RESEARCH PAPER

The Role of Mathematics Education in Developing Students' 21st Century Skills, Competencies and STEM Capabilities

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In order to discuss the role of mathematics education in developing students' STEM Capabilities and 21st Century skills, it is necessary to define what is meant by these terms given the extent to which they are broadly used in global contexts. A literature review aimed at providing clarity, through affording a concise interpretation of each term for the Australian context, enabled the development of a working framework for defining 21st Century skills and STEM capabilities. This paper provides working definitions and reports on initial findings from a larger three-phase study aimed at exploring secondary mathematics teachers' beliefs, attitudes and practices, towards the role mathematics education plays in developing students' STEM capabilities and 21st Century skills.

Industry and education policy makers, politicians, environmentalists, economists and futurists are all in agreement that in order for Australia to maintain its global prosperity and remain innovative and resourceful, we need to build and sustain a STEM capable workforce (Australian Academy of Science [AAS], 2016; Australian Industry Group [AIG], 2015; CSIRO, 2020) which is able to readily employ 21st Century ways of thinking and working (Business Council of Australia [BCA], 2017; Torii & O'Connell, 2017). To support the development of Australia's future STEM workforce and provide opportunities for all Australian students to develop the sound STEM skills necessary to be successful in their future career pathways (AIG, 2015; BCA, 2017), a number of National and State initiatives have been enacted, aimed at supporting STEM education in Australian schools (e.g., Australian Curriculum, Assessment and Reporting Authority [ACARA], 2016; Department of Education Skills and Employment [DESE], 2021; Education Council, 2015). Hatisaru et al. (2019) shared that although it is widely supported that STEM education is crucial for students' future success, there exists no universally accepted definition of STEM, and as a consequence, STEM skills and STEM capabilities are conceptualised, interpreted and defined in diverse ways (Anderson et al., 2020) dependent upon the audience and context through which it is used. The Organisation for Economic Cooperation and Development (OECD), in the Education 2030 project, identified three broad global challenges for a 21st Century society, which include environmental, economic and social challenges (OECD, 2018). To address these challenges students will need to:

> … apply their knowledge in unknown and evolving circumstances. For this, they will need a broad range of skills, including cognitive and meta-cognitive skills (e.g., critical thinking, creative thinking, learning to learn and self-regulation); social and emotional skills (e.g., empathy, self-efficacy and collaboration); and practical and physical skills (e.g., using new information and communication technology devices). (OECD, 2018, p. 5)

STEM Capabilities

STEM evolved as an acronym for Science, Technology, Engineering and Mathematics (Anderson et al., 2020) and as an initiative in the United States towards the end of the 20th century (Myers & Berkowicz, 2015). For many educators, STEM education remains a

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relatively new idea (English, 2016; Hatisaru et al., 2019; Myers & Berkowicz, 2015) and common definitions of what are STEM capabilities are not well established (Anderson et al., 2020; Hatisaru et al., 2019). In 2014, the Office of the Chief Scientist (OCS) published a report highlighting the importance of having a STEM capable workforce and the shortfalls predicted if initiatives were not put in place to improve the STEM capabilities of Australian students (OCS, 2014). This led to the Australian Education Council (AEC) publishing the National STEM School Strategy in 2015 (AEC, 2015). As a direct result of these strategies, STEM education policy initiatives, resources, national projects and grants emerged, aimed at promoting the development of students' STEM capabilities (DESE, 2021).

21st Century Skills and Competencies

More than two decades into the 21st Century, the identification of a universally agreed list of skills that encapsulate 21st Century skills and competencies has not come to fruition; however, a number of global organisations have attempted to define and establish frameworks through which to describe 21st Century skills and competencies (Bialik et al., 2015; Greenstein, 2013; Griffin et al., 2012; OECD, 2021). The OECD Learning Compass 2030, a learning framework co-created by a number of countries participating in the OECD Future of Education and Skills Project 2030 (OECD, 2019), built upon the concept of 21st Century skills to provide the competencies necessary for students to thrive in 2030 and beyond. The framework included reference to seven elements that comprise, "core foundations", an agreed set of future orientated "knowledge, skills, attitudes and values", along with "student agency/co-agency", "anticipation-action-reflection" and "transformative competencies" (OECD, 2019, p. 16). In reviewing the literature on 21st Century skills across multiple frameworks, the overarching skills associated with creativity, critical thinking, communication and collaboration are consistently used when describing 21st Century skills (e.g., English, 2016; Griffin et al., 2012).

Organisations such as the OECD and the Center for Curriculum Redesign (CCR) assert that certain learning areas are more aligned to particular 21st Century competencies than others (Bialik et al., 2015; OECD, 2019). For example, through the learning area of mathematics, it is possible to implement pedagogies that provide opportunity for students to collaboratively utilise their strategic competence, and that mathematical reasoning skills can foster students' 21st Century skills (Bailik et al., 2015; English, 2016; Griffin, et al., 2012).

Framework

This section of the paper will provide a framework that can be used to define 21st skills, competencies and STEM capabilities for an Australian context. The three-dimensional framework of the *Australian Curriculum* (AC) aims to prepare students to be successful in the twenty-first century, and states that the *Australian Curriculum: General Capabilities* (AC: GC) play a crucial role in this preparation (ACARA, 2017b). In conducting a comparison and contrast of existing international 21st Century frameworks, drawing on work by the Center of Curriculum Redesign (CCR) and the Assessment and Teaching of 21st Century Skills (ATC21S), the various skills and competencies detailed in each framework can be clustered and aligned to the three dimensions of the AC (see Table 1). For example, the OECD 2030 learning framework's competencies of "core foundations, knowledge and skills" (OECD, 2019, p. 16) and CCR's "traditional and interdisciplinary knowledge" (Fadel et al., 2015, p. 43) can be interpreted in the Australian context as the eight Learning Areas (AC: LA) combined with the Literacy and Numeracy general capabilities (ACARA, 2017a, 2022).

Table 1
Comparison and Contrast of 21st Century Skills and Competencies Frameworks

AC	OECD	CCR	ATC21S
8 x AC: LA, Literacy & Numeracy	Core foundations, knowledge and skills, literacy, numeracy, financial literacy, programming, physical health & sustainable development literacy	*Knowledge*: traditional, interdisciplinary, environmental literacy	Life and career skills, Communication
Critical & creative thinking	Critical thinking & problem solving, learning to learn, anticipation, reflection, creating new value	*Skills:* critical thinking, creativity *Meta-learning:* metacognition, growth mindset, meta-learning, *Character:* curiosity	Critical thinking, problem solving & decision making, Learning to learn, Metacognition, Creativity & innovation, Flexibility
Digital literacy Literacy Numeracy	ICT literacy, digital literacy, data literacy, media literacy, computational thinking	*Knowledge:* digital literacy, systems thinking, design thinking	Information literacy, ICT, Communication
Personal & social capability	Cooperation, collaboration, empathy, respect, student agency, co-agency, reconciling tensions & dilemmas	*Skills:* communication & collaboration, *Character*: mindfulness, courage, resilience, leadership	Personal & social responsibility, Citizenship, Communication and Collaboration
Intercultural understanding	Global competency, respect		Global understanding
Ethical understanding	Literacy for sustainable development	*Character:* ethics	Citizenship

The ACARA STEM Connections report (2016) stated that STEM in the Australian Curriculum is addressed through the learning areas of Science, Technologies and Mathematics and through the General Capabilities, particularly Numeracy, Information and Communication Technology (ICT) capability, and Critical and Creative Thinking. The Australian Curriculum defines capability (ACARA, 2017b);

> …capability encompasses knowledge, skills, behaviours and dispositions. Students develop capability when they apply knowledge and skills confidently, effectively and appropriately in complex and changing circumstances, in their learning at school and in their lives outside school. (para. 2)

Applying the ACARA definition of capability, students' STEM capability (see Table 2) encompasses the discipline specific knowledge of the three learning areas Science, Technologies and Mathematics and the ability to apply this knowledge and the various analytical thinking, reasoning, inquiry and problem-solving skills both within and across the learning areas to complex situations, all coupled with positive dispositions towards the STEM learning areas and future STEM pathways (ACARA, 2016, 2022; OCS, 2014). Applying this working definition, the role of mathematics in developing students' STEM capabilities is more easily conceptualised.

Table 2
Students' STEM Capabilities

Science	Technologies	Design & Technologies	Mathematics
Science Understanding: Biological, chemical, earth & space, physical sciences	Knowledge & Understanding	Knowledge & Understanding	Content knowledge: Number, Algebra, Measurement, Space, Statistics & Probability
Science inquiry skills: questioning & predicting, planning & conducting, processing, modelling & analysing, evaluating & communicating	Process & Production Skills: the skills needed to create digital solutions. Systems, design & computational thinking	Process & Production Skills: the skills needed to create designed solutions. Systems, design & computational thinking	Proficiencies: understanding, fluency, reasoning & problem-solving Processes: modelling, computational thinking, statistical investigations, probability experiments & simulations
Science as a human endeavour	Privacy & security	Technologies and society	Productive disposition towards mathematics

Note: Created from AC version 9.0 (ACARA, 2022)

The National STEM School Education Strategy 2016—2026 focusses on raising the foundational skills of each of these STEM disciplines and "promotes the development of the 21st century skills of problem solving, critical analysis and creative thinking" (Education Council, 2015, p. 5). The strategy includes a suite of seven "guiding principles for schools to support STEM education" (Education Council, 2015, p. 11*)*, the third being:

> Build on students' curiosity and connect STEM learning to solving real world problems, including through collaborative and individual learning experiences that are hands-on and inquiry-based and support the achievement of deep knowledge.

The Study

There exists broad support for the notion that teacher beliefs influence their pedagogical choices (e.g., Beswick, 2012; Goos et al., 2017). Although teacher training and professional learning programs have focused on the adoption of pedagogies that enhance students' problem-solving capabilities and improve student thinking and reasoning in mathematics, a significant number of teachers have not adopted these strategies in their classrooms (Bailey, 2018). Beswick (2012) suggested an inherent disparity between teachers' perceptions of best practice and their portrayed classroom practices. There also exists an incongruity regarding the pedagogies teachers profess to use, compared to what they implement (Clarke & Lomas, 2016).

Although assumptions can be made as to why this incongruity exists, there is value in exploring the beliefs and practices of secondary mathematics teachers towards the role mathematics plays in developing students' STEM capabilities and 21st Century skills. Such an exploration is necessary to ascertain the factors that influence teachers' pedagogical choices. The influencing factors impacting upon teachers' pedagogical decisions need to initially be identified in the general context, in order to explore them in the specific.

Methodology

This study has adopted an explanatory sequential mixed method design (Creswell & Plano Clark, 2011) allowing the researcher to draw upon the findings of a large scale, statistically representative sample to inform and provide contextual support for the qualitative study. Findings from the qualitative study will be used to draw inferences to help explain the quantitative results (Creswell, 2015). The three-phase design aims to explore the phenomena from the general to the specific within a philosophical framework. Each phase will inform the next, using complementary methods with both random and purposive sampling in a Quantitative (Phase 1) → Qualitative model (Phase 2 & 3) (Creswell, 2015).

Given the interpretative nature of this research approach, emphasis is placed on interpretation constructed collaboratively by the participants and the researcher. The following research questions are being explored in the extended study, but the focus on this paper is on the initial findings around Research Questions 1, 2 and 3:

RQ1: What pedagogical approaches are extant in Western Australian Years 7-10 mathematics classrooms?

RQ2: What beliefs and attitudes do Western Australian Years 7-10 teachers of mathematics hold concerning the role of Years 7-10 mathematics in developing students' STEM capabilities?

RQ3: What beliefs and attitudes do Western Australian Years 7-10 teachers of mathematics hold concerning how Years 7-10 mathematics contributes to the development of students' 21st century skills?

RQ4: According to Western Australian Year 7-10 teachers of mathematics, what factors might afford and constrain them in the implementation of pedagogies that foster student STEM capabilities and 21st century skills?

Phase One (quantitative phase)

Instrument. Phase One involved data collection via a web-based survey aimed at providing insight into common themes. The survey instrument was validated by academic peers and consisted of 19 questions. The initial seven questions gathered background information about the participants' location, experience and training. The remaining questions gathered information on teacher pedagogical content knowledge, beliefs, attitudes and practices, comprised of six five-point Likert-type items and 5 yes/no response items, and an extended response section to provide explanation for responses. The purpose of the survey instrument was to provide insight into participants' pedagogical beliefs, practices and attitudes towards adopting pedagogies that support students' STEM capabilities and 21st Century skills and identify any common themes.

Procedure. The intended participants were Western Australian teachers of mathematics in Years 7–10 from all WA educational sectors. The survey procedure involved a recruitment email to all WA secondary school principals, that included an email link to an anonymous questionnaire using an online commercial platform. Due to COVID-19 lockdown restrictions in place at the time, it was agreed that any further contact with schools should be delayed. Further participants were then recruited later in the year through a email campaign to members of the Mathematical Association of Western Australia (MAWA). The sample ($n = 60$), although smaller than intended, was representative of the population both in location ($n = 45$ Metropolitan, $n = 15$ Regional & Remote) and teaching experience. All participants were teaching at least one lower secondary mathematics class and identified as classroom teachers (75%) or in leadership roles (25%).

Preliminary Results and Discussion

Phase 1 data analysis found that the majority of respondents agreed that the ability of their students (83%), and the curriculum year level they were teaching (77%), had influence over their choice of teaching methods. In responding to the level of influence factors of; time, pedagogical knowledge and content knowledge have over their pedagogical choices, the majority selected large or extreme (see Table 3).

Table 3
Question 11: What Impact do the Following Factors Have on Your Pedagogical Choices?

Factors	Nil or no response	Small	Medium	Large	Extreme
Academic level	1 (2%)	3 (5%)	17 (28%)	27 (45%)	12 (20%)
Curriculum level	1 (2%)	9 (15%)	19 (32%)	23 (38%)	8 (13%)
Time constraints	1 (2%)	1 (2%)	16 (27%)	26 (43%)	16 (27%)
Content knowledge	4 (7%)	2 (3%)	12 (20%)	28 (47%)	14 (23%)
Pedagogical knowledge	2 (3%)	3 (5%)	13 (22%)	28 (47%)	14 (23%)

The majority of respondents agreed with statements such as; “The role of mathematics is crucial to STEM fields”, “Mathematics should form an integral part of STEM learning in schools”, and “Mathematics supports students in developing STEM capabilities.” This contrasted with the majority responding that they never, rarely or sometimes use STEM projects (98%), authentic problem solving (78%), integrated learning tasks (93%), or inquiry tasks (81%) when teaching mathematics (see Table 4).

Very few participants indicated that they regularly provide integrated STEM and other cross curricula learning opportunities in their teaching programs. The majority responded that they either never, or only once or twice a year, used collaborative group work, problem-based learning, project-based learning or inquiry-based learning pedagogies with their Year 7–10 classes, all of which are considered to be student centred pedagogical approaches that support student development of 21st Century skills and STEM capabilities (ACARA, 2016; Anderson et al., 2020; Griffin & Care, 2015; Myers & Berkowicz, 2015).

Table 4
Question 13: How Often Do You Use the Following Tasks/tools or Resources in Your Lessons?

	Never/no response	Rarely	Sometimes	Regularly	Always
Investigations	1 (2%)	2 (3%)	32 (53%)	24 (40%)	1 (2%)
Inquiry tasks	4 (7%)	15 (25%)	30 (50%)	11 (18%)	0 (0%)
Modelling	3 (5%)	11 (18%)	25 (42%)	16 (27%)	5 (8%)
Computer simulation	10 (17%)	16 (27%)	25 (42%)	7 (12%)	1 (2%)
STEM projects	20 (33%)	22 (37%)	17 (28%)	1 (2%)	0 (0%)
Integrated learning tasks	10 (17%)	20 (33%)	26 (43%)	4 (7%)	0 (0%)
Real world contexts	2 (3%)	3 (5%)	27 (45%)	24 (40%)	4 (7%)
Authentic problem-solving	4 (7%)	16 (27%)	27 (45%)	13 (22%)	0 (0%)

Conclusion

This paper has articulated a framework through which to define what is meant by 21st Century Skills and STEM capabilities in the Australian context. It presents a snapshot of initial findings of a study aimed at investigating secondary teachers' beliefs, attitudes and practices towards the role mathematics education plays in developing students 21st Century skills and STEM capabilities. The data collected in the initial phase of this study found that teachers of secondary mathematics generally agree with the importance of students developing sound STEM skills and capabilities and address the General Capabilities in their mathematics teaching programs. Interestingly more than a third of the 60 respondents (37%) shared that they did not teach mathematical content through the proficiency strands with all of their classes. Half of the respondents reported using real world contexts or applications; however, when asked whether they agreed that the use of real world and authentic contexts are important in mathematics education, the majority responded with agree or strongly agree (88%). Further, most participants responded that the curriculum year level (77%) and the mathematical ability (85%) of their students influence their choice of pedagogy. The ongoing study aims in Phases 2 and 3 to provide a qualitative analysis of the common themes emerging from Phase 1 to contribute to the literature on teachers' attitudes, beliefs and practices towards the role mathematics plays in the development of students STEM capabilities and 21st Century skills and the factors that might afford or constrain teachers adopting pedagogies that foster these skills and capabilities.

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