Understanding and addressing mathematics anxiety using perspectives from education, psychology and neuroscience

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Acknowledgements

This work was supported by grant numbers DP120100750 (OVL) and SR120300015 from the Australian Research Council.

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Key words: mathematics anxiety, mathematics attitudes, mathematics achievement, neuroscience, cognitive psychology, intervention

Abstract

Mathematics anxiety is a significant barrier to mathematical learning. In this paper, we propose that state or on-task mathematics anxiety impacts on performance, while trait mathematics anxiety leads to the avoidance of courses and careers involving mathematics. We also demonstrate that integrating perspectives from education, psychology and neuroscience contributes to a greater understanding of mathematics anxiety in its state and trait forms. Research from cognitive psychology and neuroscience illustrates the effect of state mathematics anxiety on performance and research from cognitive, social, and clinical psychology and education can be used to conceptualise the origins of trait mathematics anxiety and its impact on avoidant behaviour. We also show that using this transdisciplinary framework to consider state and trait mathematics anxiety separately makes it possible to identify strategies to reduce the negative effects of mathematics anxiety. Implementation of these strategies among particularly vulnerable groups, such as preservice teachers, could be beneficial.

Mathematics anxiety (MA), feelings of unease and worry experienced when thinking about mathematics or completing mathematical tasks, has been widely studied because of its negative impact on mathematical learning (Richardson & Suinn, 1972). MA is characterised by both physiological (e.g. increased heart rate) and cognitive symptoms (e.g. negative thoughts) and is often considered one of the biggest obstacles to learning in the mathematics classroom (Baloğlu, 2003; Hembree, 1990). Neuroimaging studies have demonstrated that highly mathematics anxious individuals show more activation in neural regions associated with the detection and experience of pain (Lyons & Beilock, 2012). Interestingly, this pattern of brain activation was only observed in anticipation of a mathematics task and not during task completion. This finding corresponds with conceptualisations of anxiety in the achievement emotion literature that describe MA as an anticipatory emotion where failure is anticipated and control over this outcome seems unachievable (Pekrun, 2006). The purpose of this paper is to integrate research from multiple disciplines to illustrate the characteristics and effects of MA. We argue that using this integrated perspective allows for a better understanding of the experience of MA and of remediation approaches.

Feeling anxious about mathematics has been linked to avoidant behaviour, poor performance and test anxiety (Ashcraft & Ridley, 2005; Beasley, Long, & Natali, 2001; Ho et al., 2000; Kazelskis et al., 2000). In a study of Australian primary students, anxiety about mathematics was higher than literacy anxiety (Punaro & Reeve, 2012); self-reported MA was negatively associated with mathematics performance, yet there was no relationship between literacy anxiety and literacy performance. Some researchers suggest that MA occurs when an individual struggles with mathematics (Ashcraft & Kirk, 2001; Maloney, Schaeffer, & Beilock, 2013). Corroborating research reveals that poor achievement in mathematics is associated with the development of anxiety (Ma & Xu, 2004); students with severe numerical processing deficits (diagnosed with dyscalculia) also report high levels of anxiety (Rubinsten & Tannock, 2012). However, the idea that MA is merely an epiphenomenon of poor ability or low achievement is overly simplistic. Not all students who under achieve in mathematics feel anxious and some students who experience MA perform well on mathematics tasks.

Across the literature, MA has been conceptualised in different forms. For some researchers, MA is similar to a trait or an attitude (Frary & Ling, 1983; Leder & Forgasz, 2002; McLeod, 1994), whereas others regard anxiety as something that is elicited by mathematics tasks and which can influence subsequent performance (Ashcraft & Ridley, 2005; DeBellis & Goldin, 2006). Ainley (2006) argued that it is important to distinguish both affective traits and states in learning to acknowledge that they can have combinatory as well as independent roles in the learning process. In this paper, we argue that considering the state and trait forms of MA separately provides a better account of how MA impacts on learning. Specifically, we propose that state MA (or MA experienced on-task) can negatively affect performance while trait MA operates like an attitude, steering those who are anxious away from mathematics-related careers, courses, and opportunities.

Education, psychology, and neuroscience researchers have investigated state and trait effects of MA; however, it is rare for this research to be considered collectively. In this paper, we will demonstrate that integrating perspectives from these three fields contributes to a greater understanding of MA in its state and trait forms. Research from cognitive psychology and neuroscience illustrates the effect of state MA on performance and research from cognitive, social, and clinical psychology, and education can be used to conceptualise the origins of trait MA and its impact on avoidant behaviour. We will also establish that using this transdisciplinary framework to consider state and trait anxiety separately makes it possible to identify strategies to reduce the negative effects of MA.

STATE MATHEMATICS ANXIETY: INSIGHTS FROM COGNITIVE PSYCHOLOGY AND NEUROSCIENCE RESEARCH

The cognitive burden of state MA can disrupt performance on mathematics tasks (Ashcraft & Kirk, 2001; Devine, Fawcett, Szucs, & Dowker, 2012; Miller & Bichsel, 2004). Anxiety as a general emotion has been explained from a psychological perspective as a biologically adaptive, fight or flight response which prepares the body to act in threatening situations (LeDoux, 1996), therefore students with MA perceive mathematical situations as threatening. In cognitive psychology, attentional biases are identified as the mechanism that causes an anxious individual to be hyper vigilant to stimuli perceived as threatening and help to maintain anxiety over time (Bishop, 2007; Hofmann, Ellard, & Siegle, 2012).

Research describing the role of the fight-or-flight response and attentional biases in anxiety has been integrated with neuroscience research. In particular, attentional biases towards threat-related information, activated shortly after stimuli are presented, are associated with a particular pattern of brain activation. Bishop (2007) reviewed numerous neuroimaging studies to show that these biases towards threatening information are linked to hyperactivity in the amygdala (a part of the brain thought to be involved in processing negative emotions) and reduced activation of the prefrontal cortex (a part of the brain involved in emotion regulation). Young, Wu and Menon (2012), for example, found that activation in the amygdala and deactivation in parts of the prefrontal cortex associated with the regulation of emotion (the ventromedial prefrontal cortex) were greater among seven-to nine-year-old children with high

MA than among children with low MA. Interestingly, Young et al. (2012) also found that children in the high MA group had greater connectivity between the amygdala and the ventromedial prefrontal cortex. They noted that the brain activation pattern and connectivity identified in the high MA group was similar to that seen in individuals with specific phobias, or clinically persistent fears highlighting the similarity of MA and anxiety encountered in clinical settings.. Furthermore, the capacity of individuals with MA to engage strategies to control this anxiety is inhibited.

Neuroscience research has revealed other factors influencing state MA's impact on performance. Lyons and Beilock (2012) studied brain activation patterns of individuals with high MA. They found that those who showed more activation in a network of the inferior fronto-parietal region of the brain before starting a mathematics task performed better on these tasks. Research has linked this neural region to reappraisal, which is a form of emotion regulation that involves transforming the emotional impact of a situation by changing how the situation is perceived (Brooks, 2014). Lyons and Beilock (2012) proposed that the brain activation patterns of high performing individuals with MA observed in their study suggested that these individuals reappraised their anxiety when anticipating the mathematics task, thereby reducing or eliminating the negative influence of anxiety on performance. Neuroimaging studies investigating successful reappraisal of negative emotions show a balance of amygdala-prefrontal circuitry that is opposite to that seen in conjunction with anxiety (i.e. decreased activity in the amygdala and increased activity in the prefrontal cortex; Bishop, 2007). These findings provide a rationale for teaching emotion regulation strategies to individuals with MA to enable them to reappraise their anxiety (Maloney & Beilock, 2012; Maloney, Sattizahn, & Beilock, 2014; Maloney et al., 2013).

Cognitive psychology and neuroscience studies have also shown that anxiety can have a direct or on-task effect on performance, with research identifying the mechanisms that allow MA to have this impact. Maloney, Sattizahn, and Beilock (2014) argue that MA can affect performance in two ways. Firstly, the interpretation of the physiological responses elicited by situations perceived as threatening (e.g. increased heart rate and respiratory rate) draws on parts of the brain that are involved in problem-solving (i.e. the dorso lateral prefrontal cortex). Therefore, these resources cannot be used to complete mathematics tasks and performance suffers. Secondly, Maloney et al. (2014) describe how anxiety can impact on working memory, which is crucial for problem-solving. This second route linking anxiety and performance relates to a model of on-line MA proposed by Ashcraft and Kirk (2001). In this model, invasive, negative thoughts experienced as part of MA interrupt cognitive functioning by obstructing working memory processes. Several studies support Ashcraft and Kirk's model of the effects of MA on working memory (e.g. Beilock, Kulp, Holt, & Carr, 2004; Hopko, McNeil, Gleason, & Rabalais, 2002). Yet, the relationship between state MA, or on-task MA, and performance may be more complex than Ashcraft and Kirk's model suggests. Students' perceived competence in mathematics can affect the degree to which task irrelevant thoughts interfere with performance (Van Yperen, 2007). Working memory capacity can also influence MA's impact on performance; however, the research on this relationship is less clear. Some studies have demonstrated a greater impact of anxiety on performance for those, particularly children, with higher working memory capacity (Beilock et al., 2004; Ramirez, Gunderson, Levine, & Beilock, 2013; Vukovic, Kieffer, Bailey, & Harari, 2013). In contrast, Miller and Bichsel (2004) found that adults with high MA and higher working memory capacity performed better than those with lower capacity.

In this paper, we propose that state and trait MA have different consequences for students' mathematics development. This section of the paper has presented research from neuroscience and cognitive psychology to demonstrate the state effects of MA on performance. In discussing this research an important caveat must be made. The majority of research on MA, including that presented in this section of our paper on the effects of state MA, has measured only trait MA (Suárez-Pellicioni, Núñez-Peña, & Colomé, 2016). In other words, this research has assessed MA by asking participants to assess how anxious they would be in different hypothetical situations involving mathematics. Measurement of state MA would require participants to provide ratings of anxiety while they complete a mathematics task, which has rarely been undertaken in published studies (e.g. Bieg, Goetz, Wolter, & Hall, 2015; Goetz, Bieg, Lüdtke, Pekrun, & Hall, 2013). While the research provided here to support our assertion of the impact of state MA has been based on trait MA measurement, we would argue that these studies still support our proposals. This is because these studies measure trait MA in addition to monitoring state-based reactions to mathematical tasks. Future research that measures both trait and state MA would provide increased support for our proposal of the differential impact of each type of MA. However, neuroscience and cognitive psychology research investigating high MA participants' on-task or state-based reactions during completion of mathematical tasks provides support for the assertion that state MA directly impacts on performance.

TRAIT MATHEMATICS ANXIETY: INSIGHTS FROM COGNITIVE, SOCIAL, AND CLINICAL PSYCHOLOGY, AND EDUCATION RESEARCH

State MA, or the fear felt on-task or in the moment when an individual is presented with mathematical information, contrasts with trait MA, which is a stable, well-developed negative attitude or concern regarding mathematics that leads to avoidance of mathematics and mathematics careers. The cognitive difference between state and trait MA can be explained by considering the role of attentional biases and the cognitive structures that underpin them. We described earlier how the activation of attentional biases in state MA causes individuals to be hyper vigilant to threatening stimuli and can result in a pattern of brain activity associated with a decreased capacity to regulate fear (Bishop, 2007). Underlying and triggering these attentional biases are enduring, cognitive structures, sometimes thought of as belief systems, which are used to interpret stimuli (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & Van Ijzendoorn, 2007). In cases of clinical anxiety and phobias, these structures or schemata can be maladaptive and based on a set of false assumptions about the world (Wong, 2008). Izard (2007) proposed that emotion schemata are "complex emotion-cognition-action systems" (p. 265). Schemata are shaped by cultural factors and prior experience, are activated during situation appraisals and are fundamental to emotional regulation (Barrett, Mesquita, Ochsner, & Gross, 2007). Given that mathematics is often perceived negatively in the community (Wilkins, 2000), it is likely that cultural and social expectations are significant factors associated with the development of mathematics–related emotion schemata. Understanding how these negative beliefs or attitudes develop is therefore important when describing the aetiology of trait MA.

Whereas cognitive psychology and neuroscience provide a way to study state MA and the mechanisms by which anxiety impacts performance, the development of trait MA and negative beliefs and attitudes about mathematics can be explained using research from education and social psychology. According to Cemen (1987), dispositional, environmental, and situational forces lead to MA. Situational forces underlie the experience of state MA, whereas environmental factors are external to the individual and relate to the influence of parents, teachers, and the wider social context. Dispositional factors, such as personality, are internal to the individual. For instance, MA had been linked to perfectionism, which is sometimes considered as the extreme of conscientiousness (Walsh & Ugumba-Agwunobi, 2002). In this paper, we focus primarily on the role of environmental factors in the development of trait MA and associated negative attitudes and beliefs about mathematics. However, before discussing some examples of these influences, specifically parents and teachers, the relationship between gender and mathematics will be considered from both dispositional and environmental perspectives.

Gender and mathematics is a well-researched topic with a complex history (Fennema, 2002). Early studies in the area attributed the 'male advantage' in mathematics to biological differences (e.g. Benbow & Stanley, 1980). Later research suggested that socialisation is the key determinant of gender differences in mathematics (Ben-Zeev, Duncan, & Forbes, 2005; Geary, 1999). Eccles' expectancy-value model of achievement (Eccles, Adler, & Meece, 1984; Eccles & Wigfield, 2002) is a prominent theory describing the impact of social factors on achievement. She proposed that socialisation processes influence achievement through their effect on students' values, competence beliefs and emotions, such as MA. Stereotype threat research also addresses gender differences in mathematics and MA. Stereotype threat occurs when stereotypes are activated (e.g. regarding females and mathematics) and negatively impact on the individual (e.g. resulting in lower mathematics performance for females) (O'Brien & Crandall, 2003; Schmader, Johns, & Forbes, 2008). Negative stereotypes include notions that females are not mathematically able and that mathematics is not a feminine activity (Richardson & Woolfolk, 1980). Good, Rattan, and Dweck (2012) found that female college students with higher MA had a lower sense of belonging in mathematics. Furthermore, those who believed that females are less capable in mathematics and that mathematics ability is fixed had a lower sense of belonging in mathematics than male students. Good et al. (2012) argue that the notion of mathematics ability as fixed is one that is pervasive in Western culture, and one that can "undermine achievement in the face of difficulty" (p. 701). This type of maladaptive belief can contribute to the development of MA.

Research findings suggest that the relationship between gender, mathematics and MA is not straightforward. Several studies have found that females report higher levels of MA (e.g. Devine et al., 2012; Frenzel, Pekrun, & Goetz, 2007; Hembree, 1990), whereas others have found no gender differences (Kazelskis et al., 2000; Tapia & Marsh, 2004). Zettle and Raines (2000) found female college students were more likely to have high levels of MA in conjunction with high test anxiety, while male students who experienced MA were more likely to have high levels of general trait anxiety. In a longitudinal investigation of attitudes and anxiety for students over the six years of secondary school, Ma and Cartwright (2003) observed gender differences only for MA, with the rate of anxiety for female students increasing significantly faster over time than that of male students. More recently, findings from the Programme of International Student Assessment (PISA) (Thomson, De Bortoli, & Buckley, 2013) showed that 15-year-old females in Australia reported higher levels of MA than males. On the other hand, several studies by Goetz and colleagues found that girls report higher levels of trait MA but found no gender differences in levels of state MA (Bieg et al., 2015; Goetz et al., 2013). Regardless of the relationship between gender and anxiety, evidence of gender differences in avoidance that would be the expected consequence of trait MA can be seen in enrolments of female students in senior subjects involving mathematics, which are declining at a faster rate than those of male students (Mack & Walsh, 2013).

The influence of parents and teachers has also been investigated as a significant environmental factor in the development of MA and negative attitudes and beliefs about mathematics. Parental perceptions, particularly those of mothers, are related to children's competence beliefs in mathematics, their future career choices and their susceptibility to the negative effects of stereotype threat (Bleeker & Jacobs, 2004; Jacobs, 1991; Tomasetto, Alparone, & Cadinu, 2011). Research has shown that teachers who report higher levels of MA are less confident about their mathematics teaching, are more likely to teach mathematics at a surface level, and to use less effective teaching methods (Brush, 1981; Gresham, 2009; Trujillo & Hadfield, 1999). Although such research has not established that MA causes these behavioural and psychological characteristics in teachers, their co-occurrence is concerning and warrants further investigation. Some of the more troubling findings in relation to teachers and MA have emerged from research with primary or elementary school teachers. Hembree (1990) found high levels of MA in preservice primary teachers, while other research showed that highly anxious female primary teachers were more likely to have students with lower achievement and negative gender stereotypes about mathematics (Beilock, Gunderson, Ramirez, & Levine, 2010). Recent reviews of research in mathematics education have concluded that there is worldwide concern about MA in preservice primary school teachers (Philipp, 2007). Within this body of literature, fear of failure, general test anxiety, and prior experiences of learning mathematics at school that emphasise "right answers and right methods instead of on developing ways of reasoning about mathematics" (Philipp, 2007, p. 299) were identified as causes of MA. Findings such as these have prompted calls for interventions targeted at preservice teachers that are designed to reduce levels of MA (Maloney et al., 2014).

STATE AND TRAIT-BASED STRATEGIES TO ALLEVIATE MATHEMATICS ANXIETY

Given the well-documented impact of MA on performance and in avoidance of mathematics, identifying effective methods of remediation is important. Individual approaches to addressing MA in either its state or trait form are typically advocated. The majority of these approaches target state rather than trait MA, which may help individuals deal with anxiety when they must (e.g. during compulsory mathematics subjects) but are not as effective at addressing the underlying, enduring beliefs that contribute to trait MA and lead to avoidance of mathematical situations. In the following section of the paper, we discuss a range of approaches that are drawn from clinical psychology and education to demonstrate how an integrated approach can be effective.

Maloney et al. (2014) suggest strategies to target the physiological responses to and cognitive consequences of state MA on performance. To address the increased physiological arousal associated with state MA, relaxation techniques can be effective. Muscle tension is synonymous with stress and anxiety and relaxation techniques that involve teaching individuals to control muscle tension by learning to tense and release specific muscle groups can alleviate it (Conrad & Roth, 2007). Research has also demonstrated that reductions in autonomic nervous system arousal, which causes increased heart rate and sweating and decreased skin temperature, are evident with relaxation practice (Yahav & Cohen, 2008). Relaxation practice also has demonstrable effects on MA and mathematics performance. Bander, Russell and Zamostny (1982) showed that cue-controlled relaxation (progressive muscle relaxation in conjunction with a relaxed state cue word *calm*) was more effective at a delayed follow-up in reducing MA and improving mathematics performance than study skills training.

Mindfulness meditation is another approach that has significant potential in addressing the physiological arousal associated with state MA. Mindfulness depicts a psychological state of paying attention to experiences in the moment using an open and non-critical approach (Chiesa, Calati, & Serretti, 2011). Mindfulness is thought to work by reducing the resources devoted to processing negative stimuli which can be directed to other cognitive tasks. Simple mindful breathing exercises utilise sustained attention to breathing and cognitive control to redirect attention back to the focused breathing should attention wander (Moore, Gruber, Derose, & Malinowski, 2012). Even brief interventions are effective in increasing attention, improving mood, improving reaction time, and reducing stress (Tang et al., 2007; Zeidan, Johnson, Diamond, David, & Goolkasian, 2010). Mindfulness training shows benefits in reducing the physiological stress responses elicited by mathematics tasks (Tang et al., 2007) and in improving performance on mathematics tasks for individuals with high MA (Brunyé et al., 2013)

Cognitive reappraisal is another strategy proposed by Maloney et al. (2014) that can target both the physiological symptoms of state MA and the worry or negative thoughts that are the cognitive consequence of state MA. Reappraisal involves changing the way in which an anxiety-provoking situation is perceived in order to reduce its emotional impact (Gross & John, 2003). Previous work has highlighted the positive effects of reappraisal on subjective perceptions of anxiety, in regulating physiological arousal in the moment and in reducing the effects of anxiety in the long-term (Goldfried, Linehan, & Smith, 1978; Hofmann, Heering, Sawyer, & Asnaani, 2009; Shiota & Levenson, 2012). Reappraisal of a stressful task as a challenge, rather than as a threat, and of increased physiological arousal as a performance facilitator has a positive impact on achievement (Jamieson, Mendes, Blackstock, & Schmader, 2010). Brooks (2014) asked participants to reappraise their anxiety as excitement by acknowledging that although the valence of the two emotions is different (negative versus positive) the physiological symptoms of both are similar. This research found that reappraisal had a positive impact on performance and had greater benefits than attempting to suppress anxiety. Further evidence for the efficacy of reappraisal in addressing state MA was presented earlier in relation to Lyon and Beilock's (2012) study wherein higher performing individuals with MA showed increased activation in the part of the brain associated with emotion reappraisal prior to completing a mathematics task.

Other techniques outlined by Maloney et al. (2014) and others to combat the negative thoughts associated with MA include bibliotherapy, or the act of reading about and identifying with characters experiencing similar difficulties as a means of identifying difficulties and strategies to address them (Furner, 2004), and expressive writing, or the process of writing about the emotions experienced before a stressful task (Maloney et al., 2014). Such interventions have been used in preservice teacher education programs to address negative emotional responses to mathematics. Wilson and Thornton (2007/2008) used bibliotherapy techniques with preservice primary teachers in a course that focused on mathematics and learning difficulties. Course readings gave an overview of mathematics learning difficulties experienced by children in mainstream classrooms, and participants were asked to describe and reflect on positive or negative critical incidents in their own school mathematics education. Systematic reflection enabled participants to reassess their beliefs and emotions and develop enhanced self-images of themselves as teachers of mathematics and in this way address aspects of trait MA. These readily implemented interventions show promise as a means of reducing the effect of state MA on performance (Park, Ramirez, & Beilock, 2014; Ramirez & Beilock, 2011)

In addition to these educational strategies, cognitive-behavioural approaches from clinical psychology can be used to alleviate state MA and more specifically trait MA by targeting the thoughts, beliefs, and attitudes that contribute to their development. Targeting maladaptive beliefs (e.g. “my maths ability is fixed”, “girls aren’t as gifted at maths”), one of the key facilitators of trait MA, and negative thoughts or worry (e.g. “I’m never going to understand this”) by drawing on principles from cognitive behaviour therapy and schema therapy that are used to treat clinical anxiety (including phobias) may be beneficial (Gregor, 2005; Hembree, 1988). Identifying and challenging negative thinking and beliefs about mathematics and learning to express positive thoughts, can promote constructive feelings and behaviours. Counterproductive behaviours (such as avoidance and procrastination) can be challenged and positive behaviours encouraged (e.g. regular exposure to mathematics tasks to reduce anxiety). Cognitive-behavioural approaches have some evidence of effectiveness in reducing MA and improving test performance (particularly if combined with relaxation techniques) (Gregor, 2005; Zettle, 2003).

CONCLUSION AND DIRECTIONS FOR THE FUTURE

MA is a significant barrier to mathematical learning. We propose that in its state or on-task form, MA has a direct impact on performance, while trait MA leads to the avoidance of courses and careers involving mathematics. In this paper, we have adopted a transdisciplinary perspective to show that cognitive psychology and neuroscience research can illustrate the experience of state MA and the mechanisms by which it can negatively affect performance. Furthermore, we have demonstrated that research from cognitive, social, and clinical psychology and from education can describe the development of trait MA and associated negative attitudes and beliefs about mathematics. The transdiciplinary approach was extended to consider strategies that might reduce state and trait MA, with evidence suggesting techniques such as relaxation, mindfulness, cognitive reappraisal, and cognitive-behavioural approaches may be effective (Hembree, 1990; Maloney et al., 2014; Philipp, 2007).

One group that could benefit from these MA intervention strategies are preservice teachers. Early remediation of MA with this group is likely to have significant benefits both for individual teachers and their future colleagues and students who may experience MA. During teacher training, exposure to mathematics education courses acts as an intervention. Several studies have demonstrated that MA decreases after undertaking mathematics courses during initial teacher education (see for instance Gresham, 2007; Sloan, 2010; Vinson, 2001). Learning to teach mathematics during preservice teacher training seems to reduce MA through facilitating conceptual understanding of mathematics (often via teaching through the use of manipulatives) (Sloan, 2010) . By improving skills in mathematics, preservice teachers express greater confidence in their teaching efficacy and more positive attitudes towards mathematics (Bursal & Paznokas, 2006; Sloan, 2010). High MA is, however, still evident among some practising teachers (Beilock et al., 2010), thus the impact on MA of formal training in a supported university context may be relatively short-term. More long-term benefits may be gained by supplementing the skill-based approach utilised in preservice teacher education programs with the strategies outlined in this paper. These strategies align with the framework of this paper; that is, they are selected based on a transdisciplinary understanding of MA (drawn from education, psychology and neuroscience), and acknowledge both the state and trait components of MA.

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