. Participants and school sites

School A is a boy's school. The school is active in organising activities related to Design and Technology (D&T) and robotics within the school and frequently hosts other schools in their zone. During their STEM ALP lessons, students used the Arduino to build the seas perch (an underwater robotic to build an underwater Remotely Operated Vehicle). School B is a Mainstream co-educational school. The school started offering computer studies in 2006 and is now offering computing as an 'O' level subject. The STEM ALP lessons at School B were planned based on the school's niche area in clean energy and environmental technology. Their students also used the Arduino to build the seas perch in STEM APL lessons.

As shown in Table 1, A.D is the vice-principal of School A and has been in the school since 2014. A.T is Head of the Department of Design & Technology and has been teaching in School A for 12 years. Teachers A.J and A.S have had 16 and 9 years of teaching experience respectively. For School B, B.R is in charge of computing and the year head for the lower secondary and has been in the teaching service for more than 15 years. B.W is a teacher at School B has more than 6 years of teaching experience.

Table 1. Research participant profiles

School	Name (Pseudonym)	Role	Years of experience	Sex	Leader or not
A	A.D	Vice-principal	20	M	Yes
A	A.T	Head of Department	> 14	M	Yes
A	A.J	Teacher	16	M	No
A	A.S	Teacher	9	M	No
B	B.R	Year Head	>15	M	Yes
B	B.W	Teacher	> 6	F	No

3.3. Data collection and analysis

Data collection and analysis occurred simultaneously throughout the study year. Four semi-structured interviews and focus group discussions were conducted with three school leaders and three school teachers to identify their understandings of school culture, interpretations of the programme, shared interactions. A sensemaking process could reflect a complex interaction between policy messages, teacher beliefs, and practices (Coburn, 2001;

Gherardi et al., 2017). Therefore, in addition to collecting interviewee's personal information, the guiding questions of the interviews mainly consisted of three aspects: (1) interplay between policy messages and practices: questions related to participants' understandings of the programme and the role they played; (2) interplay between beliefs and policy: questions about participants' understandings and attitudes towards STEM and life-long learning; (3) practices and perceptions: elaboration on the supports they provided or received, challenges they faced in the process of implementation, as well as how they sought to overcome the difficulties. Every interview or discussion ranged in length from 50 min to 57 min, totalled 218 min. All the interview and focus group discussion were audio-recorded and transcribed verbatim. Extensive field notes were taken during the initial classroom observations and during the focus group discussions to ensure that data could be cross-checked with the audio and video recordings.

Thematic analysis was conducted manually to analyse the collected data. Following the 6 steps of thematic analysis (Braun & Clarke, 2006), two researchers first evaluated the transcribed recordings and field notes, and then familiarized ourselves with the data. From the perspective of sensemaking, the researchers (the first author and the third author) looked for the portions of data that related to school culture, curriculum materials, interactions between school leaders and teachers, as well as their interpretations of the programme. After that, each segment of relevant data was coded by the researchers separately. In contrast to the previous stage, this stage was data-driven but not theory-driven. After capturing the essence of the utterances, the first author clustered similar utterances to generalise their meanings and derive categories by considering the third author's coding. Lastly, the final dimensions of categories were confirmed by all three authors together. Data from school leaders and teachers were coded separated and two cases were analysed individually, and next, they were put together to generate common themes. It was an inductive process to generate themes, grounded in the different perspectives articulated by participants (Rossman & Rallis, 2012).

4. Findings

The findings that emerged from the data analysis indicate that four major themes guided the implementation of STEM ALP in schools. They are (1) vision, (2) flexibility, (3) communication and (4) resources. The data and interpretation are presented in the sections below. In each section, we start with School A's data, and data regarding teachers and students from the same school are put together to illustrate the commonalities and discrepancies.

4.1. Vision

As a general observation, for both the schools, the vision of the school leaders plays a crucial role in the possibilities of establishing and implementing STEM ALP, although these two schools differ in their development track and curriculum culture. The teachers can fully understand their school vision and identify with it.

According to A.D., a vice-principal of School A, the school's strong D&T culture was one of the factors that paved the way in supporting ALP in the school. The strong D&T culture was shaped by the vision and leadership of the former school leader, who viewed D&T as a vital part of education. At school A, D&T was taught with the objective of empowering students and equipping them with problem solving skills and design thinking skills. Problems were presented in class and students were invited to come up with creative solutions in response.

Another factor that influenced the school's development of ALP was the school leaders' analysis of the students' learning styles and choices. To cater to the learning needs of the students, the school had analysed their tertiary choices and discovered that a large percentage of the students ended up in engineering related courses. The school administration decided to take a more deliberate approach to help the students develop their engineering skills and it was by adopting strategies based on the understanding of how boys learn. The basic principle in an all-boys school, as the vice-principal A.D. explained, is to adopt "practices in understanding hearts and minds of boys." Teachers from School A could sense this special culture of the school. Teacher A.J. from school A said,

Our school is quite level headed when it comes to this kind of thing because we see it not so much from the perspective that the school wants to have a lot of achievements, though that is something that every school desires. More importantly, we view it from the student's perspective that we can provide them with a variety so that they can choose.

On the other hand, both teachers (A.J. and A.S.) from school A also expressed concerns about examinations. The following excerpts demonstrate how the examination demands have affected their perceptions.

No matter what we do, we must always remember students are taking their exams and it's the results that bring them to the next phase of their life. They can be very good, but the "O" levels cert won't say this student maybe 25 points but ALP excellent. It's not written there.

The process is important, the deliverables are also important because ultimately they have to meet the exam requirements ………So as educators we must always go back to our KPI. […] Of course, we want to equip them with as many skills as possible. Cannot - results never mind, the government say focus on skills […] They do need the results at last in these few years.

Teachers generally appreciated that STEM ALP is a non-examinable subject and one commented that "students will probably be more receptive towards ALP since they're not being assessed." Still, teachers did feel that a balance was needed in terms of assessment and some form of assessment should be in place to get students "a bit more interested in whatever they are doing. To get them to take it a bit more seriously but also to give them feedback. To let them know if they are on the right track." Teacher B.W from school B commented that some students did not take ALP seriously as it was not graded and would work on developing a qualitative assessment system that would provide some feedback for the students. He explained that

The feedback is very important if not they just play around and then go off. We want them to take away so after going through, playing exploring, understanding what's the takeaway. We want them to internalize, verbalise.

School B's computing background plays a strong role in the school's learning culture. According to B.R, a leader of school B, the role of computing was highlighted in the school and explained how computing can be used as a significant tool in any subject or field of expertise. Since 2009, the school has been trying to integrate computing into core subjects, instead of having computing as a stand-alone subject. B.R highlighted that the students do not study "computing for the sake of computing'' as the students would not know how to apply it. She further explained that they did not want the students to see computing as just another programming tool, but as a platform for creative innovation, to cultivate students' analytical and problem solving skills.

From the teachers' experience of School B, infusing computing into core subjects has been an effective way to engage students. The computing department collaborates with the Science, Math and D&T departments and uses computing tools to help students learn through a hands-on approach. For instance, when the teachers found it hard to engage students during biology lessons, the computing and biology teachers came together and developed a package to teach concepts about digestion. Their students were first taught digestive concepts, followed by the programming tool, scratch. The students, now equipped with both biology concepts and basic programming, were asked to work on a project to create a storyboard on the movement of digestion. The teachers found that it made lessons more interesting and engaged students more effectively. The students had to internalise what they were learning and began to understand the seemingly dry concepts better. More importantly, the teachers can determine if the students have fully understood the topic by looking at their story boarding, and their thinking process.

In sum, the central notion that the school leaders and teachers shared is that the idea of STEM ALP is being explored to meet the learning needs of students with different learning styles and creating a sustainable learning ecology for lifelong learning. Contextual factors ranged from school's culture to examination demands, influence or affect how teachers expressed or enacted their beliefs.

4.2. Flexibility

The implementation of the programme involves changes at the teacher and school levels. Each school possesses its uniqueness in development in the programs, jointly defined by its historical trajectories and contextual conditions. In analysing the focus group responses of teachers and school leaders, we also noticed that schools and teachers have some freedom to implement the policy.

The school leader from school A (A.D.) said they realised that older teachers who were more conventional were more resistant, while younger teachers were more daring and willing to try new approaches, but they were not so experienced and lacked subject knowledge. The school's strategy was to adopt a "community of learning," where they would organise discussions and deliberately break the teachers into groups and mix the young and old teachers. They found that these discussions as a group on teaching methods were effective as the teachers could influence and learn from each other. A.D observed that from the "community of learning," it evolved to "a community of sharing" and from there, a "sharing program" where all departments have teaching packages so they work in groups to develop teaching packages. He cited an example that

[…] the older teachers will say, I don't know computers very well, I am not a digital native, the young teacher will say, never mind I will do this package for the class, I'll share with you […] through the community of learning we also have a community of sharing, so of course […] all should have sharing program and all departments have teaching packages so they work in groups to develop teaching packages.

The teachers of school A stated that they had the freedom to choose the domain and design and preparing learning materials by themselves based on the structure of the design prepared by the vendor (the Science Centre). The school leaders met with the vendors and introduced them to teachers. Teacher A.S. explained that

we need to follow the domain that we've chosen, which is robotics. Key is science and tech, engineering maths. The components or rather the syllabus must have the components engineering design. These are not restricted. These are the instructions given to us. This is the domain the school ticked this domain; these are the requirements we have to follow.

However, Teacher A.S. also mentioned that the risk assessment was very strict in the STEM ALP project implementation. He said,

under the current framework, there're a lot of things we can't do because of the risks involved. Anything we do must undergo risk assessments. School leaders, MOE got to approve before we can proceed.

According to B.R, teacher sharing also played a role in the development of ALP in School B. Some of the teachers were straddling between two subject departments. For instance, a teacher could be teaching both science and computing and collaborating with the math department. The teacher would share resources, experiences and influence other teachers to embark on cross-curricular instruction between multiple subjects. Infusing computing into core subjects was an effective way to engage students. As some teachers were also new to computing, the process of sharing with others would help them to internalise their knowledge. Teacher B.W further explained,

[…] we tweak the timetables so that they coincide at the same time. There are times of course one of us not around but most of them we are there […] we are together.

B.R shared that in the last year due to teacher sharing, the humanities department worked with the computing department and got students to make short animations and games. The teachers of School B were encouraged to not only share within the school but to share with other schools and communities. This culture of sharing also extended beyond the teachers to that of the students. The students were given opportunities to share in other schools and also at other community activities.

On the other hand, because of the close collaboration with external vendors (the Science Center), teachers in School B had limited flexibility in setting learning objectives and content. Teacher B.W said,

the design part was kind of done by the science centre so our own teachers didn't really have that much of a role in the design of the package, the whole ALP package. It's just the conducting. […] like me, science teacher, I had no background on computing and till now, even though it's our second year that we are doing it, I also have kind of struggle with programming part, which is why we decided to collaborate with the computing department because the teachers there have more experience.

Schools implemented the programme in diverse approaches, but the collaboration culture is the common vision we captured. The collaboration includes internal collaboration across departments, as well as collaboration between schools and external vendors. Both teachers and schools have some autonomy in deciding who to work with and how to work, though the process of risk assessment of curriculum content is strict.

4.3. Communication

The ways in which school leaders communicate with teachers are instrumental in the teachers' execution of initiatives. A.T., the head of the department of D&T in School A, shared that having dialogue sessions with the teachers are important and that the school is very "mindful" before rolling out any changes. He said, Teachers experience school leaders first. MOE has a lot of policies but how we want to roll it out in the school is something we can take …. Because if you don't think through and you are very careless in rolling out certain policies, you will affect the teachers. And that will affect the students.

The communication between schools and parents is also emphasised. As B.R. of School B stated,

It's also communication. We do send letters, during parent teacher's session we do talk about it and then also for example for scratch we want to be a bit more serious in not just play around.

Additionally, she also highlighted the role of government, saying that

It's good now we have a nationwide initiative, and they engage parents. Thru all this sharing and also in schools we do a lot of sharing. The awareness is there but still, parents are a bit reluctant […] for a start the government is doing a good job in terms of pushing it.

4.4. Resources

As the Arduino is an open-source platform used for building electronics projects, the user would ideally need some basic understanding of electronics and programming although it was not totally necessary. The main idea behind it was that the user would start learning how to use the platform by doing and by experimentation. Most of the teachers did not have prior experience and most were uncomfortable with not having basic knowledge of both electronics and programming. Not only preparing for lessons time-intensive, but they also did not have the time to start experimenting on their own. As a result, they needed the support of STEM educators. Teacher B.W. from school B was worried that once the science centre pulled out the STEM educators from the school, they would have trouble coping.

School A leader A.T. described how the school tried to manage teacher training, by starting small with one department and conduct regular training sessions with not only the students but also with the teachers. They started by introducing scratch. A.T said,

To be a whole-school approach we started small with the science department. … but we not only trained the students, we also trained the teachers on how to use this (scratch), how it is important. The process we go through is mind mapping, storyboarding, analysing data, so there are some of the things the teachers go through to understand. Of course, it takes time for them to pick so it took about 2, 3 years before most of the teachers become fluent in using scratch.

Of crucial pedagogical importance in the STEM ALP approach is a shift away from dispensing ready-made knowledge to an environment that facilitates exploration. It appeared that not all teachers were ready for this pedagogical shift. Some teachers adopted a more task-oriented approach and were conservative in giving the students autonomy. However, in school A, the teachers felt that there were insufficient training and support for conducting STEM ALP lessons. According to them, for each topic, they only received a single training session within one afternoon, and this was inadequate for them to be proficient enough to conduct ALP lessons on their own. Although STEM educators were assigned to support teachers in conducting lessons, the turnover rate of these educators was very high. As a result, teachers often have to figure out how the lessons should be conducted in their absence. Furthermore, materials for lessons were not provided in advance before the lesson, and teachers have to put in substantial time on top of their regular workload to prepare the required materials for ALP lessons. Teacher A.S commented that

ALP is not like teaching in class, (where) we take the textbook and we just start teaching. We need to prepare the materials but it is not given to us, and I spend most of the afternoons preparing for the next day's lesson.

In School B, support from STEM educators was good and the STEM educators helped with facilitating and preparing the materials well. However, the organization providing the STEM educators would be pulling out next year. Teachers were going to face logistical and time issues and to prepare and test the equipment before each lesson.

All the teachers have expressed that they were overwhelmed with a large number of maker-centred programmes in the school and have insufficient time and energy to focus and do a good job with the programmes. A teacher commented, Right now, we have so many programs going on […] all these things take up resources, time and space, and there is no one particular envelope under which they all come under.

Cost constraint is another issue. The costs of equipment and materials needed to conduct ALP lessons are substantial, and this places constraints on what can be done during lessons. The program budget only allows an additional 10% of excess materials, hence there are not enough resources to allow students the freedom to make mistakes, iterate and learn from the process. Teachers expressed that they would like the students to experiment a lot more, however, they are forced to put in "controls and boundaries" during the lessons. "If 50% (of the students) make mistakes then we can't run the programme" teacher A.S explained.

5. Discussion

This paper presents the results of school culture, resources and connections between actions and understandings of school leaders and teachers in the implementation of the STEM ALP programme in two Singapore secondary schools. The research question that guided the study was how school leaders and teachers perceive and enact their implementation role in the programme. In this section, we will revisit the findings and discuss the affordance and tensions in the programme from the practitioners' sensemaking.

Our findings show all the school leaders and teachers participating in this study share a common idea about the essence of STEM ALP, which is meeting the learning needs of students with different learning styles and creating a sustainable learning ecology for supporting lifelong learning. It appears that by capitalising on and catering to students' varying abilities, a learning environment can be instrumental in paving opportunities for students to learn based on their interests, with an emphasis on ownership and relevancy. In doing so, students develop skills and competencies that go beyond routine cognitive tasks, such as the ability to critically seek and synthesise information, the ability to create and innovate (Dede, 2010). However, the findings also reveal that teachers perceived the conflict between examination demands and the designed learning outcome of STEM ALP. STEM ALP is a means not just for students to develop and cultivate interests, but also for the MOE to lessen the stress and emphasis on summative high stakes exams. It has been supported in existing studies (e.g., Coburn, 2005; Penuel et al., 2008) when the reform initiative is coupled with an intense and pervasive message about their importance and meanings, teachers are more likely to transform their practice. Our study further confirms the positive role of the national initiative of lifelong learning and the non-examination of STEM ALP in the implementation of STEM. The effectiveness is not only reflected in teachers' enactment but also in the communication between schools and parents.

On the other hand, our qualitative analysis of interviews also indicates that the approaches to implementing STEM ALP are very different in schools. As shown in the findings, each school possesses its uniqueness in development in the programme, and it is the result of sensemaking by school leaders taking account of historical trajectories and local resources. As shown in the findings, School leaders expressed the opinion that they should use their discretion as leaders of a unique setting. School leaders are sense-makers who enact their interpretation to promote their local interests (Bridwell-Mitchell, 2015), which affects how the programme is implemented. This practice is congruent with the suggestions drawn from the existing studies that school leaders make key decisions which they should emphasis to teachers and which they should filter out (Honig & Hatch, 2004; Ganon-Shilon, & Schechter, 2018). With the school leaders' understanding of the importance of the programme, they ensure that the involvement and empowerment of staff are necessary, and where necessary to provide support for changes to grow from the willing participation of all teachers.

Meanwhile, in both schools, the ways school leaders communicate with teachers are instrumental in the teachers' execution of initiatives. This echoes previous research that suggests the key role in setting a tone of openness and communication and encouragement of collaboration culture among teachers (Coburn, 2001; Wen & Wu, 2017). The requirement of collaboration across disciplines and professional boundaries in STEM education has been widely acknowledged. However, collaboration is not straightforward (Edwards, 2011). It is pointed out in Christensen and Laegreid's study (2007) that this collaboration effort cannot be easily imposed from the top down. Evidence from our studies support this analysis and also suggest that the collaboration culture is nurtured maybe because of the natural complexity of STEM. Future studies could investigate how teachers' agency increase when they are involving a STEM programme, or how the co-design of STEM activities may support teachers' collective agency.

In addition to collaboration across disciplines and professional boundaries, the need for teachers to undergo appropriate professional development is also emphasised in the field of STEM education. Studies have indicated that teachers' subject knowledge of STEM is positively correlated to their ability and confidence levels in teaching STEM (Nadelson et al., 2013; Lee & Houseal, 2003). In addition to possessing strong content proficiency and multidisciplinary knowledge across the STEM domains, educators require adequate professional development to inform their pedagogical practices to develop and plan a holistic STEM integrated curriculum (Kelley & Knowles 2016; Sanders 2009; El Nagdi, Leammukda & Roehrig, 2018). In the study, we also observed that beyond subjective knowledge, teachers also can or should benefit from pedagogical knowledge training. In the STEM ALP class, there is a need for change in classroom culture and pedagogy that supports students as producers, rather than consumers of knowledge, and the affordances of technology cannot be well appropriated without substantial teacher training and development. In building the teachers' practice in their pedagogical enactment, sufficient training should be designed to support teachers in actively responding to such a change. Teachers who have never experienced these making-centred practices in their own education will have difficulty in making sense of them in their classrooms.

Our study extends the literature on STEM education, providing teachers opportunities for active learning and collective reflection also contribute to their sensemaking of the programme. Similar to findings from Holmlund's et al. study (2018), even when teachers experience similar professional development sessions and work in the same context, they may make sense of what the new pedagogy means quite differently. Studies have indicated that teachers' professional development should provide regular opportunities for teachers to be involved in active learning and reflection with their colleagues (Garet et al., 2001; Looi et al., 2018). In STEM education, teachers need to be provided opportunities to experience active learning, and they need opportunities to engage in collaborative and sustained sensemaking to see, understand, and work through incongruities they perceive between goals and strategies promoted in professional development (Allen & Penuel, 2015).

Teachers' sensemaking is a collaborative, reflective, and interactive process that can surface the differences and commonalities in their understandings to better ensure consistency (Holmlund et al., 2018). Though existing studies have revealed that teachers' sensemaking may be affected by wider contextual factors, such as school culture (Gawlik, 2015), examination demands or curricular constraints (Allen & Penuel, 2015). Our study shows that teachers' and school leaders' sensemaking of the programme, associated with school vision and culture, flexibility of implementation and professional development, curriculum resources, communication with colleagues. The findings also show that there is still some inconsistency between school leaders' and teachers' perceptions of the programme. This inconsistency may be caused by school leaders' and teachers' different roles and responsibilities. Yet the findings of this study underscore that the discrepancy is mainly reflected in the allocation of resources rather than teaching beliefs. The presence of contradictions related to time echoes findings in other teacher education studies, as constraints on time due to competing demands (Lee & Tan, 2019). Therefore, in addition to the quality and access to external support and professional development available for teachers, teachers and school leaders should also pay close attention to a two-way communication on arrangements of cost and logistical issues of preparing and implementing STEM ALP curricula.

6. Conclusion

This study was undertaken to contribute towards how the larger system goals influence STEM practitioners' perceptions and enactment in the practice, and during the process what affordances and tensions the innovative programme provides. Based on the sensemaking theory, we examined school leaders' and teachers' understandings and responses to the STEM ALP programme within two schools in Singapore. In sum, the affordances for STEM implementation in schools, including a common understanding about the essence of the programme shared by school leaders and teachers, the positive effect of the national initiative of lifelong learning and the non-examination mechanism in the implementation of STEM, as well as the flexibility and authority of school implementation. Furthermore, both internal and external collaborations are essential, and collaboration culture is not only emphasized by school leaders but also by teachers. The tensions are mainly reflected in the conflict between examination demands and designed learning outcomes of STEM, received professional development, as well as the allocation of curriculum time and cost of materials. Hence, more appropriate professional development with opportunities for active learning and collection reflection should be provided for STEM teachers. As the discrepancy between school leaders and teachers is mainly reflected in their perceptions of resources but not beliefs, teachers and school leaders should also pay close attention to a two-way communication on arrangements regarding curriculum time and costs of equipment and materials. Future studies could pay attention to how to promote this two-way communication.

The study is subject to several limitations as well. First, the study concentrates on the STEM ALP programme, not accounting for other interdisciplinary and multidisciplinary STEM majors. Second, though two cases were reported in the study, only 3 school leaders and 3 teachers were interviewed and this study mainly investigated the interpretation and enactment of the programme in 6 months. Given the process of sensemaking is continuous and ongoing (Maitlis & Christianson, 2014), further studies should take into account the change of teachers' perceptions and enactments over longer periods. Third, the main data source was the practitioners' interview data. Further research should involve class observation data to elaborate on how teachers design and enact activities around their sensemaking processes.

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References

Al Salami, M. K., Makela, C. J., & de Miranda, M. A. (2017). Assessing changes in teachers' attitudes toward interdisciplinary STEM teaching. *International Journal of Technology Design and Education, 27*, 63–88.

Allen, C. D., & Penuel, W. R. (2015). Studying teachers' sensemaking to investigate teachers' responses to professional development focused on new standards. *Journal of Teacher Education, 66*(2), 136–149. doi:10.1177/0022487114560646

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*, 77–101.

Bridwell-Mitchell, E. N. (2015). Theorizing teacher agency and reform: How institutionalized instructional practices change and persist. *Sociology of Education, 88*, 140–159. doi:10.1177/0038040715575559.

Christensen, T., & Laegreid, P. (2007). The Whole of government approach to public service reform. *Public Administration Review*, *67*(6)1059–1066.

Clough, M. P., Berg, C. A., & Olson, J. K. (2009). Promoting effective science teacher education and science teaching: A Framework for teacher decision-making. *International Journal of Science and Mathematics Education, 7*, 821–847.

Coburn, C. E. (2001). Collective sensemaking about reading: How teachers mediate reading policy in their professional communities. *Educational Evaluation and Policy Analysis, 23*(2), 145–170. doi:10.1016/j.cattod.2011.12.032

Coburn, C. E. (2005). Shaping teacher sensemaking: School leaders and the enactment of reading policy. *Educational Policy, 19*(3), 476–509. doi:10.1177/0895904805276143.

Dede, C. (2010). Comparing frameworks for 21st century skills. In J. Bellanca & R. Brandt (Eds.), *21st Century Skills* (pp. 51–76). Bloomington, IN: Solution Tree Press.

Dervin, B. (1992). From the mind's eye of the user: The Sense-making qualitative- quantitative methodology. In J. D. Glazier, & R. P. Powell (Eds.), *Qualitative Research in Information Management* (pp. 61–84). Englewood, NJ: Libraries Unlimited, Inc.

Edwards, A. (2011). Building common knowledge at the boundaries between professional practices: Relational agency and relational expertise in systems of distributed expertise. *International Journal of Educational Research, 50*, 33–39. doi:10.1016/j.ijer.2011.04.007

El Nagdi, M., Leammukda, F., & Roehrig, G. (2018). Developing identities of STEM teachers at emerging STEM schools. *International Journal of STEM Education, 5*(1), 36. doi:10.1186/s40594-018-0136-1

Ganon-Shilon, S. & Schechter, C. (2018). School principals' sense-making of their leadership role during reform implementation. *International Journal of Leadership in Education, 22*(3), 279–300.

Garet, M. S., Porter, A. C., Desimone, L. M., Birman, B. F., & Yoon, K. S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal, 38*(4), 915–945.

Cavlazoglu, B., & Stuessy, C. (2017). Changes in science teachers' conceptions and connections of STEM concepts and earthquake engineering. *The Journal of Educational Research, 110*(3), 239–254.

Gawlik, M. A. (2015). Shared sense-making: How charter school leaders ascribe meaning to accountability. *Journal of Educational Administration, 53*, 393–415. doi:10.1108/JEA-08-2013-0092

Gherardi, S. S. (2017). Digitized and decoupled? Teacher sensemaking around educational technology in a model 1:1 program. *Mid-Western Educational Researcher, 29*(2), 166-194.

Holmlund, T. D., Lesseig, K. & Slavit, D. (2018). Making sense of “STEM education” in K-12 contexts. *International Journal of STEM Education, 5*(32), 1–18.

Honig, M. I., & Hatch, T. C. (2004). Crafting coherence: How schools strategically manage multiple, external demands. *Educational Researcher, 33*, 16–30. doi:10.3102/0013189X033008016.

Kelley, T. R., & Knowles, J. G. (2016). A Conceptual framework for integrated STEM education. *International Journal of STEM Education, 3*(11), 1–11.

Lee, C. A., & Houseal, A. (2003). Self-efficacy, standards, and benchmarks as factors in teaching elementary school science. *Journal of Elementary Science Education, 15*, 37-55.

Lee, M. H., Chai, C. S., & Hong, H. Y. (2019). STEM education in Asia Pacific: Challenges and development. *Asia-Pacific Education Researcher, 28*(1), 1–4. doi:10.1007/s40299-018-0424-z

Lee, L. H. J., & Tan, S. C. (2020). Teacher learning in lesson study: Affordances, disturbances, contradictions, and implications. *Teaching and Teacher Education, 89*. doi:10.1016/j.tate.2019.102986

Looi, C. K., Sun, D., Kim, M. S., & Wen, Yun. (2018) The Impact of a professional development model for a mobilized science curriculum: A Case study of teacher changes. *Research in Science & Technological Education, 36*(1), 86-110. doi:10.1080/02635143.2017.1409704

Maitlis, S., & Christianson, M. (2014). Sensemaking in organizations: Taking stock and moving forward. *The Academy of Management Annals, 8*, 57–125. doi:10.1080/19416520.2014.873177

Margot, K. C., & Kettler, T. (2019). Teachers’ perception of STEM integration and education: A Systematic literature review. *International Journal of STEM Education, 6*(2), 1–16.

Merriam, S. B. & Tisdell, E. J. (2015). *Qualitative research: A Guide to design and implementation* (4th ed). San Francisco, CA: Jossey-Bass.

Milner-Bolotin, M. (2018). Evidence-based research in STEM teacher education: From theory to practice. *Frontiers in Education, 3*. doi:10.3389/feduc.2018.00092

Nadelson, L. S., Callahan, J., Pyke, P., Hay, A., Dance M., & Pfiester J. (2013). Teacher STEM perception and preparation: Inquiry-based STEM professional development for elementary teachers. *The Journal of Educational Research, 106* (2), 157–168.

Ng, P.T. (2003). The Singapore school and the school excellence model. *Educational Research for Policy and Practice, 2*(1), 27-39.

Penuel, W., Fishman, B. J., Gallagher, L. P., Korbak, C., & Lopez-Prado, B. (2009). Is alignment enough? Investigating the effects of state policies and professional development on science curriculum implementation. *Science Education, 93*(4), 656–677. doi:10.1002/sce.20321

Rossman, G. B., & Rallis, S. F. (2012). *Learning in the field: An Introduction to qualitative researc*h (3rd ed.). Thousand Oaks, CA: Sage Publications.

Sanders, M. (2009). STEM, STEM education, STEMmania. *The Technology Teacher, 68*(4), 20–26.

Slavit, D., Holmlund, T., & Lesseig, K. (2016). The Teachers’ role in developing, opening and nurturing an inclusive STEM-focused school. *International Journal of STEM Education, 3*(7). doi:10.1186/s40594-016-0040-5.

Sung, J., & Freebody, S. (2017). Lifelong learning in Singapore: Where are we? *Asia Pacific Journal of Education, 37*(4), 615–628.

Teo, T. W. (2019). STEM education landscape: The Case of Singapore. *Journal of Physics: Conference Series*, 1340, 1–3.

Waterman, R. H. (1990). *Adhocracy: The Power to change*. Memphis, TN: Whittle Direct Books.

Wells, J. G. (2008, November). *STEM education: The Potential of technology education.* Paper presented at the 95th Annual Mississippi Valley Technology Teacher Education Conference, St. Louis, MO.

Weick, K. E. (2009). *Making sense of organization: Vol. 2. The Impermanent Organization*. Chichester, UK: Wiley.

Wen, Y., & Wu, J. (2017). A Study on Singapore Chinese language teachers’ professional proficiency and training needs for sustainable development. *Journal of Teacher Education for Sustainability, 19*(2), 69–89.

Wu, L., & He, S. (2018). Learning dynamics and contextual conditions in enabling the building of making-centered learning spaces in Singapore. In *Proceedings of the annual meeting of the American Educational Research Association* (AERA). Retrieved from https://www.aera.net/Publications/Online-Paper-Repository/AERA-Online-Paper-Repository