Theorizing STEM Leadership: Agency, Identity and Community

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Abstract

STEM education, when perceived as integrated learning that encompasses knowledge, skills and practices of Science, Technology, Engineering and Mathematics, points to a need to re-examine ways of classification of school subjects and learning. Consequently, dilemmas related to integrated STEM education arise. School leaders are faced with the task to organize teams to address issues such as the ownership of STEM, identity issues such as STEM teacher or teacher of STEM subjects, evaluation of STEM programs and resources to support STEM education. The unique characteristics of integrated disciplines demand leaders who understand the unique characteristics and demands of each discipline and to apply them to build a synergistic platform to magnify the similarities and harness the differences for learning. In this paper, we present an argument for STEM leadership to focus on building STEM teachers' agency,

identity and sense of belonging to a community. These three aspects are important for meaningful planning, enactment and sustainability of STEM programs since teachers' beliefs, intentions, actions and empowerment are known to be instrumental in the success of many educational reforms.

Keywords

STEM – leadership – science education – community – identity

1 Introduction

STEM (science, technology, engineering, and mathematics) has been one of the most nebulous terms in the literature for the past two decades. As the academic and practitioner communities are still deciphering what STEM is all about, individuals and groups have taken on diverse leadership roles to implement STEM (in whichever form) in schools. This is by no means an easy feat, as STEM contests the basic constitution of schools, which are defined by specific disciplinary departments and teachers labelled as “a science teacher” or “a mathematics teacher.” Is taking on STEM as easy as introducing a new lesson, subject, or department into an institution? If the answer is “no” (and we suspect that to be the case), then what does it take for a school principal and teacher to lead in STEM – by this, we mean integrated STEM.

Disciplinary boundaries, whether clear or diffused, have defined a course of study for learning in schools. The traditional boundaries of science, mathematics, design, and technology have been used to design school curricula such that students learn science and mathematics. Teachers are also trained to be either science or mathematics teachers. Consequently, school leaders organize their teams based on subjects: mathematics department, science department, or English department. Members of these departments are typically teachers who specialize in one specific discipline. Teachers within monodisciplinary teams have a common understanding and appreciation of epistemic, conceptual, and social structures within their specific disciplines. To organize and lead these traditional subject groups, school leaders and curriculum leaders rely on familiar leadership styles. It is uncertain if these well-established leadership styles work for teams that are more heterogeneous, such as integrated STEM. Integrated STEM requires teachers from different disciplines to work together to find commonalities in epistemic practices and social norms

between science, technology, engineering, and mathematics. The process of establishing social norms and epistemic understanding is likely to require leaders with in-depth understanding of the requirements of integrated STEM.

In the past century, leadership theories have undergone several transformations from an efficiency-driven model (Taylor, 1911) to Mintzberg's (2008) bureaucracy model. Leadership was thought of as managing a group of teachers and administrative personnel to run a system (Hoy & Miskel, 2008). Most recent works in the 21st century have defined leadership as a collaborative endeavor where the principal in a school delegates power while creating functional teams, networks, and community partnerships.

In this paper, we attempt a conception of school leadership that emphasizes support for STEM integration in K-12 classrooms. Given the limited research available on principal leadership specifically for integrated STEM, current ideas of leadership styles form the basis of our best thinking about what leadership for STEM might look like. Unlike generic leadership, the conception we define focuses on leadership on a set of collective actions and influence that is necessary for schools adopting integrated STEM programs. Education policymakers and reformers recognized that it was no longer viable to conceive leadership where the leader thinks and the followers act (Senge, 1990). The general recommendations for school leadership have been clustered into notable areas, including collaborative leadership and professional learning communities. Collaborative leadership, also known as the distributed model, is a set of actions that is focused on collective goals. The leader sets the tone that leadership rests on a base of experts rather than one individual of positional authority (Copland, 2003). This approach promotes empowerment among all teachers and heads to realize the school's goals. STEM leadership demands collaboration among teachers within disciplines and across instructional domains, as well as with their respective school leaders, to facilitate a shared focus or common understanding of the importance of all the four disciplines for their students' progress. An integrated STEM community is established when individuals have a shared identity and take on responsibilities to promote inter-disciplinary work like pieces of a puzzle.

In this paper, we draw upon the literature from leadership studies and juxtapose it with the nature of STEM to unpack the qualities of STEM leadership from the school and curriculum levels. The theoretical insights that we offer here are applied to suggesting new research agenda for STEM leadership that we believe deserves more work. The questions guiding our deliberations are:

- (1) What are the key considerations for STEM leadership in schools?
- (2) What are the desired outcomes of STEM leadership?

2 Issues with Integrated STEM

STEM has received considerable global attention over the past 2 decades due to claims that interdisciplinary knowledge is increasingly important for understanding and solving complex real-life problems (Honey, Pearson, & Schweingruber, 2014). STEM education involves solving complex, persistent, and extended real-life problems using practices from the four disciplines, while drawing the connections *within* and *between* disciplines (Tan, Teo, Choy, & Ong, 2019). The advancement of integrated STEM education efforts in K-12 has not taken off as well as expected due to a variety of contextual, policy-, and teacher-related factors (Tan, Teo, Choy, & Ong, 2019).

There have been many different understandings of STEM or integrated STEM. In fact, some researchers have viewed it from a monodisciplinary angle while others do not even want to define STEM in their research. Some studies published in the *International Journal of STEM Education* were monodisciplinary, with STEM referring only to science (for example, Kahana & Tal, 2014; Lund & Stains, 2015) or to mathematics (Siyepu, 2015). STEM can also be perceived in an integrated manner. The four disciplines of STEM (science, technology, engineering and mathematics) can be perceived as parallel disciplines, multidisciplinary, interdisciplinary, or transdisciplinary (Drake & Burns, 2004). When organized as parallel disciplines, the content of the four disciplines is sequenced and students discover the implicit linkage between the disciplines. Taken from a multidisciplinary perspective, the four STEM disciplines are organized as a unit or a course and can be presented to students as a theme to show the complementarity of the disciplines. The four disciplines of STEM can also be organized in an interdisciplinary manner, typically in a project-based manner, to show the connectedness of the disciplines. Finally, students can learn to share conceptual frameworks and draw together discipline-specific theories, concepts, and approaches to address a common problem in a transdisciplinary manner. STEM is uniquely interdisciplinary in the sense that researchers globally try to make the disciplinary boundaries less distinct through a combination of content or context (Bryan et al., 2016).

Our definition of STEM focuses on its integrated nature and is perceived as an enterprise that requires the amalgamation of knowledge, skills, and practices of at least two disciplines. Hence, the implementation of an integrated STEM curriculum requires teachers to collaborate across two or more subject domains in schools. Working across different departments or domains in schools could pose some problems. Teachers in a few STEM studies (Al Salami et al., 2017; Lesseig et al., 2016) have reported constraints in working with colleagues in other subject areas due to communication concerns, lack

of adequate team preparation time, and structural scheduling barriers. STEM implementation demands a rethinking of current school organization in terms of timetabling, professional development and collaboration, and a culture of learning. This entails deliberate efforts in schools to plan and organize curriculum and instruction in teams. Tan, Teo, Choy, and Ong (2019) have discussed some of the limitations that exist in schools structurally and contend that to facilitate teaching of integrated STEM, teachers will need to plan and teach in teams. This team formation requires school leaders to grant time and space for teaching teams to meet, participate in professional dialogue, exchange knowledge on the various disciplines, and share implementation lessons.

Currently, integrated STEM education has been perceived as a “special” school project or a gifted program that requires specialized knowledge and skills to understand. It is characterized not merely by expert knowledge and skills in science, but also in engineering, mathematics, and technology. Each of the four disciplines making up STEM have traditionally been characterized as “strongly classified.” Strongly classified curriculum knowledge refers to disciplines that are well-insulated from one another (Bernstein, 2003) and typically have specialized vocabulary and unique ways of working. The well-insulated identity of various STEM disciplines has made it difficult for teachers, learners, and administrators to access the knowledge and skills. Consequently, STEM disciplines are often perceived to be distant, aloof, insufficiently inclusive, and catering for the privileged few. In fact, some STEM programs are specifically called inclusive STEM education (NRC, 2011) to increase the accessibility of STEM to more students. To empower teachers and learners with STEM learning opportunities to acquire STEM knowledge, school leaders need to develop a knowledge base of STEM and its characteristics and how this knowledge can be shared and made available to all stakeholders.

Oftentimes, STEM teachers find it challenging to implement STEM, whether monodisciplinary or integrated (Al Salami et al., 2017; Lesseig et al., 2016), because they have to ensure that student performance in assessments is not being compromised. While there are some studies that have reported on student learning outcomes and STEM lessons (Han et al., 2015; Hansen & Gonzalez, 2014), there have up to now been few direct measures of specific knowledge and skill sets in STEM. There have also been no rigorous research designs to ascertain the direct impact on the students’ learning simply because it is difficult to differentiate the impact from STEM lessons from other lessons or developmental maturity, and the nature of STEM lessons are not intended to be the same as the monodisciplinary lessons. As such, while STEM leadership may offer the heads of departments and teachers access in the form of “permission” and “top-down support” to implement STEM lessons, they may

not actually have the resources (e.g., materials, know-how, and means) to implement the intended version of STEM that they believe in (and compromise with a trimmed-down version) and to ascertain the outcomes of STEM implementation.

The tensions that exist in integrated STEM education result largely from the ambiguity of what STEM is and the inter-disciplinary nature of integrated STEM. To resolve these tensions, school structures need to be transformed by leaders who understand the intent of STEM education. Leaders champion initiatives, gather support for new and innovative programs, reach out to their networks who might support their vision, and work to problem-solve the barriers that may inhibit their goal achievement (Rogers, 2003; Hallinger, 2003; Leithwood & Riehl, 2003). Successful schools are those that demonstrate quality in terms of teaching, learning, and school outcomes; enable strong communities among teachers; recognize the importance of accountability and evaluation; and advance teacher and student empowerment (Fullan, 2001; Mulford et al., 2007). School leaders who are successful recognize the importance of establishing a school culture and how that influences positive school outcomes (Fullan, 2001).

Li et al.'s (2020) recent systematic review of the research trends in STEM education demonstrated that the most dominant categories of research in STEM education include the topic of goals, curriculum, policy, evaluation, and assessment within K-12 education. Their review corroborates the same categories as that of Li et al. (2019). This demonstrated that limited yet consistent areas of concerns exist in the field of STEM, but not particularly in STEM leadership.

We consulted general leadership literature and found that research studies have documented different models of school leadership: instructional, distributed, transformational, curriculum, teacher, and networked (Leithwood et al., 2020; Hallinger & Heck, 1996). Even among the rich research in school leadership, there have been relatively few studies that have attempted to understand the role of school leaders in programs encompassing the STEM disciplines.

Although there are different types of STEM schools, STEM requires conventional structural boundaries in schools to be blurred (Honey et al., 2014). Such boundaries include departments that artificially segregate the school fraternity into subject-specific territories where internal competitions become inevitable during teacher work appraisals. Integrated STEM does not condone such segregations that are based on conventional school subjects such as science, mathematics, computing, design and technology, and the humanities. Rather, teaching the STEM curriculum will require resources from across departments to be deployed, expertise to be harnessed flexibly, and teacher promotions to

look beyond students' grades in subject-based examinations. Better still, if the school leaders are adept in STEM, they can provide constructive help to the STEM teachers on where to access useful STEM resources, forge external partnerships with STEM-related industries, and so on. In short, some aspects of STEM leadership remain to be understood, including, which aspects of current leader models could be applied to make sense of STEM leadership, what it means to be a STEM leader, and what a STEM-specific leadership looks like.

3 Theories in School Leadership

STEM leadership is an emerging term that is nested within the broader discourse about school leadership. In this section, we discuss some well-established theories in school leadership to enhance our theorization of STEM leadership. According to Bush and Glover (2003):

Leadership is a process of influence, leading to the achievement of desired purposes. Successful leaders develop a vision for their schools based on their personal and professional values. They articulate this vision at every opportunity and influence their staff and other stakeholders to share the vision. The philosophy, structures and activities of the school are geared towards the achievement of this shared vision. (p. 8)

At the core of most definitions of the concept of leadership are two essential functions: exercising influence to bring change and providing vision and directions. The enactment of leadership is also influenced by the personal characteristics of the leaders, such as personal values, beliefs, knowledge, and experience (Day, 2007). Most enacted actions by the leaders focus on creating necessary conditions within their respective schools to support teachers as they engage in instruction, planning, developing a community, and enacting their vision (Foote et al., 2016).

3.1 *Instructional Leadership*

Research scholars in the field of school leadership have discussed school leadership in teaching and learning areas as instructional leadership (Hallinger, 2003). According to Hallinger (2003), instructional leaders aim to create conditions within the schools that foster improved teaching and thus support student learning. The leadership literature frames the leadership actions as content neutral: a set of broad actions that cuts across curricular areas, not requiring specific knowledge of disciplinary areas (Rigby et al., 2017). A few

studies (see e.g., Gamoran et al., 2003; Theodardis & Brooks, 2012) have focused on leadership in mathematics and science, but there has been limited research on content-specific leadership in schools. The possible reasons for this could be that school leaders are largely involved in establishing vision and work processes with limited direct involvement in curriculum and instruction matters. The leaders distribute the responsibilities in specific disciplinary areas to teacher leaders. School leaders broadly provide a vision for mathematics or science content in their schools, grant autonomy to teacher leaders, and support them in further developing their vision (Cobb & Jackson, 2011).

3.2 *Distributed Leadership*

Distributed leadership is also referred to as shared leadership, collaborative leadership, delegated leadership, and democratic leadership that can be influenced by societal and cultural values and norms (Hairon & Goh, 2015). A characteristic of distributed leadership is its emphasis on a collective, group leadership within an organizational setting to achieve a common goal, and distributed leadership underscores the shared nature of engagement by the school leaders, rather than focusing on an individual's contribution. Harris (2009) found that for distributed leadership to be effective, principals need to establish trust and grant autonomy while stepping aside.

Harris (2003) opined that school leadership studies have a wide array of definitions and theories that need to be consolidated, and there are overlaps in the constructs of instructional and distributed leadership. More clarity is also needed in the distinction in instructional leadership between the roles of principals and teacher leaders. Seong and Ho (2012) found in his study on ICT reform in Singapore schools that both the principals and middle-level school leaders exhibited instructional leadership and were interdependent and reinforced one another. What this means is that school leaders and teacher leaders in STEM schools should work in tandem, with teacher leaders being empowered to innovate practice and support their department colleagues in STEM implementation. Structures should also be put in place to allow for communication and collaboration between teacher leaders across different departments.

The distributed perspective argues that although the school leaders' support is critical for teacher leadership development in schools and that leaders should take the lead in delegating responsibilities to others in the schools, teachers carry an important role to contribute to the agency of teacher leadership (Harris & Spillane, 2008). By this they mean teachers' self-initiation to step up to demanding roles. When there is mutual influence, the development of the distributed leadership roles becomes smooth and less dichotomous.

According to Spillane (2006), to be able to understand leadership, there is a need to understand how leaders work together or separately to execute leadership functions effectively. They propose varied models or social arrangements, as they term it, for distribution of leadership tasks. The three arrangements are (1) *collaborated distribution*, where leadership practice is stretched over the work of others who collaborate in time and place; (2) *collective distribution*, where leadership practice spread over others who work separately but inter-dependently; and (3) *coordinated distribution*, which are practices that entail expanding opportunities for teachers to participate, to learn, and to influence.

3.3 *Teacher-Level Leadership*

Teacher leadership is observed when teachers are involved in shared decision-making processes in schools, contribute to the professional development of others, share their expertise with their peers, are autonomous in making decisions in their work, and contribute to innovative ideas for their schools (Leithwood & Jantzi, 2000). Researchers in the field of leadership began focusing on teacher leadership as a construct and teacher leaders' critical roles in the school in the 1990s (Blasé & Blasé, 1998; Harris, 2003; Spillane, 2006). The shift in the discourse began when teachers assumed leadership in a variety of programs in schools that empowered them and contributed to school improvements. This is a result of school structures that are less hierarchical, where leadership is assumed by teachers beyond the classroom. Teachers lead in collaborative efforts on school improvement curriculum and pedagogy and have a voice in the shaping of school vision and goals (Gonzales & Lambert, 2001; Harris & Muijs, 2004; Portin et al., 2013).

In summary, school leaders may engage one or more different models of leadership. However, those who show higher levels of instructional leadership are those who report devoting more time to establishing the necessary conditions and having more responsibility for the curriculum (OECD, 2020).

4 Leadership for STEM Schools

To understand the successful components that make up inclusive STEM schools through a bottom-up approach, Laforce et al.'s (2016) collected data from 20 schools across seven states in the United States. Based on information gleaned from leaders and other documents and interviews, the framework summarized eight essential elements for an inclusive STEM school. The eight elements included six core (four instructional and two non-instructional) and two supporting elements. The data showed that for the core instructional

elements related to teaching and learning to function smoothly, some key foundational enablers from the leadership needed to be in place. These factors include school leaders' facilitation of staff development, opportunities for collaboration, leaders' modelling practice, autonomy, support for risk-taking, participatory decision-making, STEM instructional leaders' support, and a culture of trust and respect. These factors, particularly participatory decision-making and autonomy, suggest the need for distributed and teacher leadership.

Holmlund, Lesseig, and Slavit's (2018) interest was to examine the commonalities and differences in conceptualizations of STEM education among key groups of stakeholders involved in STEM education in schools. Thirty-four participants were part of the study, and the findings showed that the professional roles and contexts of the participants influenced the vision of STEM education. This points to a need to tackle the identity of teachers related to STEM. A teacher's expanded awareness of self-as-teacher and self-as-learner (teachers' subjectivities) and as a leader shapes teaching identity and fosters agency (Adams, 2020). Teacher leaders, school administrators, and other stakeholders make sense of the STEM education in different ways, which is an important point raised in the study.

Since we cannot assume that all school leaders may necessarily have content expertise in STEM disciplines, how the leaders distribute the responsibilities of the STEM implementation to their lead teachers or subject head teachers needs more emphasis. Putting ideas of leadership styles and affordances of STEM together, we propose that developing teacher agency and consideration for emotions related to varied perceptions of STEM are fundamental features of leadership in STEM schools. STEM leadership is uniquely different from other forms of leadership, which tend to be hierarchical in nature even if the power is distributed. STEM leadership involves lateral delocalization of accountability in curriculum implementation as agentic social agents from across disciplinary departments working together.

We perceive STEM leaders as social agents working within institutional structures defined by departments and individual disciplines. School-based and national examinations and international tests (e.g., TIMSS, PISA, PIRLS) remain disciplinary based. School departments and textbooks are generally subject specific. In essence, accountability works through the disciplines and holds individuals (teachers, students, and heads of departments) and groups (schools and departments) responsible for the outcomes of schooling. As such, how does STEM leadership function within the confines of institutional structures rooted in long traditions of pure disciplines, each claiming to be the "mother of all other knowledges"? How can STEM leaders build a culture of collaboration within existing structures of schools?

STEM leadership entails the lateral delocalization of accountability as diverse departments work together. The structure of the delocalization of accountability needs to be understood further. Do different departments have different accountability for the implementation of STEM or are the science or mathematics departments held more accountable? Does the leadership of the school determine who is accountable or do STEM teams and departments have the agency to negotiate among themselves how accountable they ought to be for teaching their own disciplines as well as for the outcomes of STEM? In hindsight, schools stand to gain from a successful STEM program as there is one more avenue for the demonstration of school success (or to call the program “pilot” or “exploratory” if deemed as unsuccessful) and there is increased likelihood of success as accountability is co-owned by more than one department within the school.

STEM leadership requires handling the emotions of stakeholders to ensure readiness for STEM. Teacher emotions have been studied since the 1980s, and the subject essentially is about understanding the teaching practice as affective, involving a huge amount of emotional labor. Teacher emotions research over the past decade and a half has shifted attention towards the idea of social relationships within the context of the classroom and school (Hargreaves, 2000). This is about exploring the social interactions among teachers, students, and their school leaders. Zembylas (2002) argued that teachers’ feelings and emotional display at the intrapersonal level are governed by their interactions and manifest in their practice and social relationships with students and colleagues.

Knowledge, skills, and dispositions related to STEM disciplines have traditionally been considered essential for work and citizenship in the 21st century and a platform for economic advancement for nations. Countries with advanced research in STEM areas are leading the global economy, and they continue to invest in STEM education to enhance STEM literacy to create a competitive talent pool. This makes STEM education a privileged route for the “talented” and “gifted” students in mathematics and science. This elite perception undermines inclusion and streams the low achievers away from the system. Super Science Schools in Japan, Science Schools for the Gifted in South Korea, and the NUS High School of Mathematics and Science in Singapore are examples of schools in Asia. Olympiads, Amazing Science-X Challenges in Singapore, science and engineering fairs, and national robotics competitions are contests to attract high-achieving student participation.

A tension between STEM as an elite track for university entry and social advantage versus STEM for all students has emerged over the years, and this tension could be mirrored in schools. This dichotomy of STEM and non-STEM

teachers could possibly result in either healthy competition or frustrations among teachers, as some non-STEM subjects are considered non-essential to talent and economic development. School leaders need to be able to manage these perceptions and the emotions tagged to these perceptions. What then is the relationship between leadership and the emotions of stakeholders? Everything! A leader does not simply give instructions or set a vision for stakeholders to follow. Instead, a leader needs to exemplify their vision by modeling through their actions, discourses, and support for the people involved in implementing STEM. By this we mean that the act of leading is not an end in itself. Rather, leadership is about building relationships between different parties, and it requires reciprocity. The readiness of the leader in making STEM decisions affects the confidence of the teachers and students in STEM learning. The positive STEM experiences of stakeholders in turn give the leader a sense of satisfaction to provide continued support for STEM learning.

Based on our proposition that STEM leadership demands that the leaders consider the agency of teachers and the emotions of stakeholders in designing STEM programs, we posit that the nature of STEM leadership rests on a few important factors that can be defined as the three Cs of STEM: culture and context, collaboration, courage for change.

4.1 *Culture and Context*

Leadership research has suggested that it is the enactment of leadership practices in establishing a culture that makes a difference in organizations (Spillane 2006; Supovitz & Riggan, 2012). Culture is understood as a set of values, beliefs, shared goals, perceptions, actions, and even philosophies (Zhu & Engels, 2014). School culture is about “system learning, system-wide innovation, and purposeful collaboration that can lead to large-scale and ongoing school improvement” (OECD, 2020, p. 57). School culture includes values and practices observed within a school or within a group of individuals in the school or community. It has been observed that teachers who have opportunities to engage in decision-making in their schools also tend to engage in deeper forms of collaborative activities more frequently (OECD, 2020). The importance of a sense of collegiality in schools for enhancing collaboration among teachers cannot be underestimated since teachers who reported working in a collaborative school culture were more disposed to participate often in professional collaboration. This sort of a “team” culture is likely to be fundamental to successful STEM implementation. Cunningham and Lochmiller’s (2019) research found that school leaders who influence instructional changes create conditions within schools that support their teachers to effectively engage in instruction, planning, collaboration, mentoring, building communities, and so on.

STEM leadership is also about developing partnerships to engage teachers, students, and the instructional program with the context surrounding the formal learning environment. Given the rapid pace of changes in STEM fields, school leaders will need to develop partnerships with industry, business, and academia to draw experts and expertise into their schools. Since the nature of STEM involves different subject areas, it is safe to assume that individual teachers may lack deep understanding of specific content areas and that the absence of this specialization can be addressed by partnering with other education colleagues. The co-teacher/co-instructor model becomes very important. A science teacher teaches a specific concept whereas the expertise in engineering design may be offered from a colleague with expertise in engineering pedagogy and content. A culture of interdependence with others rather than monopoly by specific teachers would be needed for the adoption of integrated STEM in schools.

Implementation of STEM in school also necessitates a culture of inclusive practices. By “inclusive,” we mean having access and accessibility to resources from across the four disciplines to support the implementation of STEM in schools. Having “access” means being able to find and use the resources (e.g., human resources such as teachers who have the know-how to integrate disciplines) and “accessibility” means that the individual has the power and control over the acquisition and deployment of relevant resources to implement STEM. The distinction between access and accessibility alludes to the challenges reported in the broader STEM education literature.

To reiterate, the implementation of STEM involves different departments working together. Thus, for STEM schools, there needs to exist a culture where the school leader has the vision and involves their key teacher-level leaders. The responsibilities for planning and implementation of the vision need to be distributed among important stakeholders in the schools, and lead teachers see themselves being empowered and innovating beyond their traditional classroom walls and rallying their teachers in supporting the school's STEM vision.

4.2 *Collaboration*

We envisage that to implement STEM in most schools, school principals must make the call and authorize specific individuals (usually the head of department for science or mathematics) to lead the STEM initiative. This means that the power, and accountability, is now delocalized, as the head of department for science or mathematics plays the role of a brokering agency to negotiate, engage, encourage peers, make colleagues feel participative, and deploy resources across more than one department in consultation with other

individuals/groups. The net of school accountability is cast wider as more are roped into the collective school accountability.

The nature of STEM highlights the importance of teacher collaboration within disciplines and across instructional domains. The professional learning community (e.g., Stoll & Louis, 2007) is perhaps one of the most important models that permits teachers to have the structural, social, and other resources to collaborate and to co-construct STEM pedagogical practices through dialogue and reflection. These communities can help spread the tacit knowledge among the teachers and learn best practices from one another. STEM leaders need to make investments in professional development for classroom teachers, framing master schedules that allow for inter-disciplinary collaboration that previously did not exist, and developing their teachers and administrators through professional development, mentoring, coaching, and other capacity-building activities (Plecki et al., 2009). Teaching STEM in an integrated fashion requires subtle teaching innovations that must be recognized and supported by leadership. Teachers need to have the freedom to choose who they collaborate with and create collegial partnerships rather than receiving mandated directions. Collaboration models could include co-teaching and/or co-participatory STEM curriculum design.

Co-teaching is where two teachers work together and share the planning, organization, delivery, and assessment for instruction in a classroom. Co-teaching involves mutual engagement, joint enterprise, and shared repertoire (Wenger, 1998). Different models of co-teaching are available in the literature, such as team teaching, parallel teaching, and one teach-one assist. This could be one way that teachers from different disciplines within the S, T, E, and M could collaborate for instruction. A co-participatory curriculum design approach is one that involves different stakeholders intermittently in the design and decision-making about the curriculum. Taylor (2003) grounds this approach on creating a partnership among different stakeholders in the curriculum and generating a sense of ownership in the process. By increasing stakeholder participation, gradual curricular impacts on learning and sustainability of implementation are believed to transform. The stakeholders' motivation also increases as they feel empowered as co-developers and co-designers. These two models are important for STEM as the process involves four disciplines and multiple stakeholders to collaborate for implementation.

Thibaut, Knipprath, Dehaene, and Depaeppe's (2018) study used a survey to understand what contextual and personal factors influence teachers' attitudes towards the teaching of integrated STEM. Social context-related factors such as collaboration opportunities, management vision of STEM, logistics support in the school, and professional development opportunities came out as

significant factors. The article highlighted the need for school leaders to offer opportunities to their teachers to collaborate and learn from STEM PD activities in their schools during implementation.

Nevertheless, collaboration presents significant challenges. The introduction of teachers from multiple subjects to co-teach courses could prove expensive, and with any collaborative endeavor, the outcomes largely depend on the willingness of the teachers to work together to teach STEM and to establish shared commitments.

4.3 *Courage to Change from Comfort Zone*

Throughout the history of school reform initiatives, school leaders have been tasked to bring about academic improvement, drive effective change efforts, and shape strong, professional school cultures (Peterson & Deal, 1998). Schlechty (2001) argues that systemic change focuses on commitment and not compliance. Generating a commitment for change for STEM is evidenced by a leader's ability to create enabling conditions for STEM implementation.

Any new change faces opposition, and a key facet of leadership resides in the ability to influence the change, provide support for the change, and address resistance to the change (Crum & Sherman, 2008). Change is unsuccessful if those involved in the change do not see the need for the change (Williamson & Blackburn, 2009). Teachers are often perceived to be resistant to changes in policies and programs due to factors such as increased workload, fear of the unknown, and an inhibition to push oneself from the comfort zone (Elizondo-Montemayor et al., 2008). Leaders who are change oriented provide opportunities for individuals within their organizations to internalize the vision and improve their self-efficacy by promoting trust and being approachable (Leithwood et al., 2020). As part of the trust-building process, principals encourage teachers to take risks and try new instructional methods in their classroom (Sebring & Bryk, 2000). They also empower teachers and motivate in a manner where all are convinced to identify and embrace the school's culture (Fullan & Hargreaves, 1991). Copland (2003) notes that the work that education professionals accomplish in changing their own and their colleagues' instructional practice for the better through collaboration constitutes the most important and powerful kind of instructional leadership in schools and school systems.

The implementation of new forms of curriculum is always stressful and challenging for schools and teachers because it entails designing new materials, teaching new lessons for the first time, dealing with uncertainties that arise during a lesson, purchasing additional materials, learning and building up one's knowledge in new areas, attending professional development lessons

that take time from regular schoolwork, and so on. As such, when school leaders decide on implementing a STEM curriculum in schools, they must manage the emotional pushback from teachers who are already burdened with enormous amount of work in school. At the same time, teachers who are not involved in the implementation of STEM may question why they are being left out. There is a well-established set of literature on how teacher emotions can adversely affect their performance and have an impact on students' learning.

Table 1 is a checklist of questions that relates the concepts of agency, identity, and community to the considerations of context and culture, collaboration and courage for change.

TABLE 1 The 3 Cs model for STEM leadership

	Context and culture	Collaboration	Courage for change
Agency	How do different departments make decisions?	Who has the power to make decisions? Who decides on working teams?	Are there avenues for individual STEM teachers to initiate change? Can teachers nominate themselves to be in STEM teams?
Identity	Do teachers identify themselves as STEM practitioners?	How are new identities for interdisciplinary teams created?	Are there mechanisms to recognize transient identities? Are there mechanisms to recognize multiple identities?
Building a community	Are current departments collegiate in their interaction? How do different departments work? What does each department value? Are there collaborations with industries or the community?	Are school schedules conducive for interdisciplinary teams to meet? Are there mentors to develop the novice STEM teachers within the teams? Are there structures for professional development in STEM?	Are STEM teams inclusive? How can STEM teams be inclusive? How can changes in interdisciplinary teams be evaluated?

5 Conclusion

We started this theorization of STEM leadership with the intention to seek answers to the following questions: What are the key considerations for STEM leadership in schools? What are the desired outcomes of STEM leadership? Given the complexities that revolve around issues of understanding of STEM education, ownership, and identity of STEM educators, we are convinced that it is pivotal for STEM leaders to be able to reconcile the gaps that exist between different disciplinary norms, ownership, and identities of teachers teaching the different STEM disciplines. As such, the key considerations of STEM leadership in schools pertaining to instructional leadership (dealing with teaching and learning) include: (1) Do school leaders appoint multiple instructional leaders? (2) How can school leaders facilitate unity and consolidations of ideas from different instructional leaders?

Viewing from the ideals of distributed leadership (building collective and group leadership), STEM leaders need to consider if autonomy should be granted to all instructional leaders from all the four disciplines and if all the disciplines are equally autonomous. Finally, from a teacher-level leadership (teachers involved in shared decision-making) perspective, school leaders could consider teachers' level of readiness (pedagogical knowledge for STEM education and understanding of affordances of STEM) for STEM programs and their willingness to mediate their identities as a science teacher, mathematics teacher, or technology teacher and instead adopt a STEM teacher identity. These various considerations convinced us that STEM leadership should focus on building agency in the team, developing a community of STEM practitioners, and creating a robust and common STEM identity.

To build a sustainable STEM community and identity in schools, STEM school leaders must actively incorporate considerations of culture and context, collaboration, and courage for change in their leadership decisions. In particular, we propose that it ought not to be viewed as a generic school leadership but differentiated as a STEM leadership model.

The three Cs are particularly important for STEM school leadership as they take into consideration the peculiar nature of STEM leadership. School leaders could consider doing away with the set-up of disciplinary departments in schools but move towards the creation of STEM departments. STEM teachers' interdisciplinary work needs to be actively recognized, and new teaching roles called "STEM teachers" need to be created so as to legitimize their roles and identities.

6 Implications

As the STEM education field continues to elicit new scholarship and perspectives on curriculum and instruction in classrooms and STEM-focused schools prompt discussions on the elements of successful STEM implementation in schools, the ways that school leaders enable its success need to be understood and reconceptualized. We hope this theoretical discussion will stimulate more discussion in this area that needs further scholarly expansion. This paper is relevant to any school around the world that still operates with traditional monodisciplinary department structures, which exist in most schools around the world. It would be a first step to prepare the students for their journey towards higher education and the world of work. It is worthwhile to note that as we write, one of the premier universities in Singapore will embark on a new interdisciplinary graduate program, with the aim of integrating knowledge and connections across disciplines and preparing its students for a volatile future. This is in line with the several global institutes of higher learning that have begun to offer interdisciplinary programs to prepare their students to glean insights and perspectives from several disciplines, thereby enabling them to solve multifaceted real-world problems.

This paper speaks to *APSE*'s aim to examine educational issues related to teaching and learning of science and STEM in the Asia-Pacific region as well as sharing of insights involving issues in Asia to other areas of the world. We hope our model will encourage thoughts about STEM identity and agency in teachers in the region and beyond.

Finally, we draw on the general leadership literature that may be largely informed by Western ideologies. As readers in the Asia-Pacific reads this paper, we wonder how much of this resonates with them? We believe the issues we have raised about leadership in STEM will echo the sentiments to science educators in the geographical region and to others in the extended international community. This raises new questions on whether STEM leadership in Asia-Pacific is different (or similar) to Western styles of leadership and, if so, what implications there would be for school leaders and STEM teachers who want to initiate STEM work in their school.

Abbreviation

STEM Science, Technology, Engineering, and Math

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Ethical Consideration

The data reported in this study does not require human subjects' approval.

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