University Mathematics Bridging Courses: MathStart, MathTrack, A Review of Existing Approaches and Recommendations for Moving Forward.

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Thesis submitted for the degree of Master of Teaching

March, 2019

SCHOOL OF EDUCATION

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Contents

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Glossary

fMRI functional magnetic resonance imaging. v, 3, 6

MARS Maths Anxiety Rating Scale. v

MAS-R Maths Anxiety Scale — Revised. v, 6

NAPLAN National Assessment Program — Literacy and Numeracy. v, 3

OECD Organisation for Economic Co-operation and Development. v, 3

PISA Programme for International Student Assessment. v, 3

PTSD Post-Traumatic Stress Disorder. v

STEM Science, Technology, Engineering and Mathematics. v, 3

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Abstract

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Chapter 1

Introduction

University mathematics bridging courses serve an important stop-gap role in the Australian educational system, and other educational systems internationally.

This project can be thought of as consisting of two broad bodies of work:

- A review of Australian mathematics bridging courses, a state of the field of research in this area, and commentary on the role, purpose, and approaches important to implementing effective and impactful mathematics bridging courses in Australia and internationally.
- A focus on the bridging courses offered by the University of Adelaide through the Maths Learning Centre: MathStart and MathTrack. Placing these in the broader context, and taking lessons learnt from the broader literature and applying them in practice. In this component, I have implemented several improvements which can be immediately useful to the bridging programs offered at the Unviersity of Adelaide.

This thesis will be structured as follows:

- The remainder of this introductory chapter (Chapter 1), I will give a broad overview of the concepts, challenges, and setting for this project.
- In Chapter ?? I will provide a indepth discussion of the existing literature, what is known, approaches attempted in the past both in Australia and internationally, and some deeper discssion on some of the particularly relevant related concepts, such as maths anxiety.
- In Chapter ?? I will map the Australian Curriculum (AC) to South Australian Certificate of Education (SACE) to the content currently in MathStart and MathTrack, the mathematics bridging courses offered at the University of Adelaide through the Maths Learning Centre. I will also include a discussion of how this content aligns with the biggest first-year mathematics courses at the University of Adelaide. I will identify gaps and mis-alignment, discuss the tension between different perspectives on the role of university mathematics bridging courses and how this impacts on content, and I will suggest modifications to the bridging courses that would allow them to be more closely aligned with the AC should that be wanted.
- Finally, I will wrap up with commentary on what is being done well, reccomendations for how to improve, and a summary of the work I have done outside

of this thesis to generate resources and content that can be used to improve these programs moving forward in Chapter 4.

1.1 The Role of University Mathematics Bridging Courses

Students will usually enroll in university mathematics bridging courses because they are required to demonstrate a certain level of mathematical knowledge/ competance before commencing study at university, but either do not meet those requirements, or do but feel a lack of confidence in their abilites and feel like they need to refresh/ revise/ learn the mathematics prior to commencing their studies.

Many of these students will be adult-entry students, and reasons why these students do not either meet the entry requirements, or feel a lack of confidence in their abilities can be quite varied:

- A long period of time may have passed since they last studied mathematics (or studied at all).
- They may have performed poorly in mathematics in highschool.
- They may have chosen not to study mathematics at a higher level in highschool.
- They may suffer from maths anxiety (which would make them likely to fit into the above two categories as well).

The role of mathematics bridging courses is to take these students, and:

- Bridge their content knowledge so they are prepared for university entry.
- Support the growth of their confidence and self-efficacy surrounding mathematics.
- Ultimately prepare them to be successful in a university context.

From the perspective of content, what content should be taught in a university bridging course is actually a question that has dramatically different answers from different perspectives on the role of such a course:

- If you take the perspective that the role of such a course is to fill in the gaps in student's knowledge left from an incomplete or maths-light highschool education, then the content that should be taught should be up to and including the advanced year 12 australian curriculum. This is particularly appropriate if you do not know the direction of the students, or if they are potentially just doing the bridging course with you and they are planning on studying a degree at a different university say, interstate.
- If you take the perspective that the role of such a course is to prepare students for entry into the particular courses they are about to commence studying, the content relevant to them will be dramatically differnet. The senior mathematics australian curriculum is extremely generalist and contains many topics that would be completely irrelevant to any particular field of study.

In terms of choosing what content to teach in a university bridging course, the above two competing perspectives will often be at odds with each other.

Chapter 2

Literature Review

2.1 Bridging Courses

- (Gordon & Nicholas, 2013) describes the perspectives of students enrolled in an Australian university bridging course.
- (Johnson & O'Keeffe, 2016) describes the impact of a bridging course on students maths anxiety and self-efficacy in Ireland.
- (?, ?) Conference proceedings analysing the impact of bridging course on students success in first year university level calculus courses.
- (Nicholas & Rylands, 2015) is very relevant but I can't find the actual paper, just references too it.

2.2 Maths Anxiety

Why is Maths Anxiety Important?

Maths anxiety is hugely prevalent, the 2012 Programme for International Student Assessment (PISA) report states that across Organisation for Economic Co-operation and Development (OECD) countries, over 30% of 15 year old students "get very nervous doing mathematics problems", and over 60% of students "worry about getting poor grades in mathematics" (OECD, 2013). As teachers our foremost concern should be for the wellbeing of our students. It has been shown that students with a high level of maths anxiety often literally experience the anticipation of a maths task as visceral pain (Lyons & Beilock, 2012b). There is a clear and overwhelming moral imperative (and ethical duty of care) on us to do everything in our power to protect students in our care from maths anxiety.

Even if the wellbeing issue was not enough, there is also a clear maths anxiety-performance connection, and all the stakeholders in a students academic success in maths. One example of this is highlighted by Foley et al. (2017) who juxtaposes the internationally rising demand for Science, Technology, Engineering and Mathematics (STEM) professionals with the negative correlation between maths anxiety and performance shown in the 2012 PISA report (OECD, 2013) to highlight the relevance of addressing maths anxiety in filling this demand. The relationship between maths anxiety and maths-qualified professionals in the workforce is supported throughout the literature: when a student has low self-concept (correlated with high maths anxiety), they will tend not to enroll in maths beyond the minimum requirements for graduation (Ashcraft, Krause, & Hopko, 2007), and students affect towards maths can predict their university major (LeFevre, Kulak, & Heymans, 1992). Beyond this example, the list of stakeholders in a students academic success in maths goes on and on: parents; the student's themselves; schools (which are often funded based on the results of standardised testing such as National Assessment Program — Literacy and Numeracy (NAPLAN)), and teachers amongst them.

Maths Anxiety as Distinct from General Anxiety

The existence of maths anxiety as "emotional disturbances in the presence of mathematics" has been noted as early as the 1950's, Dreger and Aiken Jr (1957) even postulated that what he tentatively designated "Number Anxiety" and later became to be known as Maths Anxiety could be a distinct syndrome from general anxiety. Later the landmark meta-study of Hembree (1990) supported this hypothesis, showing a correlation of only 0.38 between maths anxiety and general anxiety. In more recent times, this hypothesis has also been confirmed by Young, Wu, and Menon (2012) using functional magnetic resonance imaging (fMRI) to show that the brain activity in a person experiencing maths anxiety is measurably distinct from that in a person suffering general anxiety. These later studies, as well as the the work of Kazelskis et al. (2000) and more, have also delineated maths anxiety from test anxiety, and these different anxieties exisitng as meaningfully distinct constructs is now quite well accepted. For more on the history of maths anxiety, Suárez-Pellicioni, Núñez-Peña, and Colomé (2016) offers a more detailed review.

Frameworks for Understanding Maths Anxiety

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Only a few studies focus on maths anxiety itself (primarily fMRI studies such as those of Young et al. (2012) or Lyons and Beilock (2012b)). Instead the bulk of the literature is focused on the maths anxiety-performance link. Specifically, there seem to be two distinct theories being pursued and I will adopt the terminology of Ramirez, Shaw, and Maloney (2018) to describe them: the "Disruption Account" and the "Reduced Competency Account". Ramirez et al. (2018) go on to make a convincing argument that although these two theories might seem to compete, they are not actually mutually exclusive and instead quite compatible with each other. Ramirez et al. (2018) suggests a third "Interpretation Account" which encapsulates observations made by both lines of research, see Figure 2.1.

First, a little more detail on the existing theories. The "Disruption Account", spearheaded by the work of Ashcraft et al., is centered around the concept of working memory (Ashcraft & Kirk, 2001; Ashcraft & Krause, 2007). Specifically that anxiety about maths takes up students working memory, which prevents them from using that working memory to complete maths tasks and thereby impacts their performance. The "Reduced Competency Account" on the other hand proposes the opposite causality: that lower ability in maths leads to negative experiences associated to maths, which in turn cause maths anxiety to develop. There is also a significant body of work to support this hypothesis, including the milestone meta-analysis of Hembree (1990) and the longitudinal study of Ma and Xu (2004) which found that

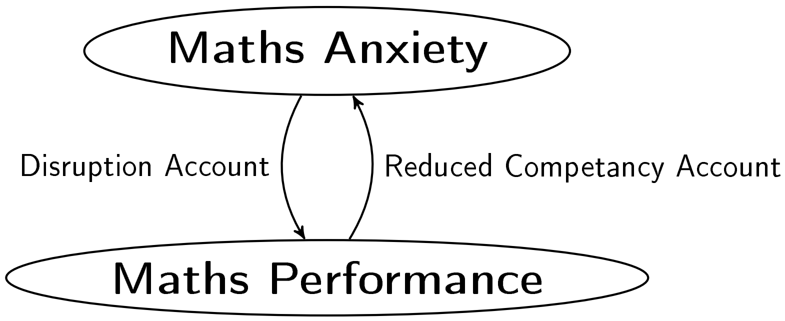

Figure 2.1: The Interpretation Account of Ramirez et al. (2018) for the maths anxiety-performance link showing how the Disruption Account and the Reduced Competency Account can be compatible.

although past maths anxiety was correlated with future maths performance it was a small effect, while past maths performance had a strong effect on future maths anxiety.

Complexities in Finding Effective Interventions

These theoretical views are of course broad oversimplifications of what is an incredibly complex and interconnected topic. They also imply very different approaches for intervention. The "Reduced Competency Account" would imply interventions to boost maths performance and hence allow students to experience success in math should also help to reduce maths anxiety. The results of Supekar, Iuculano, Chen, and Menon (2015) seem to support this hypothesis as when students are given an intensive 8-week tutoring program to boost their maths skills, this is associated to a reduction in maths anxiety. The earlier work by Faust (1996) further supports this by demonstrating an anxiety-complexity effect in which low and high maths anxiety groups performed similarly on low complexity problems, but in high complexity problems the high anxiety groups performance was impacted. On the other hand, Jansen et al. (2013) showed that it is not neccessarily that simple, by showing that when students experience more success they attempt more problems and perform better. However their improved performance is almost completely predicted by the number of problems they attempted, not their experience of success, and their level of maths anxiety was not affected in a significant way which raises a lot of interesting but unanswered questions about this approach.

On the other side of attempted interventions are those in line with the "Disruption Account", in which the maths anxiety itself is addressed in the hopes that will free up extra working memory and hence boost students performance. Park, Ramirez, and Beilock (2014) demonstrate a direct and successful attempt at this in which they used expressive writing exercises to help guide students self-perceived narratives about their maths experiences and thereby reduce their maths anxiety. Notably the approach of Park et al. (2014) is in line with successful treatments for clinical anxiety disorders (see McNally (2007); Becker, Darius, and Schaumberg (2007); Foa et al. (2005)). Another approach that has shown success in this vein does not attempt to directly reduce the anxiety experienced, but rather reappraise it's symptoms (Jamieson, Peters, Greenwood, & Altose, 2016). This is another technique from clinical psychology in which stress is reconceptualised as a coping tool, an evolutionary method for heightening performance in response to a challenge to be overcome, instead of a symptom of exposure to something to be feared and avoided. This change in the perspective of stress is also very much in line with the "Interpretation Account" of Ramirez et al. (2018).

The work of Wang et al. (2015) showed the role that intrinsic motivation has mediating the relationship between maths anxiety and performance, and suggested the importance of a mindset centred on viewing the process of learning maths as one of "productive struggle". This reconceptualisation to a 'productive struggle' model is supported by other literature as well, Lin-Siegler, Ahn, Chen, Fang, and Luna-Lucero (2016) exposes students in a classroom to struggles experienced by famous scientists in order to help normalise the concept of productive struggle, and Hiebert and Grouws (2007) discuss the importance of this same concept in a maths context.

One of the implications of the "Interpretation Account" is that if an intervention targets only one of these two possible links in the cycle (see Figure 2.1), the cycle may re-establish itself after the intervention is over and negate any potential longterm effects. However there is only a very limited amount of research out there on such longterm effects, and several authors have discussed the need for further research into this (Suárez-Pellicioni et al., 2016; Chang & Beilock, 2016). My hypothesis is that a multi-faceted approach targetting both directions simultaneously could disrupt the cycle shown in Figure 2.1 and result in significant longterm effects.

Instruments for Measuring Maths Anxiety

In order to track the effectiveness of these interventions, we will be collating assessment results as a measure of performance, but will also want to measure maths anxiety and maths affect/ self-concept. Significant work has been done over the years to develop psychometrics to measure maths anxiety, almost exclusively consisting of self-reporting surveys (with the exception of some more modern fMRI work, such as that of Lyons and Beilock (2012a)). We will use a recently developed scale: the Maths Anxiety Scale — Revised (MAS-R) of Bai, Wang, Pan, and Frey (2009), which has been shown to be remarkably self consistent by incorporating both positive and negative affect items (Bai, 2011). It is short, easy to implement, and cheap in comparison to fMRI methods. In order to measure maths self-concept, Jansen et al. (2013) modified the Perceived Competence Scale for Children of Harter (1982) to measure "Math Competance". The methodological process imployed by Jansen et al. (2013) was quite rigorous and so we will use their instrument, or a minor modification thereof (we will do it in English), to measure maths self-concept.

Chapter 3

Curriculum Mapping

One of the important roles of university mathematics bridging courses is to fill the content knowledge gap for students who did not complete Mathematical Methods or Specialist Mathematics in highschool. What exact content knowledge is expected from having competed Mathematical Methods and/ or Specialist Mathematics can also vary from state to state in Australia, and will vary even more dramatically internationally. The terms themselves "Mathematical Methods" and "Specialist Mathematics" even vary, but essentially these correspond with the highest levels of mathematics in the final year of highschool, which is often required for entry into many university programs.

This chapter will examine the alignment of the content of MathStart and MathTrack (the mathematics bridging courses offered at the university of adelaide) with the AC and SACE, see Figure 3.1. Beyond that, this chapter will also briefly discuss the alignment of these bridging courses to first year university mathematics courses and bridging courses offered by other universities in Australia, and the relationship between the seeming gaps in alignment between the AC and SACE and the bridging courses and the requirements of these first year university courses. However, overall the focus is on the alignment of the bridging courses and AC/ SACE, rather than their alignment to the first year university courses for one clear and important reason: not all students enrolling in these bridging courses are commencing these first year university courses, or may be doing so at a different university in which their first year content is different. Hence, it is most fair to attempt to align the content with the AC/SACE as this is the content other students should be covering in highschool prior to enrolling in university in any case, and hence puts people at a fair standing with those students, and also being aligned with the AC in particular is useful for guaranteeing a certain level of knowledge for enrollment in universities interstate.

3.1 AC-SACE-MathStart-MathTrack Alignment

Each senior highschool curriculum being considered here is broken down into topics, and within each topic sub-topics. Figure 3.1 shows the topic-level alignment between the AC (senior mathematical methods and specialist mathematics), SACE (mathematical methods and specialist mathematics), MathStart and MathTrack. Although sub-topic alignment within these topic alignments is not always perfect, it is fairly strong in each case but individual cases will be discussed in more detail below.

The notation used in Figure 3.1 is as follows:

- AC:
  - "MMu[#1]t[#2]": Senior Mathematical Methods Unit [#1], Topic [#2].
  - "MMu[#1]t[#2]": Senior Specialist Mathematics Unit [#1], Topic [#2].
- SACE:
  - "S1M[#]": Stage 1 Mathematics, Topic [#].
  - "S2MM[#]": Stage 2 Mathematical Methods, Topic [#].
  - "S2SM[#]": Stage 2 Specialist Mathematics, Topic [#].
- Univesity of Adelaide Bridging Courses:
  - "MS[#]": Maths Start, Topic (Booklet) [#].
  - "MT[#]": Maths Track, Topic (Booklet) [#].

Table [...?...] lists the names of these topics, including a brief summary of the key sub-topics/ content knowledge.

AC has four levels of mathmatics, including also essential and general mathematics. Mathematical Methods and Specialist Mathematics are the two highest level mathematics, intended (partly) for preparation to university entry.

Table 3.1: Description of AC Mathematical Methods and Specialist Mathematics Topics. For brevity I use a code for each topic, see ...

Code	Name	Description
MMu1t1	Functions I	Lines, Quadratics, Inverse Proportions, Polynomials, Relations, Translations and Dilations
MMu1t2	Trigonometry I	Unit Circle, Radians, SOH CAH TOA, Sine Rule, Exact Values, Amplitude/ Period/ Phase, Sum of Angles Identities
MMu1t3	Combinatorics I	Binomial Coefficients, Set Complement Intersection and Union, Probability, $P(A \cup B) = P(A) + P(B) - P(A \cap B)$, Conditional Probability, Independance
MMu2t1	Exponentials	Index Laws, Fractional Indices, Functions, Asymptotes, Graphs
MMu2t2	Sequences	Arithmetic and Geometric Sequences as Recurrence Relations, Limiting Behaviour, and Partial Sum Formulae, Growth and Decay
MMu2t3	Differentiation I	Average Rate of Change, First Principles, Leibniz Notation, Instantaneous Rate of Change, Slope of Tangent, Derivitive of Polynomials, Linearity of Differentiation, Optimisation, Anti-Derivitives, Interpret Position-Time Graphs
MMu3t1	Differentiation II	Define e as a s.t. $\lim_{h\to 0} \frac{a^h-1}{h} = 1$, Derivitives of e^x $\sin(x)$ and $\cos(x)$, Chain Product and Quotient Rules, Second Derivitives

MMu3t2	Integration I	Integrate Polynomial Exponential and Trigonometric Functions, Linearity of Integration, Determine Displacement given Velocity, Definite Integrals, Fundamental Theorem of Calculus, (signed) Area Under a Curve
MMu3t3	Discrete Random Variables	Frequencies, General Properties, Expected Value, Variance, Standard Deviation, Bernoulli and Binomial Distribtions
MMu4t1	Logarithms	Logs as Inverse of Exponentials, Log-Scales, Log Function Graphs, Natural Log, $\frac{d}{dx}\ln x = \frac{1}{x}$, $\int \frac{1}{x} dx = \ln x + c$ for $x > 0$
MMu4t2	Continuous Random Variables	Probability Density Function, Cumulative Distribution Function, Probabilites Expected Value, Variance and Standard Deviation as Integrals, Linear Transformation of Random Variables, Normal Distribution using Technology
MMu4t3	Confidence Interval for Proportions	Simple Random Sampling, Bias, Sample Proportion, Normal Approximation to the Binomial Proportion, Wald Confidence Interval, Trade-Off Between Width and Level of Confidence

SMu1t1	Combinatorics II	Multiplication of Possibilities, Factorial Notation, Permutations with and without Repeated Objects, Union of Three Sets, Pigeon-Hole Principle, Combinations, Pascals Triangle
SMu1t2	Vectors in $\mathbb{R}^2$	Magnetude and Direction, Scalar Multiplication, Addition and Substraction as a Triangle, Vector Notation, $a\mathbf{i} + b\mathbf{j}$ Notation, Scalar Dot Product, Projection, Parallel and Perpendicular Vectors
SMu1t3	Geometry	Notation for Implication ($\Rightarrow$) and Equivalence ($\Leftrightarrow$), Converse ($B \Rightarrow A$) Negation ($\neg A \Rightarrow \neg B$) and Contrapositive ($\neg B \Rightarrow \neg A$), Proof by Contradiction, $\forall$ and $\exists$ Notation, Counter-Examples, Circle Theorems, Quadrilateral Proofs in $\mathbb{R}^2$
SMu2t1	Trigonometry II	Graph and Solve Trig Functions, Prove Various Trig Indentities, Reciprocal Trig Functions
SMu2t2	Matrices	Notation, Addition and Scalar Multiplication of Matrices, Multiplicative Identity and Inverse, Determinant, Matrices as Transformations
SMu2t3	$\mathbb{Q}$, $\mathbb{R} \setminus \mathbb{Q}$, and $\mathbb{C}$	Rationality and Irrationality, Induction, $i = \sqrt{-1}$, Complex Numbers $a + bi$ and Arithmetic ($+$, $-$, $\times$, $\div$), Complex Conjugates, Complex Plane, Complex Conjugate Roots of Polynomials
SMu3t1	Complex Numbers	Modulus and Argument, Arithmetic ($\times$, $\div$, and z^n) in Polar Form, Convert between Polar and Cartesian Form, De Moivre's Theorem, Roots of Complex Numbers, Factorising Polynomials
SMu3t2	Functions II	Composition of Functions, One-to-One, Inverse Functions, Absolute Value Function, Rational Functions

SMu3t3	Vectors in $\mathbb{R}^3$	$a\mathbf{i} + b\mathbf{j} + c\mathbf{k}$ Notation, Equation for Spheres, Parameterised Vector Equations, Equations of Lines, the Cross Product, Equation for a Plane, Systems of Linear Equation (Elimination Method) and Geometric Interpretation of Solutions, Kinematics via Differentiation of Vector Equations, Projectile and Circular Motion
SMu4t1	Integration II	Substitution, $\int \frac{1}{x} dx = \ln\|x\| + c$ for $x \neq 0$, Inverse Trig Functions and their Derivitives, Integrate $\frac{\pm 1}{\sqrt{a^2-x^2}}$ and $\frac{a}{a^2+x^2}$, Partial Fractions, Integration by Parts, Volume of Solids of Revolution, Numerical Integration using Technology
SMu4t2	Differential Equations	Implicit Differentiation, First-Order Seperable Differential Equations, The Logistic Equation, Kinematics (Rates of Change)
SMu4t3	Inference	Central Limit Theorem and the Resulting Confidence Interval for a Mean

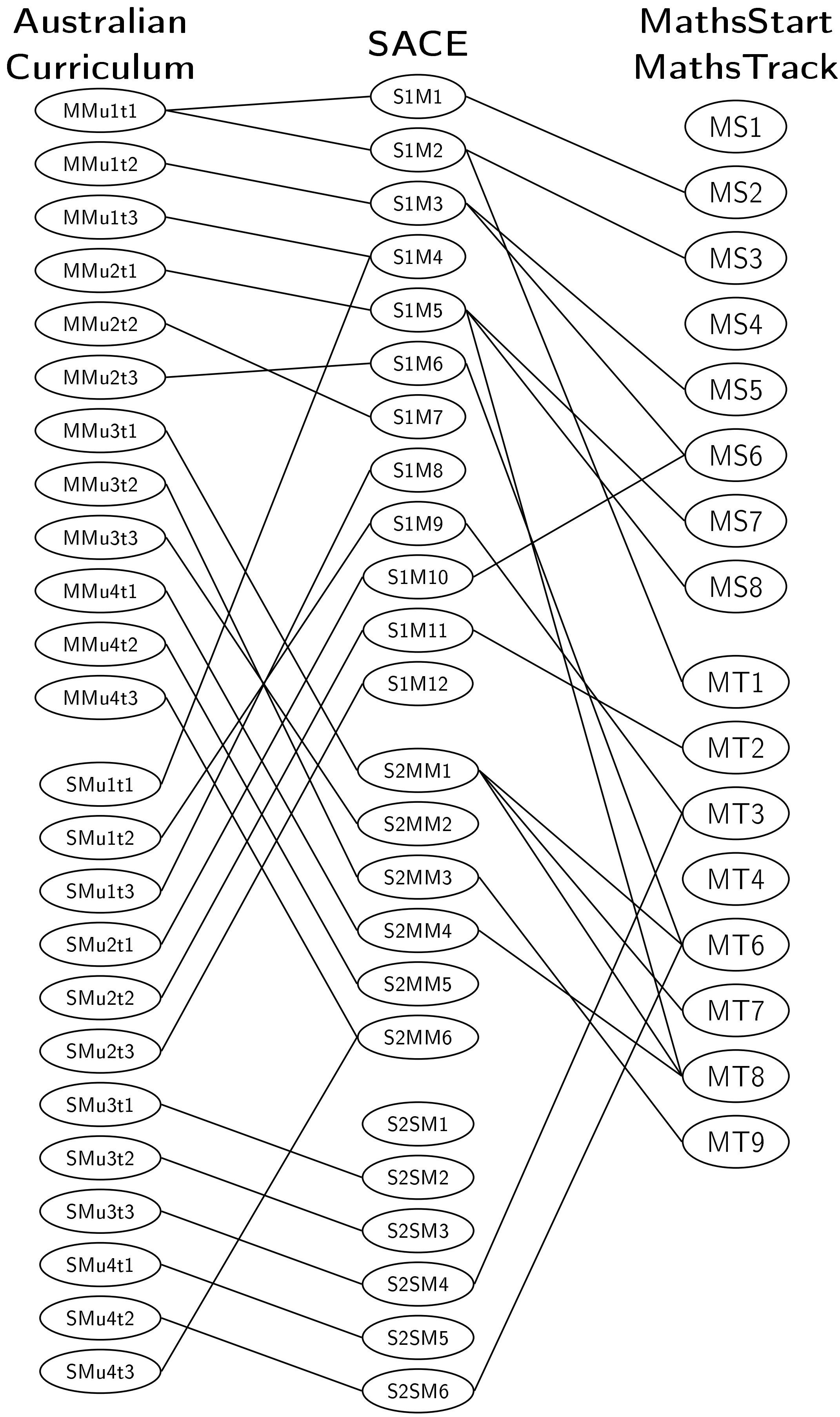

Figure 3.1: Curriculum Mapping

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Chapter 4

Moving Forward: Improvements

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Conclusions and Reccomendations

With respect to the bridging courses run through the university of adelaide's maths learning centre: MathsStart and MathsTrack,

- The self-paced and feedback focused approach to assessment is certainly the highlight of the programs, should be continued, encouraged, potentially further resourced, expanded, and reccomended to other bridging course facilitators.
- The role of bridging courses as what is often student's first experience at university implies that potentially students wellbeing and retention could be improved by structuring the programs to provide more opportunities for students to meet each other and work together: either in the maths learning center drop-in area, or a seperate area, but potentially assigning a certain time on a certain day perhaps weekly or fortnightly during which students are encouraged to come and work together, could allow them to make freinds, build social networks, and better aclimitise them to the university environment in order to better prepare them for success in their studies.
- The smallest but perhaps easiest to implement improvement could be to better align the course content with curriculum, both the highschool curriculum (AC/ SACE) in the case of students doing the bridging course to then comence study interstate or overseas, or with specific first year entry level courses, to better match the potential gaps in knowledge students may encounter.

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