MATHEMATICS TEACHING toolkit

ISSUES IN THE TEACHING OF MATHEMATICS

The STEM Agenda

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THE EDUCATION STATE

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THE BIG PICTURE: THE STEM AGENDA

"At the core of almost every agenda is a focus on STEM: science, technology, engineering and mathematics."
(Office of the Chief Scientist [OCS], 2014, p. 5)

SHARPENING THE FOCUS ON SCHOOL MATHEMATICS

Mathematics is central to STEM – without mathematics there is no STEM.

However, Australian students' performance on international assessments of mathematical literacy has declined significantly since 2003 *(e.g. Thompson, De Bortoli, Underwood, & Schmid, 2019)* and participation rates in advanced mathematics courses in Year 12 have plummeted *(e.g. Australian Mathematical Sciences Institute, 2017; 2020)*.

This situation is inequitable and untenable given the centrality of mathematics to STEM and the critical importance of STEM skills for 'the economic and social well-being of the nation' *(Australian Industry Group [AiG], 2013, p. 1)*. In terms of access, it is inequitable as it disproportionately impacts females, Indigenous students, and those living in lower socio-economic circumstances or rural regions *(Masters, 2016; Office of the Chief Scientist [OCS], 2016, 2017)*.

It is untenable as an estimated 75% of the fastest growing employment opportunities require 'significant science or maths training' *(Becker & Park, 2011, p. 23)*, and the problems we face as individuals and as a society require ever increasing levels of scientific, technological, and mathematical literacy. In terms of outcomes, this is not just an issue for secondary schools as all of the understandings and attitudes needed to succeed in school mathematics, and thereby to participate in STEM studies more broadly, have their origins in the early and middle years of schooling.

This monograph invites school leaders and teachers to consider the implications of the STEM Agenda for the teaching and learning of mathematics at their school in terms of two related issues:

Access

Why are students opting out of STEM related studies? What can school mathematics do to increase student options with respect to STEM?

Outcomes

Are we focussing too much on the reproduction of mathematical procedures and techniques at the expense of the sort of skills that industry and a STEM literate society demands? How can school mathematics support the development of STEM skills?

KEY TERMS AND DEFINITIONS

Mathematics

Mathematics aims to understand the world by performing symbolic reasoning and computation on abstract structures. It unearths relationships among these structures and captures certain features of the world through the processes of modelling, formal reasoning and computation *(OCS, 2014, p. 24)*.

STEM

Refers collectively and individually to the disciplines of Science, Technology, Engineering and Mathematics whose distinct and complementary approaches to knowledge and practice benefit society as a whole *(OCS, 2013)*.

The acronym is shifting from a noun that represents four crucial content areas to an adjective that is used to describe just about anything and everything that anyone is doing related to science or mathematics *(Shaughnessy, 2012, p. 1)*.

STEM Education

Not having a single agreed definition is an issue. For instance, STEM education could refer to teaching and learning in individual STEM subjects, across any two or more of the STEM subject areas, and/or involving one or more STEM subjects and a non-STEM subject such as the Arts.

> ***'STEM education is a broad enterprise that starts in early childhood education, continues through the years of schooling and extends into tertiary education supported by contributions from extra-curricular and enrichment activities, science centres and museums.' (Timms, Moyle, Weldon, & Mitchell, 2018, p. 1).***

STEM Integration

Definitions vary according to the extent of integration. In general, STEM integration refers to units of work, subjects or electives that require students to use knowledge and skills from multiple disciplines in the course of solving a particular problem or undertaking an inquiry into some 'real-world' phenomena.

STEM Literacy

Again there is no agreed definition, but one view is that STEM literacy encompasses the sorts of knowledge and skills needed to participate effectively and responsibly as citizens in a technology-oriented world (e.g. interpret measures, interrogate statistical evidence, make sense of graphical representations).

> ***… the knowledge and under-standing of scientific and mathematical concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity (National Research Council, 2011, p. 5).***

STEM Skills

Variously cited these include the general skills of problem-solving, collaboration, communication, creativity, and critical thinking. STEM skills may also include active learning, analysis, design thinking, digital literacy, innovation, inquiry processes, logical reasoning, open-mindedness, objectivity, and self-direction *(e.g. Prinsley & Baranyai, 2015; Rosicka, 2016)*.

STEM education and training covers the specific knowledge and skills found in science, technology, engineering and mathematics disciplines. It also covers the interrelationship between these areas, allowing learning to be delivered in an integrated way, helping a deeper engagement in the four disciplines.

For Foundation to Level 10 (F-10) school students, STEM knowledge and skills are embedded within the Victorian Curriculum, in Mathematics, Science, Design and Technologies, and Digital Technologies. STEM education also develops capabilities such as critical and creative thinking, collaboration and ethical decision making. *(Victorian Department of Education & Training website)*

EVIDENCE BASE FOR THE STEM AGENDA

Mathematics is central to STEM careers and STEM literacy.

Success in school mathematics is a strong predictor of STEM engagement *(Lowrie, 2017; Wai, Lubinski & Benbow, 2009)*. Very little of any substance can be achieved in the fields of science, technology, and engineering without mathematics *(Siemon, Banks, & Prassad, 2018)* and very little of our everyday lives is unaffected by mathematics in some form *(Australian Academy of Science, 2016; Finkel, 2017)*.

Mathematics is widely regarded as an enabling discipline that 'has been, and will continue to be, at the heart of our search for ways to solve, manage, mitigate or adapt to some of the great challenges that confront us as a nation and as part of humankind' *(Chubb, 2014)*. The following quotes are included to emphasise this point but also to question – **is school mathematics living up to the promise? Does it equip young people with the knowledge and confidence they need to work collaboratively to solve unfamiliar problems and communicate and explain their solutions?**

> ***Mathematics has always been the language of science, and statistics is at the heart of good evidence and experimentation. (Australian Academy of Science, 2016, p. 2)***

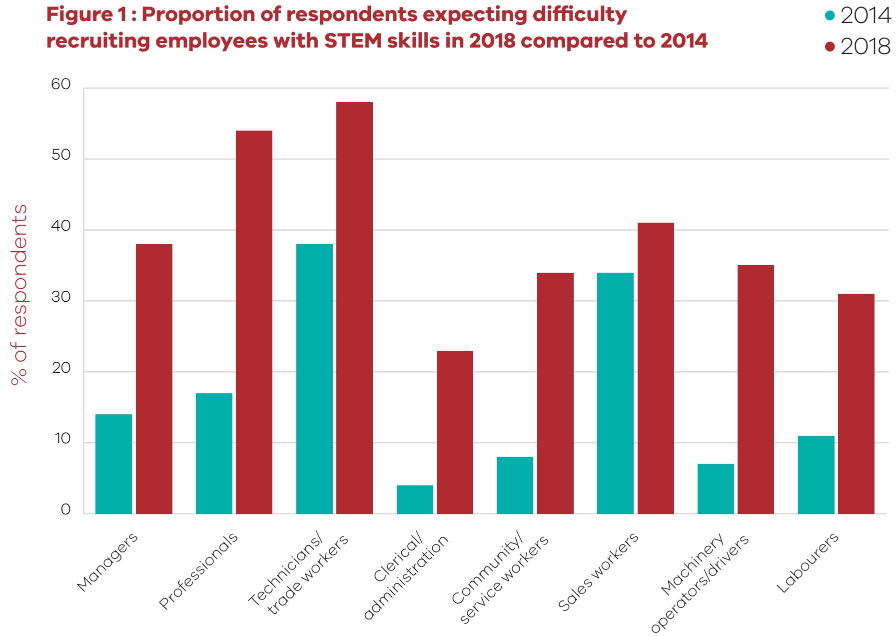
> ***Fundamental to social well-being and economic prosperity, the mathematical sciences are crucial to enhancing Australia's innovative and creative culture, global competitiveness, and the safety and health of its people. (Australian Mathematical Sciences Institute, 2020, p. 5)***

> ***Mathematical literacy is foundational to STEM education, where skills in dealing with uncertainty and data are central to making evidence-based decisions involving ethical, economic, and environmental dimensions. (English, 2016, p. 4)***

Reality check

One only has to read the quotes above to be convinced that mathematics is central to STEM. However, there is a perception among employer groups that **Australian schools are not equipping young people with the skills they need for the STEM jobs of the future** *(Australian Industry Group [AiG], 2013, 2015; Prinsley & Baranyai, 2015)*. The skills most commonly identified by employer groups included active learning (i.e. ability to learn on the job), complex and creative problem solving, collaboration, critical thinking, communication, design thinking, and mathematical modelling. These can be delivered by mathematics teaching and applied to STEM *(The Australian Association of Mathematics Teachers & AiG, 2014; Deloitte Access Economics, 2014; Marginson, Tytler, Freeman, & Roberts, 2013)*.

Figure 1 : Proportion of respondents expecting difficulty recruiting employees with STEM skills in 2018 compared to 2014



Source: Workforce Development Needs: Survey Report 2018 (AiG, 2018)

The **key role of school mathematics:** several respondents to the Deloitte Access Economics *(2014)* survey 'identified issues with the way Mathematics was taught in school' as one of the reasons for the mismatch of skills and pointed to 'the need for the teaching methods to show how Maths relates to the real world, including the role of technology' *(p .67)*.

Jobs for the future

Numerous industry and government sponsored reports point to the threat posed to Australia's economy by lack of access to employees with the appropriate knowledge, skills and experience in STEM fields *(Business Council of Australia, 2015; OCS, 2012, 2013, 2016; Pricewaterhouse Coopers [PwC], 2015)*. This is reflected in the fact that 45% of Australian employers expect their workforce requirements for STEM-qualified employees to increase in the next five to ten years *(PwC, 2015)*. Importantly, this is not limited to those with formal STEM qualifications, STEM skills are required across a wide range of occupations as shown in Figure 1 below from AiG's 2018 survey of 298 employers. In addition to the dramatic increase in some sectors, it is worth noting that most of the skills identified are ones that link directly with the goals of learning school mathematics (refer to the Learning Mathematics page of the Victorian Curriculum: Mathematics).

99%

of employers are **affected in some way by low levels of literacy and numeracy** in their workforce

AiG, 2018, p. 3

Disturbingly, 99% of employers are affected in some way by low levels of literacy and numeracy in their workforce' *(AiG, 2018, p. 3)*. Given this and the suggestion that an estimated 75% of the fastest growing employment opportunities require 'significant science or maths training' *(Becker & Park, 2011, p. 23)*, it is not surprising that this situation has prompted widespread calls for a focus on STEM education *(AiG, 2013, 2015; OCS, 2014, 2016)*. A call that is so widespread and popular that Sanders *(2009)* has referred to it as STEMmania.

BUT... STEM participation rates are falling and access is inequitable:

Despite attempts by governments and other stakeholders over the last decade to increase student participation rates in the key areas of advanced mathematics, physics and chemistry, these have declined significantly *(e.g. Cooper & Berry, 2017; OCS, 2017)* along with Australian students' performance on international assessments of mathematics and science such as the Trends in International Mathematics and Science Study *(TIMSS)* and the Programme of International Assessment *(PISA) (Masters, 2016; OCS, 2017; Thomson et al, 2019)*. This situation is even more concerning when it is considered by student type where, for example, the proportion of females studying Year 12 advanced mathematics or physics has declined sharply to around 6% nationally. Also, Indigenous students and those living in remote or rural regions and lower socio-economic circumstances are significantly outperformed by their non-Indigenous, metropolitan, higher socio-economic peers on the PISA assessments of mathematical and scientific literacy. Mathematics is an important enabling subject. **Without mathematics, access to other STEM domains is compromised.**

STEM education – a contested notion.

While there is no agreed understanding of what is meant by 'STEM Education' *(e.g. English, 2016; Rosicka, 2016, Timms, Moyle, Weldon, & Mitchell, 2018)*, there is no doubt that business leaders and Australian governments of all persuasions are of the view that a 'renewed national focus on STEM in school education is critical to ensuring that all young Australians are equipped with the necessary STEM skills and knowledge that they will need to succeed' *(Education Council, 2015, p. 4)*.

But what does this mean in practice?

Evidence for the efficacy of integrated approaches is lacking. Many claims are made about the advantages of integrating STEM subjects, such as increased motivation, deeper understanding, critical thinking, problem solving, communication, and creativity *(e.g. Rosicka, 2016)*. Process-oriented skills associated with inquiry or problem-based learning, such as analysing, explaining, generalising, evaluating, applying and refining are also claimed as advantages of integrated STEM approaches *(Timms et al, 2018)*.

While these are highly desirable learning goals and there is evidence to suggest that integrated approaches provide 'opportunities for more relevant, less fragmented, and more stimulating experiences for learners' *(Furner & Kumar, 2007, p.186)*, there is little evidence that integrated approaches lead to a deep understanding of important mathematical ideas and the connections between them *(Becker & Park, 2011; English, 2016, 2019; Larson, 2017)*. This is not to say that integrated STEM approaches should not be considered just that there are some important considerations to keep in mind from the perspective of mathematics teaching and learning, not least of which is ensuring that the mathematics involved is important mathematics otherwise 'the M in STEM will remain silent' *(Shaughnessy, 2013, p. 324)*.

> ***If in the STEM program the mathematics isn't on grade level, or if the mathematics isn't addressed conceptually but rather as a procedural tool to solve various disjointed applications, or if the mathematics is not developed within a coherent mathematical learning progression, then the 'STEM program' fails the fundamental design principle. ... to develop the content and practices that characterize effective mathematics programs while maintaining the integrity of the mathematics. (Larson, 2017, p. 2)***

Another important consideration to keep in mind is teacher knowledge and confidence in relation to STEM. According to the ABS *(2014)* only 19 per cent of Australian secondary school teachers employed in 2010-11 had university level STEM qualifications and, at the primary school level, there are known issues with 'the confidence and competence of teachers to support deep intellectual engagement during the learning of science and mathematics' *(Tytler, Osborne, Williams, et al 2008, p. 115)*.

Venville, Rennie, and Wallace *(2009)* point to other barriers to integrated STEM programs such as curriculum expectations, assessment and reporting processes, and school structure *(e.g. discipline-based departments)*. Other challenges faced by schools in implementing an integrated STEM program include teacher workload, the extent of school leadership support, access to staff professional development, and parental expectations *(Little, 2019)*.

ISSUES AND CHALLENGES

> Australian schools are **not producing the sort of skills that industry and a STEM literate population requires**

Opting out of STEM in the senior years

Unlike many other countries (e.g., Finland, the USA and China), mathematics and science **are not mandated studies at Year 12** *(Wilson, 2015)* and intermediate or advanced level mathematics is not necessarily an entry requirement for further STEM related studies at many Australian universities *(Academy of Science, 2016)*. A worrying trend reported by Conolly (2016) is that many able students are choosing not to take higher level mathematics courses because they see this as a **threat to their ATAR** score due to what they see as the 'opportunity cost' involved (e.g. 3 hours/day for 6 days/week). While the number and diversity of subjects at this level ensure these students have plenty of other study options to consider, many others have little or no choice when it comes to choosing STEM subjects particularly, intermediate or advanced mathematics, because of their **mathematics results in previous years.**

'My maths isn't good enough'

There are many reasons for the relative decline in mathematical literacy as measured by PISA and the significant decline in participation rates in the more advanced mathematics subjects at Year 12, but two that are often cited are:

- Shortage of qualified mathematics teachers *(Prince & O'Connor, 2018)*.
- The ways in which school mathematics is traditionally taught and learnt *(AiG, 2015; Deloite Access Economic, 2014; Little, 2019; OCS, 2012)*.

While there is little individual schools can do to address the first of these proposed reasons, the second is related to what teachers believe they have to teach, that is, the **content of school mathematics.** If this is presented in lists of discrete, measurable skills, it is not surprising that the text and computer-based resources produced to support the teaching and learning of mathematics in schools adopt a similar approach. Given the shortage of qualified mathematics teachers, It is also not surprising that these resources come to be relied upon by out-of-field teachers. This raises the question of **what are we achieving in school mathematics?**

What you test is what you get

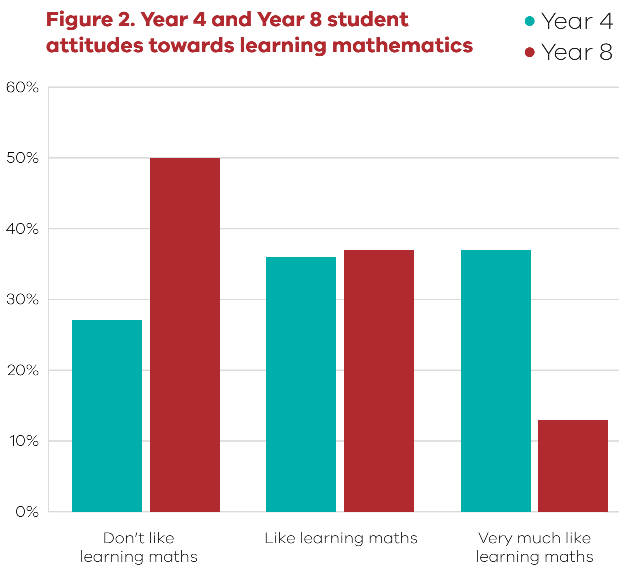
Swan and Burkardt *(2012)* refer to this well-known phenomenon as WYTIWYG, which can have a 'damaging backwash effect' *(p. 4)* on what is taught and how it is taught. For instance, if what is assessed values the reproduction of mathematical procedures over complex problem solving, it is highly likely that the former will be the focus of teaching which risks over scaffolding at the expense of engaging students in challenging tasks.

Australia's declining results on PISA assessments of mathematical literacy that focus 'on young people's ability to apply their knowledge and skills to real-life problems and situations' *(Thomson et al, 2019, p. xiv)*, reinforces the claim that Australian schools are not producing the sort of skills that industry and a STEM literate population requires.

School mathematics has an image problem

In their report of Australia's results on TIMSS 2015 *(Thomson et al, 2017)* reported that 27% of Year 4 students and 50% of Year 8 students do not like learning mathematics, roughly double the corresponding proportions of students who reported that they do not like learning science. But it is the significant decline in the proportion of Year 8 students who very much like learning mathematics (i.e. from 37% to 13%) that is particularly worrying as shown in Figure 2 below.

Figure 2. Year 4 and Year 8 student attitudes towards learning mathematics



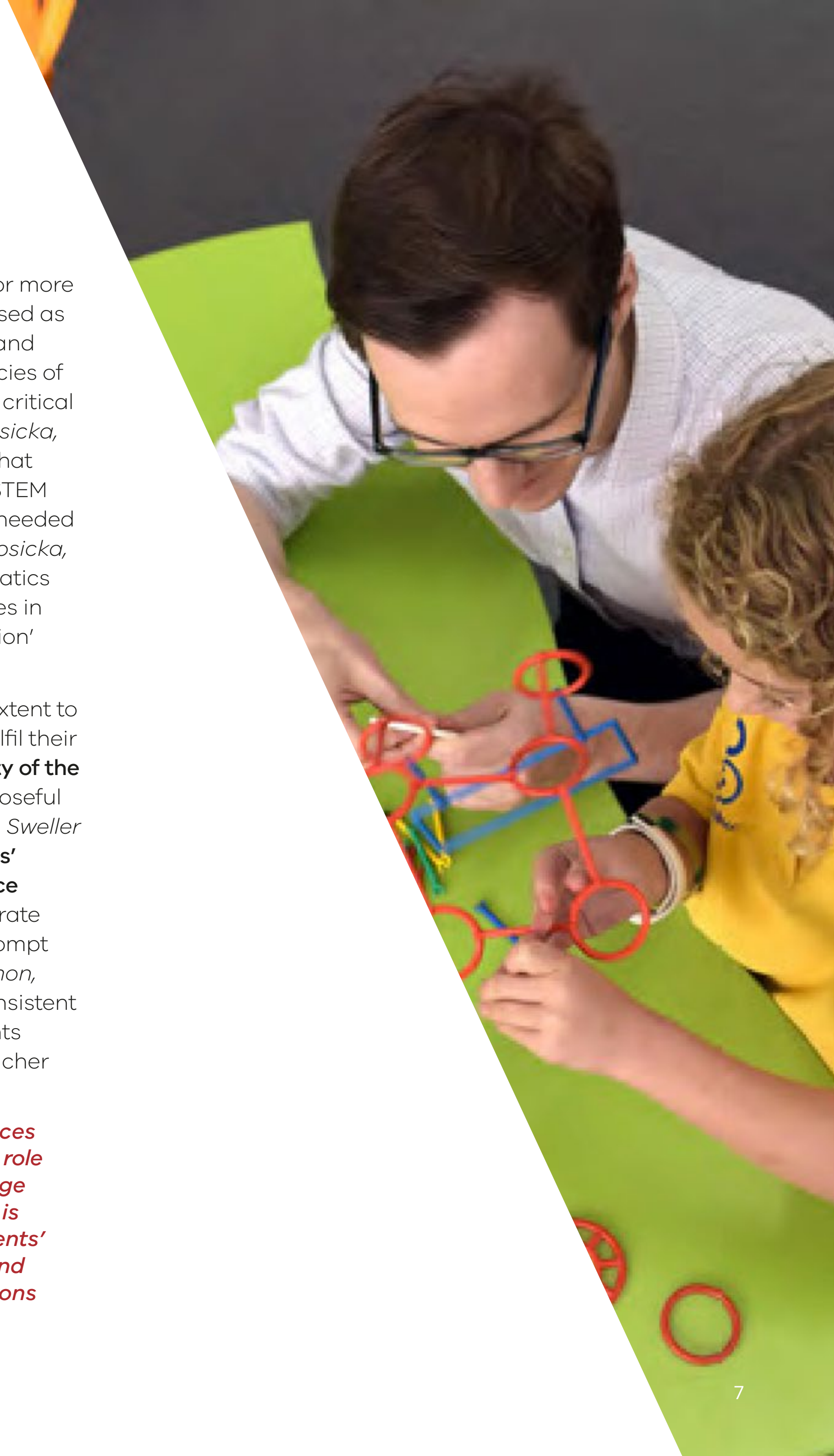
Source: TIMSS 2015: Reporting Australia's Results (Thomson et al, 2017)

The M in STEM risk

Teaching mathematics in the context of one or more of the other STEM disciplines has been proposed as a way to make mathematics more engaging and as a means to develop the desired competencies of problem solving, collaboration, creativity, and critical thinking *(Furner & Kumar, 2007; Little, 2019; Rosicka, 2016)*. However, it is generally acknowledged that more research into the impact of integrated STEM education programs on student outcomes is needed *(English, 2016; Fraser, Earle & Fitzallen, 2018; Rosicka, 2016)*, particularly as it appears that 'mathematics learning benefits less than the other disciplines in programs claiming to focus on STEM integration' *(English, 2016, p. 1)*.

One possible explanation for this is that the extent to which integrated STEM programs/activities fulfil their potential is entirely **dependent on the capacity of the teachers** involved to guide the inquiry in purposeful and productive ways *(Badley, 2009; Kirschner, Sweller & Clark, 2006)*. It also depends **on the students' prior mathematical knowledge and experience** and the extent to which they are able to generate the sort of questions and plans that might prompt a consideration of the potential content *(Siemon, Banks, & Prasad, 2019)*. This can result in inconsistent mathematics **content coverage** where students are taught by a non-mathematics trained teacher *(English, 2016; Little, 2019)*.

> ***Too often in connected learning experiences with science, mathematics plays a servant role where students use pre-existing knowledge and simple procedural applications. This is problematic for the development of students' knowledge and skills in mathematics … and provides insight into why some interventions have failed to improve achievement in mathematics. (Little, 2019, p. 456)***



WHAT DOES ADDRESSING THE M IN STEM LOOK LIKE IN PRACTICE?

FIRST STEPS: WHAT DO SCHOOL NEED TO DO ABOUT THE M IN STEM?

The most urgent thing that schools can do in light of the evidence that is driving the STEM Agenda is to consider how to engage more students in mathematics for longer. The aim is to ensure that as many students as possible not only have the option to choose further study in STEM related areas but also attain a level of numeracy that will stand them in good stead when it comes to employment. School mathematics also has a particular role to play in supporting the development of STEM skills such as problem solving, collaboration, communication, and critical and creative thinking, both in its own right and as an important component of an integrated STEM activity.

Recognise what makes a difference

A recent report commissioned by the Australian Government looked at the characteristics of schools judged to be 'successful' in mathematics *(Callingham, Beswick, Carmichael et al, 2017)*. A total of 619 schools were involved in the project and case studies were conducted in 52 of these schools (28 primary, 17 secondary and 7 combined). The report makes interesting and compelling reading and points to what makes a difference to students' mathematics learning which is summarised in Figure 3.

Figure 3. Key findings from case study schools successful in mathematics

100% of case study schools **had senior leadership, who understood and valued mathematics; and a mathematics leader who had input into school policy decisions**

90% of case study schools **had teachers who liked mathematics, and were enthusiastic about teaching mathematics (as perceived by student groups that were interviewed)**

87% of case study schools **used data to monitor individual students' progress; and had a classroom focus on mastery. (i.e. developing understanding) rather than procedural fluency**

94% of case study schools **had 'in-school' professional learning communities, and 73% had had formal, in-school professional learning**

Source: Nothing left to chance: Characteristics of schools successful in mathematics (Callingham, Beswick, Carmichael et al, 2017, p. 1)

The Nothing left to chance report provides a detailed explanation of what is meant by mastery and performance orientations to learning and the impact of each on student engagement. The report also includes the survey and case study instruments used to collect the evidence.

Mathematical Mindsets (Boaler, 2016) – challenges the assumption that maths is just for some people and presents evidence to show that most, if not almost all students are capable of excelling in and enjoying maths. Teaching strategies to support a growth mindset towards mathematics learning are also included.

Practice Principles for Excellence in Teaching and Learning together with the Framework for Improving Student Outcomes (Victorian Department of Education and Training, 2018) – provides a Vison for Learning and a process for school improvement that while not specific to mathematics is consistent with the key messages in the Nothing left to chance report and Jo Boaler's work on growth mindsets.

A useful video on the difference between fixed and growth mindsets to use with students can be found at: https://www.youtube.com/watch?v=KUWn_TJTrnU

Focus on important mathematics

The use of assessment data to monitor and progress student learning is recognised as one of the most effective ways to improve student learning outcomes *(e.g. Timperley 2011; Wiliam, 2006, 2011)*. At the same time there is a growing recognition that not every aspect of school mathematics needs to be assessed and not everything needs to be differentiated. Attention is turning to the role of evidence-based frameworks and big ideas in mathematics as a means of developing deep understanding and achieving greater curriculum coherence *(e.g. Charles, 2005; Hiebert & Carpenter, 1992; Hurst & Hurrell, 2014; Siemon, Bleckly, & Neil, 2012)*. For instance, given the overwhelming evidence that **access to multiplicative thinking is responsible for the 7-year range in mathematics achievement** at each year level from Year 5 to 9 and that **targeted teaching works** *(e.g. Siemon, Banks, & Prasad, 2018; Siemon, 2019)*, one very obvious way forward is to focus on identifying and responding to where students are in relation to this critically important idea that underpins a very large proportion of school mathematics in the middle years.

Invest in professional learning

A key characteristic of the successful schools was their commitment to ongoing professional learning. One of the most effective forms of which is **working with colleagues to better understand student reasoning** (*Carpenter, Blanton, Cobb et al, 2004; Wiliam, 2006)*. This is borne out by the experience of teachers working in the Early Years Numeracy project *(e.g. Clarke, 2001)*, the Scaffolding Numeracy in the Middle Years project *(Siemon, Banks & Prasad, 2018)* and more recently, the Reframing Mathematical Futures II project *(Siemon, Callingham, Day et al, 2018)*. As suggested above, working in professional learning communities on worthwhile data sets (i.e. ones that relate to important mathematics) is one way forward. Another is to work with colleagues to **plan, trial, and review alternative approaches to teaching mathematics using rich tasks**. Rich tasks provide opportunities to explore a variety of solution strategies/approaches, facilitate connections between different aspects of mathematics, support collaborative group work, promote discussion, build on what student already know and can do, and explore common misconceptions *(Clarke, 2003; Swan, 2005; Sullivan, 2011)*. Some professional learning suggestions are provided below.

RESOURCES

Two important resources to identify and respond to learning needs in relation to multiplicative thinking and big ideas that underpin this can be found on the DET website: the ***Scaffolding Numeracy in the Middle Years*** (SNMY) materials for multiplicative thinking and the ***Assessment for Common Misunderstandings*** *(AfCM)*, both of which offer evidenced-based diagnostic assessment tools and targeted teaching advice.

The Grattan Institute report, ***Targeted teaching: How better use of data can improve student learning*** *(Goss & Hunter, 2015)* – provides some case studies of successful targeted teaching.

Towards a growth mindset in assessment *(Masters, 2013)* – presents a case for defining, assessing, and reporting school learning in terms of the progress individuals make over time which is consistent with the notion of targeted teaching.

Maths 300 – provides a wealth of opportunities to explore alternative approaches to teaching mathematics that students and teachers alike find engaging and purposeful.

ReSolve – a relatively recent collaboration between the Australian Academy of Science and the Australian Association of Mathematics Teachers, this resource provides a number of exemplary investigations that explore an important aspect of mathematics.

Teaching for Robust Understanding *(Schoenfeld, 2013)* – provides a framework (TRU) for thinking about how classrooms can be set up to support powerful mathematics learning.

Another important resource in this space is the link to a nrich activities complied by Hewson *(2011)* (https://nrich.maths.org/6458) that specifically sets out to address the mathematical problems faced by advanced STEM students. Easier as well as harder applications of key aspects of mathematics are identified and linked to teaching activities.

With eyes wide open, take the plunge

While Mathematics is too important to be left to chance and more needs to be done to improve students' school mathematics experience and outcomes, **there is room for integrated STEM activities** where these increase student interest in learning mathematics and support the development of STEM skills such as problem solving, collaboration, communication, and critical and creative thinking. However, to ensure that the 'M in STEM does not remain silent' in any integrated STEM activity, it is important to ensure that:

- There must be a problem to solve.
- There must be significant mathematics involved in the problem.
- The problem should require the teamwork that draws on knowledge and approaches from several disciplines *(Shaughnessy, 2013, p. 342)*.

The following references/resources provide some images of what some integrated STEM programs look like in practice.

RESOURCES

From concept to classroom: Translating STEM research into practice *(Rosicka, 2016)* – this provides some practical ideas from STEM education research for primary classrooms together with some examples of STEM Education programs, and a framework for tracking STEM process skills.

STEM Program Index (AiG, 2016) – provides an extensive list of STEM related programs sourced from a wide variety of contributors including industry, universities, schools, and professional organisations.

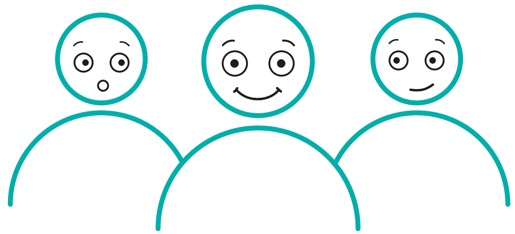
The Girls in STEM Toolkit (https://www.thegist.edu.au) – provides a range of resources aimed at encouraging more girls to explore STEM activities and opportunities

The STEM Agenda

SUPPLEMENTARY MATERIALS

Activities and reference material

TEAM-BASED ENGAGEMENT ACTIVITIES



ACTIVITY 1:

M in STEM review

Many schools are already well down the track of considering how they will respond to the STEM challenge. Where a STEM program has been implemented, consider initiating a regular review (whole school staff in primary settings, STEM teaching staff in secondary settings) to determine the extent to which the program meets its intended objectives.

For example:

- What evidence is there that the program generates transferable capabilities such as collaboration, communication, problem solving and critical thinking?
- Given that mathematics is often the least served by integrated STEM activities, what evidence is there that the program has had a positive impact on mathematics such as improved mathematics learning outcomes or increased engagement in and attitudes towards mathematics?

ACTIVITY 2:

Critically examine an integrated STEM activity

As we have seen above, while integrated approaches can provide opportunities to apply and extend the mathematics that is already known, if the mathematics considered is only prompted on a 'need to know' basis, there is a real risk that mathematics will be 'tacked on' and/or reduced to a set of narrow, disconnected skills and procedures. To this end it is worth dissecting and reflecting on integrated stem activities

Primary teachers

Work in teaching teams to unpack and critically reflect on an integrated STEM activity that you have used in the past or one that you might consider using at your year level (see resources below). Identify the opportunities to explore some important aspects of mathematics. Next, examine the extent to which the activity offers opportunities to explicitly develop and/or exercise STEM recognised skills such as collaboration, problem solving, creative and critical thinking, and communication. Document your findings to use as a guide when choosing other integrated STEM resources.

Secondary teachers

Either choose an existing integrated STEM activity or use the one below to explore the extent to which the activity provides an opportunity to develop a deep understanding of important mathematics and to exercise STEM recognised skills. Document your findings to use as a guide when choosing other integrated STEM resources

ACTIVITY 2: CONT

Design and construct a school kitchen garden – a Year 7 STEM inquiry

In addition to providing opportunities to develop and/or exercise recognised STEM skills such as collaboration, problem solving, creative and critical thinking, and communication, this project has the potential to explore a number of interdisciplinary connections. This project has the potential to generate problems as shown below.

Year 7 Content descriptions that might be addressed in the context of a kitchen garden STEM inquiry

Science

- Biological sciences – plant types, beneficial animals or insects
- Chemical sciences – soil pH, nutrients, fertilizer (ethics)
- Physical sciences – light, energy, location, wind velocity or speed levels
- Nature and development of science – cultural, historical agricultural practices
- Science as a human endeavour – advances (and disasters) in agricultural science, sustainability (composting, water consumption)
- Science inquiry skills – questioning and predicting, planning and conducting, recording and processing, analysing and evaluating, communicating.

Engineering & technology

- Optimal design given space, location, cost
- Scale models, pilot experiments/trials
- Choice of fit-for-purpose materials, considerations (e.g. cost, environmental impact)
- Use of digital tools (e.g. computer drawing programs, calculators, spreadsheets)

Mathematics

- Solve problems involving all four operations and whole numbers (Year 6)
- Add, subtract (Year 6), multiply and divide decimal fractions
- Recognise and solve problems involving simple ratios
- Investigate and calculate 'best buys'
- Establish the formulas of areas of rectangles, triangles and parallelograms
- Calculate the volume of rectangular prisms
- Draw different views of solids and prisms formed from a combination of prisms
- Investigate conditions for two lines to be parallel
- Construct and compare a range of data displays

Siemon, D. Banks, N., & Prasad, S. (2018). Multiplicative thinking a STEM foundation. In T. Barkatsas, N. Carr & G. Cooper (Ed.), STEM education: An emerging field of inquiry. Sense Publications.

Potential kitchen garden problem

ACTIVITY 3:

What will it take? Where might we start?

While improving mathematics is a long-term goal, understanding what makes a difference is an important place to start. Some options are suggested below.

1. Read the Smith, Ladewig And Prinsley (2018) article on improving the mathematics performance of Australia's students. Canberra: Office of the Chief Scientist (available from: https://www.chiefscientist.gov.au/sites/default/files/Improving-the-mathematics-performance-of-Australias-students.pdf). Discuss in terms of how well the school measures up against the key characteristics of schools successful in mathematics, keeping in mind that these included schools from low SES areas and non-English speaking backgrounds. Consider what the school could do as a starting point to improve school mathematics.
2. While you may disagree with the metric used to determine successful schools, there is an independent evidence base for many of the characteristics of these schools, particularly the value of mastery over performance-oriented classrooms. Download and read the short article by Carol Dweck on mindsets and consider the implications of this for classroom practice. https://portal.cornerstonesd.ca/group/yyd5jtk/Documents/Carol%20Dweck%20Growth%20Mindsets.pdf
3. Successful schools use data to inform their teaching. Access the *SNMY* or *Assessment for Common Misunderstanding* (AfCM) material from DET website which can be used to identify and respond to where students are at in relation to the big ideas of Number. Administer one of the SNMY Assessment Options as per the instructions and/or trial a number of the individual performance-based tools from the AfCM. Mark and moderate student responses as a team and use the relevant teaching advice to plan a targeted teaching response.

ACTIVITY 4:

Establish a school or locally based STEM professional learning community

Involve interested teachers, school leadership, and community representative(s). Invite participants to download and read *Challenges in STEM Learning in Australian Schools (Timms, Moyle, Weldon, & Mitchell (2018)*, then call a STEM Summit to discuss possibilities for community partnerships.

For secondary schools

Invite STEM leaders and teachers to download, read and then meet to discuss *Studying STEM subjects will ruin my ATAR* by Bryon Connolly of the Chief Information Officers (CIO) Australia. Consider conducting a survey of Level 8 to 10 students on their views about studying a STEM subject in VCE, VET or VCAL and their reasons for and against.

ACTIVITY 5:

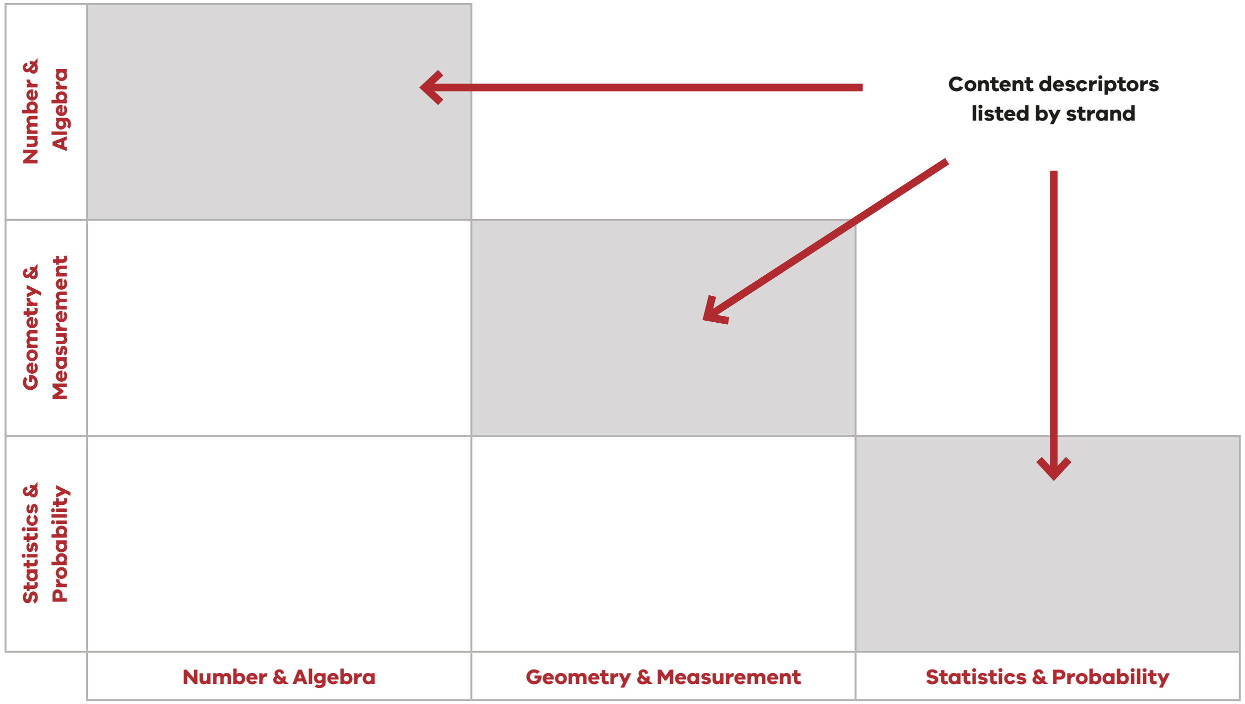
Curriculum planning exercise

This approach to mathematics curriculum planning is designed to ensure that priority is given to important mathematics and the proficiencies by generating time and space in the 'crowded curriculum' for integrated activities that are explicitly based on the mathematics.

The proficiencies are variously foregrounded and backgrounded to ensure that these are given the attention they deserve both explicitly and implicitly. For instance, when considering content listed in the shaded cells conceptual understanding and procedural fluency are foregrounded and problem-solving and reasoning are backgrounded. This situation is reversed when considering the content descriptors listed in the integrated unshaded cells (e.g. see (**4**) below).

The following activity[1] is best undertaken in teaching teams using multiple copies of the curriculum planning matrix as it generates a significant amount of discussion about the meaning of the content descriptors and the relationships between them. The steps in this process are listed below.

Figure 4. A curriculum planning matrix



1. Use a word version of the Victorian Curriculum to cut and paste the content descriptions (text not codes) for each strand from a particular year level into the shaded cells to create a Curriculum Planning Matrix (a planning proforma is provided for this purpose – if using paper copies it is best to prepare this in A4 then enlarge to A3 on a photocopier before copying).
2. Work as a team to decide and highlight which aspects of Number and Algebra will be considered in Term 1. The reason for this is that this is the area most responsible for the range in student mathematics achievement. Choosing a few of the most important descriptors (e.g. those that relate to the big ideas of place value or multiplicative thinking) provides an opportunity to find out where students are in their learning journey at the beginning of the year. The number of content descriptors selected will vary by year level, but it should be somewhere between a third and a half of the number of content descriptors.
3. Decide and highlight which aspects of Geometry and Measurement and Statistics and Probability will be considered in Term 1. Where possible, prioritise those that have a connection to the content descriptors chosen for Number and Algebra (e.g. metric measurement system is connected to place value, probability is connected to fractions). Again, the number will vary by year level, but generally no more than a third to one half of the number of content descriptors.

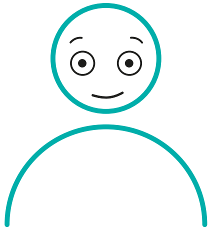
[1] *Based on a professional development workshop offered by the author from 1995-2020*

Figure 5. An example of what a Curriculum Planning Matrix might look like at this stage

Number & Algebra Use index notation with numbers to establish the index laws with positive integral indices and the zero index Carry out the four operations with rational numbers and integers, using efficient mental and written strategies and appropriate digital technologies and make estimates for these computations Investigate terminating and recurring decimals Investigate the concept of irrational numbers, including π Solve problems involving the use of percentages, including percentage increases and decreases and percentage error, with and without digital technologies Solve a range of problems involving rates and ratios, including distance – time problems for travel at a constant speed, with and without digital technologies Extend and apply the distributive law to the expansion of algebraic expressions Factorise algebraic expressions by identifying numerical factors Simplify algebraic expressions involving the four operations Use algorithms and related testing procedures to identify and correct errors Plot linear relationships on the Cartesian plane with and without the use of digital technologies Solve linear equations using algebraic and graphical techniques. Verify solutions by substitution Plot graphs of non-linear real life data with and without the use of digital technologies, and interpret and analyse these graphs Solve problems involving profit and loss, with and without digital technologies		
Investigate the concept of irrational numbers, including π Solve problems involving the use of percentages, including percentage increases and decreases and percentage error, with and without digital technologies Investigate the relationship between features of circles such as circumference, area, radius and diameter. Use formulas to solve problems involving determining radius, diameter, circumference and area from each other	**Geometry & Measurement** Choose appropriate units of measurement for area and volume and convert from one unit to another Find perimeters and areas of parallelograms, trapeziums, rhombuses and kites Investigate the relationship between features of circles such as circumference, area, radius and diameter. Use formulas to solve problems involving determining radius, diameter, circumference and area from each other Develop the formulas for volumes of rectangular and triangular prisms and prisms in general. Use formulas to solve problems involving volume Solve problems involving duration, including using 12- and 24-hour time within a single time zone Define congruence of plane shapes using transformations and use transformations of congruent shapes to produce regular patterns in the plane including tessellations with and without the use of digital technology Develop the conditions for congruence of triangles Establish properties of quadrilaterals using congruent triangles and angle properties, and solve related numerical problems using reasoning	
		Statistics & Probability Identify complementary events and use the sum of probabilities to solve problems Describe events using language of 'at least', exclusive 'or' (A or B but not both), inclusive 'or' (A or B or both) and 'and' Distinguish between a population and a sample and investigate techniques for collecting data, including census, sampling and observation Represent events in two-way tables and Venn diagrams and solve related problems Explore the practicalities and implications of obtaining data through sampling using a variety of investigative processes Explore the variation of means and proportions of random samples drawn from the same population Investigate the effect of individual data values including outliers, on the range, mean and median

4. Having highlighted all the descriptors in the shaded cells the next task is to populate the unshaded cells by copying and pasting descriptors that **'go together mathematically'** (e.g. a Number and Algebra descriptor referring to locating fractions on a number line might be copied and pasted into the Number and Algebra x Statistics and Probability cell (bottom left) with a descriptor from the Statistics and Probability cell that refers to ordering of chance events. It is important at this stage NOT to think about contexts or possible tasks but how the mathematics is connected. Figure 5 shows what this might look like for the Number & Algebra x Geometry & Measurement cell.
5. When the unshaded fills have been populated, work in smaller groups to read and re-read the content descriptions in one of the unshaded cells until a context or problem becomes apparent – it is important NOT to let a particular context or problem determine the mathematics as this would end up with the mathematics being 'tacked on'. Once a context or problem is decided, rewrite the content descriptors in terms that students will understand (e.g. by the end of this unit I/We will be able to…) – these become the learning goals or objectives. The next step is to plan an integrated activity or unit of work that draws on other disciplines, provides an opportunity for students to learn explicitly about problem solving and reasoning, and includes an indication of how the unit will be assessed.
6. Debrief and review before repeating this process over the course of the year to create a matrix for each term. Revisit the important mathematics (e.g. place value, fractions, etc) each term so that by the end of the year, students have had multiple opportunities to develop a deep understanding of important mathematical ideas and to apply that knowledge in a broad range of contexts.

INDIVIDUAL ENGAGEMENT ACTIVITIES



Teacher knowledge and confidence has been identified as the most important factor impacting the quality of mathematics teaching *(Ball, Hill, & Bass, 2005; Sullivan, 2011)* and the success of integrated STEM activities *(Rosicka, 2016; Tytler et al, 2008)*. The following activities are aimed at supporting key aspects of teacher knowledge, and while they can be done individually, it is best if the experience is shared with colleagues.

ACTIVITY 1:

Teachers need to know their students and how they learn

One of the most powerful ways of doing this is to explore students' thinking in relation to an important aspect of mathematics.

1. Read the article, 'Targeting the Big Ideas in Mathematics', available from: https://www.teachermagazine.com.au/articles/targeting-big-ideas-in-mathematics
2. Investigate the *Assessment for Common Misunderstanding* (AfCM) materials and the *Scaffolding Numeracy in the Middle Years* (SNMY) resources both of which are available on the DET website. The AfCM materials address key ideas that need to be in place at key levels of schooling (Foundation to Level 10). They comprise short individual interviews that assess an aspect of a big idea in Number known to make a difference to student learning. The SNMY materials offer class-based assessment options suitable for Levels 4 to 9 that profile where students are in relation to multiplicative thinking. Both resources offer teaching advice that can be used to target student's learning needs.
3. Either choose and administer one or two of the AfCM tools with a small number of students OR use one of the SNMY options to identify where students are in relation to these important ideas. Following this, use the AfCM teaching advice or the Learning Assessment Framework to plan and implement a targeted teaching response aimed at a small group of students.

ACTIVITY 2:

Teachers need to know the content and how to teach it

Many primary teachers and those teaching out-of-field in secondary schools have not necessarily had the opportunity to develop a deep, interconnected knowledge of the mathematics they need for teaching.

1. Download and read Helen Timperley's article on 'Using assessment data for improving teaching practice', available from: https://research.acer.edu.au/research_conference/RC2009/17august/7/ then reflect on what you need to know to help your students learn mathematics. Discuss with a colleague and then choose one or more of the following activities to extend you knowledge of the mathematics needed for teaching and/or expand your repertoire of pedagogical strategies.
2. Understanding the mathematics for teaching – there are a number of texts and online resources that teachers can use to deepen their knowledge of the mathematics needed for teaching. One that deals with big ideas and traces the development of those ideas from Foundation to Year 9 is *Teaching Mathematics: Foundations to Middle Years (Siemon, Beswick, Brady, Clark, Faragher, & Warren, 2015)*. Another option is to explore the videos and tasks on youcubed available from https://numeracyguidedet.global2.vic.edu.au/resources-youcubed/ which also includes some valuable information on pedagogical strategies and the importance of growth mindsets.
3. Reflecting on pedagogy – Choose activity from reSolve, maths300, or nrich or an open-ended question or challenging task *(e.g. Lilburn & Sullivan, 2017; Sullivan, 2017)* to trial in your classroom. Prior to teaching the task, familiarise yourself with what is involved and read Section 5 of 'Teaching Mathematics: Using research-informed strategies' *(Sullivan, 2011)* available from: https://research.acer.edu.au/aer/13/. Then consider the activity in terms of the six key principles for effective teaching of mathematics.
   - What do you want to achieve as a result of using this activity?
   - How will you communicate these goals to the students?
   - What connections will you make to students' own experience or prior learning to establish a rationale for learning?
   - How will you differentiate support to ensure all students participate in the activity and learn from the experience?
   - What sort of questions or prompts might you offer to encourage deeper learning?
   - What opportunities are there for developing fluency?

   Consider making a video of the lesson and/or inviting a colleague in to participate and observe. Once you have trialled the activity, reflect on your experience in terms of the six key principles or in term of the relevant impact strategies (HITS) available from: https://www.education.vic.gov.au/school/teachers/teachingresources/practice/improve/Pages/hits.aspx. Share your experience with colleagues to seek feedback and advice and where appropriate talk to students about their experience.

RESOURCES

Responding to the STEM challenge

Assessment for Common Misunderstandings (AfCM) https://www.education.vic.gov.au/school/teachers/teachingresources/discipline/maths/assessment/Pages/misunderstandings.aspx

Hewson, S. (2011). The mathematical problems faced by senior STEM students: https://nrich.maths.org/6458

Maths300: https://maths300.com

Nrich: https://nrich.maths.org

ReSolve: https://resolve.edu.au

Scaffolding numeracy in the Middle Years (SNMY) https://www.education.vic.gov.au/school/teachers/teachingresources/discipline/maths/assessment/Pages/scaffoldnum.aspx

STARportal: https://starportal.edu.au

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