RESEARCH PAPER

Teacher STEM Capability Sets that Support the Implementation of Mathematics Active STEM Tasks

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In this paper we report on an aspect of a larger study and explore whether a framework for teacher STEM Capability Sets (SCS) enhanced teacher planning and the implementation of mathematics active STEM tasks. A case study approach was employed to understand how a classroom teacher used the digital resource, Gapminder, to teach a Year 5/6 cohort of students to interpret data as the basis for a STEM assessment. The research found that using the SCS as a guide, and emphasising mathematics in STEM learning and assessment, allowed the teacher to: reflect on existing STEM capabilities; observe the enhancement of other capabilities; and identify areas for future development.

Teacher capability that supports mathematics active STEM learning is vital to the development of responsible, discerning citizens who can engage with, and interpret, the large quantities of data that characterise modern society (Maass et al., 2019). The purpose of this paper is to report on an aspect of a two-year study (*Principals as STEM Leaders (PASL)*—DESE, 2018–2020) that aimed to define and develop the STEM Capability Sets (SCS) for school leaders, teachers, and students. Hence, a component of the study was devoted to the development of a model for teacher STEM capability. In this paper, we focus on mathematics active instruction and the development of teacher STEM capability—an aspect that has been often underrepresented (English, 2015). To achieve this, the following research question will be addressed:

> *To what extent does a framework for STEM Capability Sets support teachers' planning and implementation of mathematics active STEM tasks?*

In responding to the question, this paper first presents a concise review of relevant literature. Second, descriptions of the theoretical model and methodological approach undertaken are presented. Third, we present a case study in which a freely available digital resource, Gapminder (https://www.gapminder.org/data/), is used to integrate mathematical ideas and procedures into a STEM assessment item. Finally, the teacher STEM capabilities required to implement the assessment item are identified and aligned with the SCS.

A Synthesis of Relevant Literature

Technological advancement, such as datafication, and economic, social and environmental factors are rapidly changing the way we live our lives (Blackley & Howell, 2015). The datafication of society drives all aspects of business and social enterprise. Digital technologies are used to facilitate activities such as work, schooling, social entertainment, shopping and healthcare. The viability of these services is reliant on businesses anticipating consumer needs through the collection of consumer data (Saha, 2020). As such, citizens require mathematical and digital skills to effectively: collect, interpret, and use data to drive economic growth; and to monitor and protect their shared consumer data.

Increasingly, data literacy also centres around the ability to discern meaning from data presented in the media or used by authority to influence the behaviour of citizens, such as seen

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during the COVID-19 pandemic (Nguyen, 2020). Such data are sometimes presented in ways that display bias and may be contradictory or ambiguous. This means that citizens require essential skills to critically engage and cope with the rapid mediatisation, digitalisation and social discourse surrounding COVID-19 data. Thus, there is an urgent requirement for citizens to have the mathematical capacity to critically evaluate data and associated information so that they can form balanced judgements and make informed decisions (Maass et al., 2019).

Despite the need for a focused emphasis on mathematics within STEM teaching and learning, concerns have been raised about the lack of balance in the way STEM disciplines have been represented in integrated STEM approaches. English (2015), for example, commented that in current conceptualisations of integrated STEM education, science is over-represented and dominates the field. The over-representation of science is arguably due to national policies that have emphasised the importance of scientific innovation for economic security. This implies that scientific inquiry may be taking precedence over the important role of mathematics in society. This is echoed by Geiger et al. (2015), who emphasised the importance of numeracy capability so that students can become informed, responsible, and participative citizens who are able to cope with the mathematical demands of modern life.

Blackley and Howell (2015) have suggested that the underrepresentation of mathematics within STEM education is related to teachers' lack the capability and confidence to teach mathematics within other STEM disciplines. Despite significant initiatives being undertaken to support teachers, there remains a need for increased national collaboration to increase teacher capability through identifying areas of concern, providing teachers with access to resources and knowledge, and transforming teacher practice and identity (Blackley & Howell, 2015). This is necessary to enhance best practice teaching of mathematics as a foundation for STEM learning within the context of solving real-world problems, such as through the critical scrutiny of data.

One way mathematics can be elevated within STEM learning is through mathematics active learning. This type of instruction promotes autonomous and collaborative student learning through problem solving, experiential learning and investigative work (Singh et al., 2018). Using mathematics active learning tasks as the foundation for integrated STEM education can provide students with the opportunity to apply mathematics when solving real-world problems (Singh et al., 2018). The impact of this on student development is highlighted by Maass et al. (2019), who argued that STEM education programmes grounded in mathematics are key to the civic, cultural, intercultural, and socio-critical development of citizens.

While arguments for increasing the primacy of mathematics within STEM learning are compelling (e.g., English, 2015), there appears to be limited research on how this can be achieved within school classrooms. In taking one step towards addressing this gap in research, the following section will outline the STEM capabilities of effective teachers. This will be followed by a case study of how one teacher's STEM capability was developed through teaching students to use a data analysis tool as a foundation for their STEM learning.

Conceptual Model

The study was underpinned by a conceptual model developed from a synthesis of relevant literature—the SCS. These are an extension of the 21st Century Model of Numeracy developed by Goos et al. (2014). The SCS identify STEM capabilities required for leading, implementing and sustaining STEM teaching and learning initiatives. They consist of five dimensions, which are aligned with sets of capabilities for principals, teachers, students, the community, and researchers. The five SCS dimensions are: STEM discipline specific and integrated knowledge and practices; contexts; dispositions; and tools, which are embedded within an overarching dimension—a critical orientation to STEM see (Figure 1).

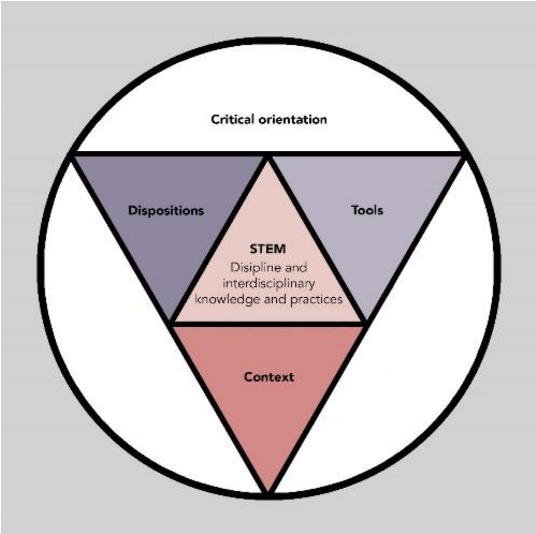

Figure 1. STEM Capability Sets (Geiger et al., 2017). © 2017 Australian Catholic University and University of Tasmania. CC BY NC ND.

Within the SCS, discipline-specific (e.g., mathematics) and integrated STEM knowledge and practices are viewed as essential to effective teaching and learning. Teachers are required to operate across numerous contexts to meet individual student needs within the constraints of available school resources. In addition, positive teacher dispositions are necessary for effective problem solving to occur. Teachers also require capability in their ability to resource and use tools when teaching STEM. Tools are mediators of meaning-making and are central to mathematics and STEM practice. Examples include physical (e.g., rulers), digital (calculators, computers, applications—Gapminder), and representational (maps, diagrams) tools. Within the SCS, teachers must both possess, and foster in students, the adoption of a critical orientation to real-world tasks, which involves the making evidence-based judgements and decisions. Descriptions of the SCS for effective practice in STEM teaching, in alignment with the five dimensions, are presented in Table 1.

Table 1
STEM Capability Sets: Teachers

STEM discipline and integrated knowledge and practices (DIKP)	Competence with concepts, skills, and practices of at least one STEM discipline (DIKP1).
	Awareness of the range of careers that require STEM skills, and the role STEM plays in both individual well-being and national economic growth (DIKP2).
	Knowledge of relevant components of the Australian Curriculum and national policy documents (DIKP3).
	Capacity to provide leadership within STEM teaching and learning initiatives (e.g., teacher professional learning groups) (DIKP4).
	Capacity to select/design/design and implement STEM capability promoting curriculum (e.g., learning programs, tasks, pedagogies) – within at least one discipline and in an integrated mode working with others (DIKP5).
Contexts (C)	Capacity to identify and utilise STEM relevant real-world situations suitable for students' teaching and learning experiences (C1).

	Capacity to fit STEM learning experiences to the learning circumstance of students (e.g., learning needs, level of development) C2). Capacity to make links to students' diverse cultural backgrounds and acknowledge their contributions (e.g., Aboriginal and/or Torres Straight perspectives) (C3). Capacity to fit STEM learning experiences to the available school resources (e.g., digital technologies, built environment) (C4). Capacity to establish or be involved in partnerships (e.g., with industry, business, tertiary education etc.) (C5).
Dispositions (D)	Belief that they themselves can develop STEM capability (D1). Belief that all students can develop STEM capability (D2). Motivation to enhance STEM teaching practice (D3). Willingness and confidence to adopt STEM based approaches to teaching (D4). Preparedness to adopt flexible and adaptive use of STEM teaching practices (D5).
Tools (T)	Confidence and capacity to teach how to use material (e.g., models, measuring instruments), representational (e.g., symbol systems, graphs, maps, diagrams, drawings, tables) and digital (e.g., computers, robots, internet of things) tools to mediate and shape thinking (T1). Possess strategies to identify resources that support effective STEM teaching and learning within their school context (T2).
Critical orientation (CO)	Capacity to develop their own, and promote their students' capacity to gather and analyse evidence to: make judgements and decisions (CO1); add support to arguments (CO2); challenge an argument or position (CO3); and defend an argument of position (CO4).

Research Design

The Larger Study

The larger study, from which the aspect reported here was drawn, was conducted within a design-based research (DBR) framework (Cobb et al., 2003). Cobb et al. (2003) argue that DBR is particularly pertinent to testing innovations within educational contexts. This approach was suitable to the study because the researchers were testing the efficacy of the SCS, as an innovation for educational improvement, through the iterative provision of professional learning (PL) to participants.

One aspect of the PL provided to participants was the notion of becoming conversant with the use of digital tools as an essential component of the techno-mathematical literacies required to be an effective employee within the modern workforce. Throughout the PL sessions, the researchers made participants aware of freely accessible resources. One such resource was Gapminder—an online non-profit, independent educational research tool that is a database of reliable global data used to not only report on international trends, but also challenge misconceptions about environmental, social, and health issues prevalent in society (Gapminder 2022). During PL, principals were shown how Gapminder could be used to analyse real-world data and apply findings in a critical way.

The Current Focus for Investigation

Following the PL sessions, many principals conducted their own in-school PL and shared resources with staff, such as the SCS and Gapminder. One school used these resources to guide an assessment piece. Data from a classroom teacher at this school, provided insight into the development of teacher STEM capability and how mathematics can be highlighted within STEM learning contexts.

Participants from the school that is the focus of this study included the classroom teacher and 55 Year 5/6 students, spread across two classes. The teacher had a dual role, acting as both a classroom teacher and as the STEM leader within the school. The participating school was a non-government primary school (Prep to Year 6) in an educationally advantaged metropolitan region of an Australian city. There were 460 students enrolled in the school.

The paper is based on two iterations of interview transcripts, supplementary materials, and video data of student assessment submissions, which were provided by the teacher. The video data were of student group "pitches", where they described how Gapminder data informed their prototype design and presented a "model" of what their prototype could look like. During researcher visits, interviews with the classroom teacher were conducted and audio recorded. These were transcribed as soon as possible after the visit. The transcript data w then analysed deductively, by way of content analysis (Mayring, 2015), using the SCS as an analytic lens.

Case Study

Renee is a primary school teacher with more than 20-years' experience. Following attendance at the PASL PL sessions, the principal at Renee's school conducted her own PL with teaching staff. An outcome of this PL was that Renee and her principal decided to modify an existing open-ended STEM assessment piece for their Year 5/6 classes to include Gapminder as a key resource. Using Gapminder was seen to emphasise the mathematical underpinning of STEM learning by teaching students how to analyse and interpret real-world data.

The modified assessment integrated Mathematics, Science and Humanities and Social Sciences into one STEM project. Within the assessment, students were required to identify real-world problems facing developing nations in Asia and to design sustainable solutions for one of the countries. Over a six-week period, students used Gapminder to analyse global data and inform their thinking about issues affecting these countries, such as access to water, electricity, food, and the impacts of war or trade policies. In small groups, students selected one country to focus on for the assessment. Students were asked to design a prototype for a product that would assist citizens to address an identified problem in a sustainable way.

As an example, one group of students first identified the Asian countries affected by poverty. After learning how to interpret trends in the data, the students investigated why each country had experienced changes to the number of people in poverty at specific timepoints (e.g., because of war, famine etc.). The students in this group then examined issues relevant to their selected country (Bangladesh), such as extreme temperature and access to electricity. Based on these findings, they created, tested, and refined a prototype for a solar power backpack that could be used to power handheld fans, solar lights, and other devices.

The assessment piece allowed Renee to emphasise the importance and relevance of mathematics active learning, by engaging with data (e.g., assumptions, graphs, trend lines, longitudinal data), as a foundation to STEM.

Results

Both Renee and the researchers observed development in her teaching capabilities within mathematics, the other individual STEM disciplines, and integration of STEM learning through her facilitation of the assessment. Her data were analysed, using the SCS (Figure 1 and Table 1) as the theoretical lens to understand her development. Changes to her understanding of mathematics-active STEM are documented against the dimensions of the SCS in the following sections.

STEM Discipline and Integrated Knowledge and Practices

After the assessment concluded, Renee observed she had attained a deeper understanding about both mathematics and integrated STEM knowledge, skills, and practices:

> I really understand mathematics and STEM better than I did last year… It has to be purposeful. It has to have a connection with the kids. It has to be a transdisciplinary approach to all of the subjects and the crossover of all of them, it has to be rich and authentic. [DIKP1; C1]

Renee also reported enhanced knowledge about using the Australian Curriculum to teach mathematics within STEM. This allowed her to design and implement an integrated assessment piece that promoted the goals of the curriculum:

> STEM is maths driven, with your critical and creative thinking at the core, driven through general capabilities. Whilst the activity, comes from understanding your curriculum, we need to recognise the general capabilities the kids are at and what we want from them. [DIKP3; DIKP5]

Contexts

Throughout the assessment, Renee developed her capabilities in using real-world situations and linking these to diversity of students' cultural backgrounds.

> We linked Gapminder to our Aboriginal Torres Strait Islander connections and compared to landlocked countries like Afghanistan. And they were saying "Oh, we'll just use the sea water" and we said, "How can you if it's landlocked?" And then "what are the tribal, what are the native people of that country? What were their sustainable ways of living and how can we borrow and use?" [C1; C3]

Renee also demonstrated some capability in tailoring instruction to fit the learning circumstances of individual students. She was able to:

> … sit with the kids and go through the process where they were stuck at their time, at their learning. So, some of these groups were here … and then some groups were down here but they're directing their own learning. [C2]

Dispositions

The researchers noted that Renee displayed positive beliefs about: students' capabilities, her capabilities, and high levels of motivation to enhance her teaching practice. Consistent with this, she was undertaking further study in a Master of Education programme.

> I am very passionate about it, and I am studying it. So, I think, not from the school's perspective—the principal supported me to get the scholarship for STEM so that's been brilliant. [D1; D3]

Throughout the assessment piece, Renee also saw the value of becoming more willing and confident to adopt STEM-based approaches to her teaching practice.

> I'm more aware of how I can embed mathematics into the curriculum, which means it's not an added extra. It makes us think more and ask questions. Ultimately, they're the core skills we're trying to develop - the general capabilities of deeper thinking, asking questions, reflecting. [DIKP3; D3; D4]

Tools

Renee demonstrated capability in guiding students in the use of a range of tools, particularly digital and representational, throughout the assessment. She learnt how to use Gapminder alongside the students, guided them to conduct further research online, and oversaw students using physical and digital tools to design their prototypes. Through this, Renee also demonstrated her ability to source and use tools that were available in her school context.

> They had to research. They had to find out “What is it that we want to find out about that country?” They had to articulate it and then look at a mind map of possible solutions…we’ve had everything from backpacks with solar panels, to using Minecraft to create their prototypes. [T1; T2]

Critical Orientation

The assessment task provided Renee with the opportunity to develop students’ critical capabilities. Students developed their capability to critically analyse the data and conduct further research so they could effectively form judgements and make decisions about their countries of interest.

> The students took it upon themselves to go “What happened in 1988? Why did that graph go down?” So they researched the history of that country to find out actually it was war torn, or "They made trade links there Miss. The trade links mean they could export which meant the government had more money.” This was the sort of stuff that was coming out. [CO1; CO2]

Renee took a focussed approach to encourage students in their critical thinking and reflection about their data research, which in turn demonstrated her own critical orientation to both the data, and to the wider goals of the assessment activity.

> I really focused on making sure the kids can think for themselves critically. We are really wanting them to pose open-ended questions about the data. So, at each stage I said to them “What do we know? What do we want to? What have I learnt?” [CO2; CO3; CO4]

Discussion

The Gapminder assessment, when analysed with the SCS, provides insight into Renee’s existing, and developing, STEM capabilities. Renee demonstrated STEM capabilities across all five dimensions of the SCS, whilst also observing new learning. Renee’s *STEM discipline and integrated knowledge and practices* were evident in her competence with the concepts, skills, and practices across several STEM disciplies and ability to design and implement a STEM learning programe. She also came to better understand that mathematics had to drive STEM education and that a thorough understanding of Curriculum requirements and general capabilities were essential.

Context capabilities were also evident in Renee’s teaching. She was able to construct and use a real-world situation where students could integrate their STEM skills that was appropriate to the their learning and cultural experiences. Renee appeared to experience some difficulties, however, in tailoring the learning to the circumstances of all students, reporting that some students struggled for weeks to identify an issue from the data they had collected.

One area where Renee reported a high level of capability was in the dimension of her *Dispositions*. Renee consistently demonstrated her belief that STEM was for all and that everyone (both students and herself) could develop their STEM capacity. The research team also noted how willing she was to adopt STEM-based approaches to teaching.

Renee was also able to guide students to use a variety of material, digital and representational *Tools*, commenting that her own capacity was enhanced through the assessment. These included the Gapminder database, other web-based search engines, graphs, diagrams, video cameras and other software applications. Renee’s ability to identify other resources that could support STEM learning was not observed during this study. An area for future investigation would be to explore how teachers identify resources that enhance the instruction of mathematics in STEM contexts.

The development of a *Critical Orientation* to STEM surrounds all STEM capabilities. Renee gave insight into her critical orientation to STEM, and her ability to foster a critical orientation in students, for example, by challenging students to defend their judgements. The scope of this study, however, did not afford the research team the opportunity to more broadly understand the depth and extent of Renee's critical orientation. This is an area for future investigation.

Conclusion

The teacher capabilities required to effectively advance mathematics active learning in STEM are described in the SCS. In this paper we have highlighted how an activity, aimed at emphasising mathematics as the foundation for STEM inquiry, can assist teachers to develop their own STEM capability. Renee's responses demonstrated that she had developed her thinking about planning for, and implementing tasks, across the dimensions of the SCS. While this preliminary research provides some tentative evidence about the potential to guide the planning and implementation of mathematics active STEM tasks in school contexts, further studies into the capabilities required of teachers in mathematics and STEM contexts are needed. For example, one area needing research attention is in teacher STEM leadership. Renee noted, in her final interview, that she was facing difficulties in leading school-wide STEM change. She faced challenges associated with finding time, financial constrants, and trying to encourage teachers who were not confident in their STEM ability, or who were unwilling to adopt STEM-based approaches. Whilst this is an area for future investigation, the SCS provide guidance that could assist teachers to enhance their capability in: STEM discipline knowledge, becoming aware of different contexts pertinent to STEM, selection and use of tools and other resources, and the development of a critical orientation to STEM.

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