Mathematics Teachers' Perceptions of a STEM Approach for Selected Student Outcomes

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A STEM approach in mathematics lessons may offer affordances to mathematics teaching, with potential benefits for students' outcomes. A survey of 30 mathematics teachers identified the perceived importance of selected student outcomes (related to cognitive, affective, and STEM capabilities), for mathematics lessons with a STEM approach compared to those considered 'typical'. Some teachers perceived that a STEM approach in a mathematics lesson places importance on developing student outcomes such as critical thinking and problem solving and contributes to mathematical understanding. A STEM approach in mathematics lessons may be beneficial if teachers can envisage, and realise, potential gains for student outcomes.

Science, Technology, Engineering, and Mathematics (STEM) is seen as vital to meet social, cultural, and economic challenges in Australia (Office of Chief Scientist, 2013). Education is identified as key to increasing STEM skills and capabilities both nationally (Office of Chief Scientist, 2013) and in the state of Victoria (DET, 2016) which is the context for this study. A STEM approach is widely assumed to involve teaching and learning through the integration of two or more STEM disciplines (English, 2016); Wang et al. (2011) suggested that connections across disciplines can result in broader and deeper student understanding. However, the National Academy of Engineering and National Research Council (NAENRC) (2014)) cautions that integration may impact the development of disciplinary knowledge, highlighting a tension between the potential benefits of integrated learning through a STEM approach and the development of disciplinary knowledge (i.e., mathematics in this paper).

The relationship between mathematics and STEM education raises numerous issues with Maass et al. (2019) suggesting that STEM activities have focussed on science. Mathematics can be incidental to STEM activities (Fitzallen, 2015) or play a service role (Tytler et al., 2019), where mathematics learning and teaching are not a priority. The NAENRC (2014) highlighted the difficulty of enhancing mathematics achievement when integrating with another discipline. Despite these challenges, there are common student outcomes for STEM and mathematics education (e.g., critical thinking and problem-solving skills; Gravemeijer et al., 2017).

Wang et al. (2011) found that different teacher perceptions of a STEM approach can lead to different classroom practices in aspects like integration, communication, and interactions. Margot and Kettler (2019) similarly noted that differences in teacher perceptions influence their design and delivery of a STEM approach. However, there is limited research on mathematics teachers' perceptions of the affordances of a STEM approach in their lessons. This paper presents findings from a survey of thirty secondary mathematics teachers about the perceived importance of eight selected student outcomes when teaching mathematics with a STEM approach, A comparison is also made with what these teachers consider important in a typical mathematics lesson (refer to Methodology section).

The research questions were:

- What are Victorian mathematics teachers' perceptions of the importance of selected student outcomes when a STEM approach is used in a mathematics lesson?
- What are the perceptions of the importance of the same outcomes in their typical mathematics lessons?
- Are there similarities and differences in the outcomes perceived to be important?

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Literature Review

Understanding teacher perceptions in STEM education is important due to its potential influence on teaching. Thibaut et al. (2018), in a survey of 135 secondary teachers, noted a negative correlation between attitude towards a STEM approach and experience in teaching mathematics. Conversely, Sevimli and Ünal (2022) found positive views on the usefulness of STEM tasks in mathematics (study of 36 secondary mathematics teachers). Research on STEM education and teachers' perceptions has focussed on the teaching of science concepts or views of science teachers, with less focus on the views of mathematics teachers (Sevimli and Ünal, 2022). Further, there is little literature on Australian teachers' perceptions of a STEM approach.

The intent of this paper is to determine student outcomes that the participating teachers perceived to be important when adopting a STEM approach in a mathematics lesson and how these may differ from those in a typical mathematics lesson. Hence the focus is on student outcomes from a STEM approach. As a result, the literature considered papers related to STEM outcomes to identify those for inclusion in the survey. Specifying student outcomes is important in enabling the effectiveness of a STEM approach to be determined (NAENRC, 2014). Although a STEM approach aims to achieve broad and deep student understanding (Wang et al., 2011), research specifying student outcomes from a STEM approach is developing (English, 2016).

Many researchers (e.g., NAENRC, 2014; Thibaut, 2018; Martín-Páez et al., 2019; Gao et al., 2020) have identified and categorised a list of student outcomes for a STEM approach, with a degree of overlap. These can be grouped as cognitive (including disciplinary content knowledge and understanding); affective or attitudinal (e.g., interest and engagement); and STEM capabilities or skills (including 21st century skills). Attard et al., (2020) noted that increasing student interest and engagement is a key driver of a STEM approach. The importance of a STEM approach for contributing to critical thinking and creativity has also been highlighted (Yildirim and Türk, 2018). This aligns with a key goal of STEM education which is to develop 21st century skills despite these not having a common definition (Maass et al., 2019). Increasing students' generic skills through adapting traditional curriculum can support students in responding to a changing global world (Millar, 2020).

Student outcomes from a STEM approach might also be guided by policy and curriculum documents. In Australia, the National STEM School Education Strategy (National STEM Strategy) refers to STEM education as an umbrella term that includes the teaching of science, technology, engineering, and mathematics (Education Council, 2015). While not specifying STEM student outcomes, the National STEM Strategy has the goals of ensuring students achieve strong foundational knowledge in STEM subjects and related skills such as critical thinking and problem solving and choose to study more challenging STEM subjects.

Although the Victorian Curriculum and Assessment Authority (VCAA) has few references to 'STEM' in the Victorian mathematics curriculum (VCAA, 2019), it incorporates many student outcomes of STEM education identified in the literature including problem solving, communication, and connections to other disciplines. Other STEM skills such as critical and creative thinking, and inquiry-based learning are general capabilities and are expected across the curriculum. The Victorian Department of Education and Training (DET) released STEM in the Education State (DET, 2016) which recognised the need to equip Victorian students with STEM capabilities and skills which it advises are incorporated in the curriculum. Based on the emphasis on STEM in Australia and the inclusion of STEM outcomes in the curriculum, Victorian teachers should be aware of student outcomes related to a STEM approach.

Methodology

This study used a mixed method, embedded design approach allowing for a quantitative data set to be the focus and a supplemental role played by qualitative data. Mixed methods design provides broader evidence than either a quantitative or qualitative approach (Creswell & Plano Clark, 2011). Quantitative analysis focused on teachers' perceptions of student outcomes, and qualitative analysis centred on teachers' perceptions of the potential benefits and drawbacks of a STEM approach in a mathematics lesson with inference drawn about student outcomes. Data collection was via a survey based on identified student outcomes.

Student Outcomes for Survey Inclusion

A list of outcomes was identified through a literature review undertaken in 2020. Papers were identified through education databases including ERIC and Google Scholar using the search term 'STEM education'. Of these, twelve papers were selected which had a focus on student outcomes. Thirty-two student outcomes were named in these papers with those most frequently mentioned identified. There were inconsistencies in the terminology used (e.g. flexibility /adaptability), so the authors used one term to represent terms with common meanings. The first named author checked to ensure that student outcomes in each category (cognitive, affective, STEM capabilities) represented those identified through the literature review. 'Cognitive' outcomes included outcomes related to cognition in mathematics rather than specific content areas (e.g. Pythagoras' theorem). For this category, we focussed on fluency and understanding (i.e., procedural and conceptual knowledge) and problem solving, encompassing thinking and application of mathematics, which is a noted outcome in STEM literature (Maass et al., 2019).

A survey was developed using Qualtrics and trialled by academic peers, three of whom have experience teaching secondary mathematics. Feedback suggested the need for a shorter survey so items that were mentioned fewest times in the literature were removed. The student outcomes included in the survey were:

- Fluency, understanding, problem solving (i.e. cognitive outcomes)
- Interest, engagement (i.e., affective factors)
- Critical thinking, creative thinking, and transfer of understanding across disciplines (i.e., STEM capabilities).

Survey

The research question compared teachers' perceptions of 'a mathematics lesson with a STEM approach' to what they considered a 'typical mathematics lesson'. Teachers opted into the survey and so contexts were not expected to be consistent. Thus these terms were not defined as they would be expected to vary from teacher to teacher. Similarly, each of the student outcomes were not defined. However, as all teachers were Victorian mathematics teachers some understanding might be expected to be in line with the Victorian mathematics curriculum where these terms are defined (for example, understanding and fluency).

For each of the eight student outcomes, teachers were asked two questions:

- In a typical mathematics lesson how important is it for students to develop [Student Outcome] (e.g. critical thinking)?
- In a mathematics lesson with a STEM approach how important is it for students to develop [Student Outcome] (e.g. critical thinking)?

Teachers indicated the importance on a 5-point Likert scale (1 = Not at all important; 5 = Extremely important). Teachers were also asked the open question, "What do you see are the potential benefits of adopting a STEM approach in a mathematics lesson?" which was then replicated for drawbacks.

The survey was advertised to Victorian secondary school mathematics teachers via social media, the Mathematical Association of Victoria (MAV) (a mathematics teacher organisation), and personal networks (mathematics teachers). Participants included 30 Victorian secondary school mathematics teachers (non-government, 17%; government, 83%), currently teaching at least one mathematics class, and a range of year levels from Years 7–12; 60% taught a subject other than mathematics. While all 30 teachers responded to the Likert style questions, only 27 teachers responded to the open questions.

Data was collected between March and August 2021, a period of disruption for Victorian schools due to Covid restrictions and potentially contributing to a small sample size. Teachers self-selected so may have strong positive or negative perceptions of a STEM approach. The survey participants are not considered to be a representative sample of Victorian secondary school mathematics teachers. Results were analysed using Microsoft Excel. Each graph presents the frequency of response for each level of importance for each outcome and compares a typical mathematics lesson and a mathematics lesson where a STEM approach is used.

Results and Discussion

This section reports Victorian secondary school mathematics teachers' perceptions of the importance of eight student outcomes in either a mathematics lesson that is perceived to be typical by the teacher (referred to as a "typical maths lesson"); or one that adopts a STEM approach ("STEM-approach lesson"). Findings (Figure) are discussed for the student outcomes within categories of cognitive (mathematics), affective, and STEM capabilities.

Cognitive (Mathematics)

Figure 1a shows teachers believed that developing Understanding was important for both typical mathematics lessons and those with a STEM approach. In the Victorian curriculum (VCAA, 2019) understanding relates to knowledge of mathematical concepts (relevant to a typical mathematics lesson) and to connecting mathematical ideas and interpreting mathematical information), (relevant to a STEM approach). As noted, research has highlighted that mathematics may be incidental in a STEM activity (Fitzallen, 2015) or plays a service role (Tytler et al., 2019). Hence there may not be an expectation that the development of conceptual understanding of mathematics is a focus when adopting a STEM approach. However, 87% of teachers indicated mathematical understanding was very or extremely important for a mathematics lesson with a STEM approach, highlighting a focus on mathematical understanding when adopting a STEM approach, rather than mathematics being incidental.

Fluency is a student's ability to undertake procedures flexibly, accurately, and efficiently (VCAA, 2019). Figure 1b shows that the importance placed on developing fluency in a typical mathematics lesson was high with over 85% indicating it was very or extremely important, compared to just over 50% for a STEM approach lesson. Fluency includes 'flexibility', which might be achieved through the solving of complex problems (a feature of a STEM approach, Gao et al., 2020). It was noted that a STEM approach has the benefit of "... apply(ing) mathematical skills in a range of situations" (Teacher 7). Despite this, the results suggest that some teachers perceived that a STEM approach is not as important for mathematical fluency with Teacher 19 noting that the drawback of a STEM approach is "... a lack of fluency in basic skills such as times tables, fraction addition, algebra…". Thus, while some teachers might perceive mathematical fluency as highly important in a STEM approach, this was not universal.

Problem solving is referenced in both the Victorian mathematics curriculum and within its general capabilities (i.e., Critical and Creative thinking), thus a high degree of importance could be expected of this student outcome for a typical mathematics lesson. Figure 1c indicates that while over 80% of teachers consider it very or extremely important for a typical mathematics lesson there is also a high percentage (93%) for a STEM approach lesson. This highlights that a STEM approach might represent a pathway for teachers to focus on the development of problem-solving skills of students. A STEM approach in a mathematics lesson can be of benefit as “Students can focus on learning basic fundamentals and then use problem solving skills to expand on these fundamentals” (Teacher 7). Problem solving reflects student ability to interpret, choose, investigate, and communicate solutions to problems (VCAA, 2019), with a STEM approach seen by some teachers as a way to achieve this.

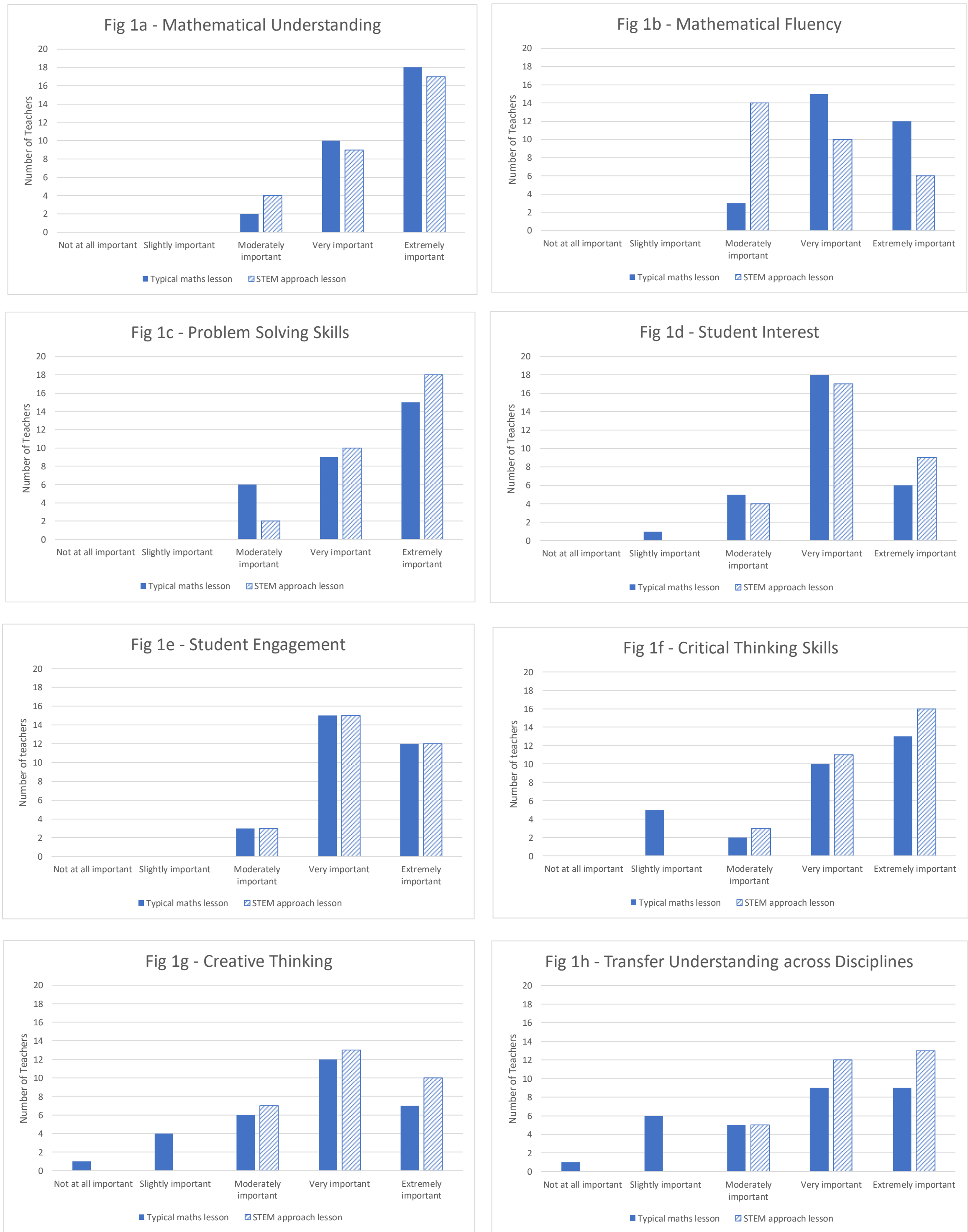

Figure 1. Importance of student outcomes for a STEM approach and typical mathematics lesson.

Mathematical understanding and problem solving were highly important (very or extremely) for either a STEM approach or a typical mathematics lesson by over 80% of teachers. A number of teachers regarded mathematical fluency to be of lower importance when using a STEM approach despite Fluency incorporating flexibility, which is connected to 21st century skills (Maass et al., 2019) and a feature of a STEM approach.

Affective Factors (Interest and Engagement)

Increased student interest and engagement is a goal of a STEM approach (Attard et al., 2020) and an area for national action in school education (Education Council, Australia, 2015). Teachers identified student interest (Figure 1d) and engagement (Figure 1e) as important for both typical mathematics lessons and a STEM approach lesson. For both approaches, 90% of teachers considered engagement to be very or extremely important reflecting Millar's (2020) observation that teachers in the STEM disciplines have long recognised the need to engage students. While teachers indicated affective factors are of similar importance for both approaches, it is not clear whether teachers consider the two approaches to be equally capable of achieving this. Teacher perceptions of interest and engagement vary with Teacher 9 suggesting a STEM approach results in "increased engagement, developing a deeper understanding of mathematics …". Conversely Teacher 8 noted "if students are not engaged in the lesson, then the learning may be completely lost". Somewhat reflecting this, Tytler (2020) has suggested that teachers are motivated to adopt STEM initiatives to improve student engagement, however, Attard et al. (2020) noted there is little to support how a STEM approach might be successful in addressing interest or engagement.

STEM Capabilities

Critical and creative thinking in the Victorian Curriculum (VCAA, 2019) is a general capability that involves students developing thinking processes and how to apply these to support logical, strategic, and flexible thinking across a range of contexts. Teachers' perceived importance of critical and creative thinking are presented in Figures 1f and 1g respectively. For a typical mathematics lesson, 77% of teachers consider critical thinking skills very or extremely important with 23% considering them only slightly important. For a STEM approach lesson, more teachers (90%) consider it very or extremely important. More teachers identified creative thinking as very or extremely important in a STEM approach lesson (77%) compared to a typical mathematics lesson (63%). For critical and creative thinking, two 21st century skills, the importance of these outcomes was slightly greater for a STEM approach than a typical maths lesson with Teacher 11 noting that a STEM approach provided "more opportunities for creativity, critical thinking, etc." (). This aligned with Yildirim and Türk (2018) findings on Turkish secondary school science and mathematics teacher views. Maass et al., (2019) noted that while capabilities such as critical and creative thinking are recognized as being of increasing importance in education, teachers have been provided little guidance on how to promote these 21st century skills. Given teachers' perceptions that critical and creative thinking might be more important in a STEM approach lesson, this might be motivation for teachers to consider implementing a STEM approach in mathematics classes.

Figure 1h shows variability in teachers' perceptions of the importance of transferring understanding across disciplines in a typical mathematics lesson; 23% considered it not at all or only slightly important and 60% considered it very or extremely important. Although Tytler (2020) suggested mathematics curricula do not prioritise interdisciplinary tasks, the Victorian curriculum (VCAA, 2019) expects mathematics to be used to solve problems in other contexts. This points to the importance of transferring mathematical understanding across disciplines, hence more teachers might have been expected to place greater importance on this outcome in a typical mathematics lesson. For a STEM approach, transfer of understanding was considered very or extremely important by 83% of teachers. Teacher 11 noted a STEM approach was advantageous for "Breaking down the subject-based silos/emphasising multidisciplinary nature of learning and work". This benefit for transferring understanding across disciplines reflects the interdisciplinary or multidisciplinary nature of a STEM approach; a commonly noted feature (e.g., English, 2016). These findings suggest that for some mathematics teachers, the use of a STEM approach may support students' transfer of understanding across disciplines.

Conclusion

This study identified mathematics teachers' perceptions of the importance of eight selected student outcomes and compared what was perceived to be important in a STEM approach lesson and a typical mathematics lesson. Understanding teachers' views is important as it can influence their teaching (Thibaut et al., 2018).

The three 'Cognitive' (mathematics) student outcomes: understanding, fluency, problem solving, varied in the perceived importance for a STEM approach compared to a typical mathematics lesson. Fluency is perceived as markedly more important in a 'typical' mathematics lesson while problem solving skills are perceived as moderately more important for a STEM approach. Understanding is perceived as similarly important for both.

The 'Affective' student outcomes: interest and engagement were perceived by teachers to be of similar importance for both options. While Attard et al. (2020) suggested that findings related to a STEM approach increasing student interest and engagement were inconclusive, it was unclear if surveyed teachers thought that student interest and engagement could be achieved through a STEM approach. Further research would be needed to determine if a STEM approach represents a potential to increase student engagement and interest.

The three student outcomes for 'STEM Capabilities': transfer of understanding across disciplines, critical thinking, and creative thinking, were perceived as more important for a STEM approach compared to a typical mathematics lesson. These outcomes all feature in the Victorian Curriculum with critical thinking considered an important student outcome for mathematics (Gravemeijer et al., 2017) and a student outcome needed for a changing world. The perceived lower importance in a typical mathematics lesson could result from a focus on discipline specific content (e.g., mathematics concepts or skills) rather than outcomes (e.g., 21st century skills) that go across disciplines. This could reflect a potential difference between the intended curriculum (which includes discipline specific content and cross curriculum goals) and the enacted curriculum.

In this study of 30 teachers, several teachers recognised potential affordances of a STEM approach in mathematics lessons for contributing to student outcomes. This suggested that a STEM approach in mathematics lessons may be worth pursuing if teachers can envisage, and consequently realise, potential gains for student outcomes. Positive perceptions of a STEM approach in mathematics lessons may contribute to teachers' willingness to employ STEM approaches and consequently impact student outcomes.

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