

Mathematics Anxiety and Metacognitive Processes: Proposal for a New Line of Inquiry

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Abstract

This paper presents a proposal for a new area of investigation that connects the metacognition literature, and especially the recently developed meta-reasoning framework, with research into mathematical reasoning, mathematics learning, and mathematics anxiety. Whereas the literature on mathematics anxiety focusses on the end result of learning and problem-solving, the metacognitive approach can offer further insight by a fine-grained analysis of the stages of these processes. In particular, it provides tools for exposing students' initial assessment of tasks and test situations, the targets they set for themselves, the process of monitoring progress, and decisions to stick with or abandon a particular solution. The paper outlines various ways in which the metacognitive approach could be used to investigate the effects of mathematics anxiety on mathematics learning and problem solving. This approach could help in answering questions like: Do anxious and non-anxious learners differ in how they prepare for an exam? Are anxious students more or less prone to overconfidence than non-anxious students? What metacognitive decisions mediate maths anxious participants' tendency to give up on problems too early? Additionally, this line of work has the potential to significantly expand the scope of metacognitive investigations and provide novel insights into individual differences in the metacognitive regulation of learning and problem solving. It could also offer some practical benefits by focusing the attention of educational designers on particular components within the learning process of anxious students.

Keywords: confidence, Diminishing Criterion Model, learning, meta-reasoning, mathematics anxiety, problem solving

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Introduction

The aim of this paper is to make a proposal to combine two areas of inquiry: research into metacognition and mathematics anxiety (MA). Whereas to date, these two areas of research have developed independently, in the current paper, we argue that creating links between these topics could lead to important new insights that would enrich both fields. Indications for some metacognition-relevant processes can be found in the literature, such as avoidance behaviours (e.g., Ashcraft & Faust, 1994) and the association between MA and low confidence in maths ability (see Hembree, 1990 for a meta-analysis). However, research into MA would benefit from a better understanding of how metacognitive processes might mediate the effects of mathematics anxiety on mathematics problem solving and learning.

Metacognitive processes that are implicated in learning and problem-solving include decisions to search for alternative solutions, to settle for an answer, to give up trying to find a solution, the regulation of effort and time allocation, and avoidance behaviours. Research into metacognitive processes offers well-established models of the monitoring and control of learning and problem-solving behaviour, but this line of research has traditionally focussed on memory tasks (Bjork, Dunlosky, & Kornell, 2013). Only recently, Ackerman and Thompson (2015, 2017a, 2017b) put forward a metacognitive framework for delving into effort regulation in the context of reasoning and problem-solving. Whereas some of these investigations included tasks with a mathematical content, mathematical reasoning and problem solving have not been systematically studied using a metacognitive approach. An additional reason why research into MA specifically could be relevant is that the main focus of this literature is on individual differences, while in the meta-reasoning research domain individual differences have not been extensively investigated.

Whereas the literature on MA focusses on the end result of learning and problem-solving processes (i.e., whether a solution is correct or incorrect and the overall time spent on the task), the metacognitive approach can offer further insight by a closer look at the processes of learning and problem solving, and breaking them down to their components: students' initial assessment of tasks and test situations, the targets they set for themselves, the process of monitoring progress, and decisions to stick with or abandon a particular solution, help-seeking. Based on our current knowledge, these processes might differ between maths anxious and non-anxious students.

This paper presents a brief review of the literatures on MA and metacognitive processes, highlighting some gaps in our current understanding. This is followed by suggestions on how creating links between the two research areas could help in answering some long-standing questions.

Mathematics Anxiety

Mathematics anxiety is commonly described as a feeling of tension, apprehension, or fear that interferes with performance on maths tasks (Ashcraft, 2002). It is well-established that there is a moderate negative relationship between MA and maths performance (a correlation of around $-.30$; see Hembree, 1990 and Ma, 1999 for meta-analyses). The concept of MA has existed since the late 1950s when Dreger and Aiken (1957) investigated the topic of 'number anxiety', showing it was distinct and separate from general anxiety.

Several studies have investigated the relationship between MA, test anxiety, and general anxiety. Results have shown that measures of MA correlate with measures of test anxiety ($.30$ to $.50$) and general anxiety ($.35$; see Dowker, Sarkar, & Looi, 2016 for a review). However, studies have also delineated MA as a specific and distinct form of anxiety (Ashcraft & Ridley, 2005; Dew, Galassi, & Galassi, 1984; Dreger & Aiken, 1957; Hembree, 1990), as measures of MA correlate more highly with each other, at $.50$ to $.80$ than with test- or general anxiety measures (Ashcraft, 2002; Dew & Galassi, 1983). Moreover, MA remains correlated with maths performance, after controlling for the effects of test- and general anxiety (Dew & Galassi, 1983; Hembree, 1990).

Whereas MA has been traditionally investigated in educational contexts, recent studies have demonstrated that it can also affect people who are no longer in formal education (e.g., Rolison, Morsanyi, & O'Connor, 2016), including older adults (Abrams, Crisp, Marques, Fagg, Bedford, & Provias, 2008). Moreover, MA has been linked to a reduced ability to make rational decisions, including poorer performance on the cognitive reflection test (Morsanyi, Busdraghi, & Primi, 2014; Primi, Donati, Chiesi, & Morsanyi, 2018; Primi, Morsanyi, Chiesi, Donati, & Hamilton, 2016), and poorer decision making on the basis of medical risk information (Rolison et al., 2016; Silk & Parrott, 2014).

The Causal Relationship between MA and Maths Performance

MA research has established a robust (although not too strong) negative association between the experience of MA and maths performance. Research shows that MA is linked to relatively low achievement in maths tests (e.g., Ashcraft, 2002; Hembree, 1990; Ho et al., 2000; Miller & Bichsel, 2004), although some individuals with high levels of MA can still perform at a normal level (Carey, Devine, Hill, & Szücs, 2017). While this association is well-known, the direction or the causal nature of this relationship is not fully understood.

Studies have typically focused on the potential of MA to disrupt maths performance (e.g., Ashcraft & Kirk, 2001; Ashcraft & Krause, 2007; Maloney, Schaeffer, & Beilock, 2013). Specifically, these authors attribute the effect of MA on maths performance to the working memory-load imposed by intrusive, anxious thoughts and ruminations. Converging evidence points to the role of verbal (rather

than visual-spatial) working memory in the effects of anxiety (e.g., Ashcraft & Kirk, 2001; Beilock & Carr, 2005; Owens, Stevenson, Norgate, & Hadwin, 2008). This line of work also established that performance differences between participants with low and high levels of MA are more pronounced in the case of complex, as compared to simple tasks (i.e., the effect of MA depends on the working memory demand of tasks). Another typical effect of mathematics anxiety is the feeling that the person's mind goes blank, and that they are unable to think clearly (Fennema & Sherman, 1976), which might also be a consequence of working memory overload.

Research has also demonstrated that experiencing MA leads to avoidance behaviours, which, in the long run, are detrimental to maths learning and mastery. Nevertheless, some of these behaviours can also have immediate effects on performance on examinations and in learning contexts. Local avoidance occurs when a maths task is undertaken and a participant rushes through the questions, increasing speed while reducing accuracy in order to finish the tasks faster, and escape the anxiety-inducing situation (Ashcraft & Faust, 1994; Faust, Ashcraft, & Fleck, 1996; Morsanyi et al., 2014).

Global avoidance entails actively avoiding mathematics in classrooms, neglecting to choose maths-oriented college courses, skipping classes and avoiding careers which could involve mathematics. This can lead to a lack of mastery through lack of knowledge and practice, as well as unnecessarily reduced career opportunities and earning potential. Lack of practice in maths anxious individuals can also lead to lower fluency in carrying out simple, routine procedures (Dietrich, Huber, Moeller, & Klein, 2015; Maloney, Ansari, & Fugelsang, 2011; Maloney, Risko, Ansari, & Fugelsang, 2010; Núñez-Peña & Suárez-Pellicioni, 2014). The lack of fluency in itself can also lead to increased working memory load (and increased chances of error) when carrying out multi-step procedures, as lower fluency means that componential answers have to be kept in mind for a longer time.

A phenomenon that might be related to avoidance is a tendency for maths anxious individuals to rely on simple shortcuts and heuristics that might lead to incorrect solutions. This tendency has been first investigated by Beilock and DeCaro (2007) who experimentally manipulated their participants' anxiety level. These researchers found that anxious participants were more likely to rely on simple strategies when they solved multi-step problems. Further evidence comes from studies that investigated the relationship between MA and performance on the cognitive reflection test (Morsanyi et al., 2014; Primi et al., 2016, 2018). The cognitive reflection test consists of misleading open-ended problems with a maths content, where there is a tendency for people to produce a typical incorrect response instead of the correct solution. This series of studies have revealed that highly maths anxious participants showed a stronger tendency to produce these incorrect responses than participants with lower maths anxiety, even when their levels of numeracy and test anxiety were taken into account. These findings suggest that the tendency to produce heuristic responses to such misleading problems was not simply a result of

lower levels of numeracy, but it was specifically related to being anxious about maths.

With regard to the causal links between MA and maths performance, the above findings lend support to the debilitating anxiety model (cf., Carey et al., 2016), whereby MA disrupts the processing and retrieval of information, which then leads to poor performance. Nevertheless, an alternative proposal, which has been termed the deficit theory, posits that poor performance history in maths leads to MA (e.g., Ashcraft & Moore, 2009). Carey et al. (2016) argued that neither of these theories alone could give a full picture of the complex relationships between anxiety and performance. Instead, Carey and colleagues believe that a reciprocal relationship is at play: poor maths performance could lead to MA in some people, while MA further reduces their performance in a vicious cycle. Ashcraft and Krause (2007) have proposed that once MA is established, it causes further performance deficits through working memory overload, which, in turn, perpetuates performance deficits, in line with the reciprocal theory (see also Luo et al., 2014 and Pekrun, 2006 for evidence for reciprocal relationships).

In summary, whereas there is undisputed evidence for a link between MA and maths performance, the exact mechanisms through which MA affects maths performance, and vice versa, are not fully understood. To complicate the picture further, there are also some other constructs, including maths-related attitudes and confidence, which might mediate the links between anxiety and performance. We discuss these in the next section.

The Links between MA, Maths-Related Confidence, and Attitudes towards Maths

A large body of research has focussed on the relationship between MA and maths-related confidence or self-efficacy. Bandura (1986, p. 391) has defined self-efficacy as "people's judgments of their capabilities to organize and execute courses of action required to attain designated types of performances". Self-efficacy has been found to strongly influence the choices people make, the effort they expend, and their tendency to persevere in challenging situations (cf., Pajares & Miller, 1994). Given its close links with effort-regulation and judgments regarding one's ability to successfully solve problems, self-efficacy is a concept that is also related to metacognitive monitoring and regulation, which we discuss later.

It is important to highlight that although the concept of self-efficacy has been used in a general sense to refer to people's beliefs about, and confidence in their ability to perform certain types of tasks (e.g., the concept of maths self-efficacy has been used to refer to people's general beliefs about their maths ability), Bandura's original conceptualisation of self-efficacy referred to feelings about performing a particular task at hand that a person was engaged in at that specific moment (Bandura, 1982). In other words, a person can be highly confident in their ability to deal with a certain type of maths task, but this does not necessarily mean that they would feel

equally capable of performing another maths task from a different maths domain. Thus, in this original conceptualisation, self-efficacy is context-specific.

Going back to the literature on maths-related feelings, the term confidence is typically used to refer to a person's confidence in their maths ability in general and is typically assessed by asking general questions about one's perceived ability to solve maths tasks (e.g., Hackett, 1985). General confidence has been found to show moderate to strong correlations with maths problem solving and course performance (e.g., Hackett & Betz, 1989). Moreover, in his meta-analysis, Hembree (1990) reported a strong negative correlation between MA and general confidence ($-.82$ for school-age pupils and $-.65$ in college students). Subsequently, many studies have proposed that high MA is synonymous with low general confidence (Ashcraft, 2002; Dowker et al., 2016; Hembree, 1990; Necka, Sokolowski, & Lyons, 2015).

Some studies also identified general confidence as a precursor of MA. Hembree (1990) reported that cognitive treatments aimed at restructuring flawed beliefs and low confidence produced moderate reductions in MA and moderate increases in maths test performance. Bandura (1986) explained the relationship between confidence and MA by proposing that it is only when people cannot predict or exercise control over events that they have reason to fear them. That is, people with high self-confidence see challenging situations as less threatening, and, consequently, experience less anxiety than people with low self-confidence.

A final concept that is closely related to MA and maths performance, is attitudes towards mathematics (Adams & Holcomb, 1986; including attitudes regarding success in maths, the usefulness of maths, teachers and maths problem solving). Hembree (1990) reported medium to strong correlations between maths anxiety and maths-related attitudes. Recent studies showed evidence of negative attitudes towards mathematics (including hatred, feeling sick, wanting to cry and frustration) as early as the first years of primary school (Larkin & Jorgensen, 2016; Ramirez, Gunderson, Levine, & Beilock, 2013; Wu, Amin, Barth, Malcarne, & Menon, 2012).

As we described above, it has been proposed that maths-related general confidence might be a (causal) precursor of MA. By contrast, attitudes are generally considered to emerge in response to previous experiences. On this basis, they might be thought of as a consequence of experiences with maths, rather than causal determinants. Nevertheless, once they have developed, they are considered to be relatively stable (cf., McLeod, 1992), which means that they might determine how students approach new maths-related content and learning situations.

Overall, as our review on the literature on MA and various related constructs demonstrate, there are long-standing, well-established findings regarding the relationship between MA, maths performance, and related metacognitive constructs. These relationships have been reliably found in adult samples and tend to be of medium strength. Nevertheless, we know very little about how these constructs interact with each other in the context of real-life learning and test situations. This is

a major gap in our knowledge, as understanding causal relationships is necessary for developing effective educational interventions.

MA and Learning Processes

Another important gap in the maths anxiety literature relates to the way in which MA might affect learning processes, especially learning outside the classroom context. Earlier, we described the concept of global avoidance whereby individuals actively avoid opportunities to practice maths and to learn about it at a high level, which can reduce familiarity with relevant concepts, as well as the ability to perform mathematical procedures quickly and easily.

Another question related to learning, which has already been touched on by earlier studies, is how learning in the classroom might be affected by MA. One of the most commonly used scales to measure MA, the Abbreviated Math Anxiety Scale (AMAS; Hopko, Mahadevan, Bare, & Hunt, 2003), consists of two subscales: *learning maths anxiety* and *maths evaluation anxiety*. The former refers to typical classroom situations where mathematical content is presented (e.g., listening to a lecture in maths class; starting a new chapter in a maths book), whereas the latter refers to test situations (e.g., thinking about an upcoming maths test a day before; taking an examination in a maths course). Hopko et al. (2003) reported that the two subscales were strongly correlated, and that they also showed similar correlations with state and trait anxiety, fear of negative evaluation and computer anxiety. However, maths evaluation anxiety was more strongly related to test anxiety and general anxiety than learning maths anxiety. A very similar pattern of results was reported by Primi, Busdraghi, Tomasetto, Morsanyi, and Chiesi (2014), who additionally found that both subscales correlated at a similar level with mathematics-related attitudes. Given these findings, it is unsurprising that most papers that use the AMAS do not consider the results for the two subscales separately.

A further scale that provides interesting information about the relationship between subject-specific anxiety and classroom learning is the Statistical Anxiety Rating Scale (STARS; Cruise, Cash, & Bolton, 1985). The STARS consists of six subscales: worth of statistics (e.g., I don't see why I have to fill my head with statistics. It will have no use in my career.); interpretation anxiety (e.g., making an objective decision based on empirical data); test and class anxiety (e.g., studying for an examination in a statistics course); computational self-concept (I don't have enough brains to get through statistics.); fear of asking for help (e.g., asking one of my teachers for help in understanding a printout); and fear of statistics teachers (e.g., Statistics teachers speak a different language.). These subscales not only measure anxiety, but also attitudes, confidence, self-concept, and decisions to seek help (which can be considered a metacognitive control process, see below). The correlations between the subscales of the STARS range from moderate to strong. With regard to asking for help, this subscale has been shown to relate particularly

strongly (correlations between .50 - .60) to interpretation anxiety, test and class anxiety, as well as to fear of statistics teachers (e.g., Baloğlu, 2003).

Apart from these limited findings regarding anxiety and learning behaviour, somewhat counterintuitively, it has been proposed that learning behaviour might be positively affected by anxiety (cf., Birenbaum & Eylath, 1994; Macher et al., 2015). Specifically, students who are very anxious about an upcoming important exam might be less confident in their chances of success, and, for this reason, they might allocate more time for learning and practice. Although this is an interesting hypothesis, it has not been empirically tested so far. In fact, based on the existing literature, it is also possible that due to their low expectations regarding their eventual performance, and because of their tendency for avoidance behaviour regarding mathematics (e.g., Ashcraft, 2002), anxious students might set a low learning target, and might be more likely to spend insufficient time on learning and practice (see Ackerman & Goldsmith, 2011 for detailed explanation). If this is the case, participants might underperform in test situations not only because of the debilitating effect of anxiety on their cognitive resources (e.g., Ashcraft & Faust, 1994), but also because they applied inefficient learning strategies before the test.

In sum, based on the existing literature, contrasting predictions can be made regarding the links between MA and study behaviour. In the following sections, we will argue that a metacognitive approach offers the potential to help filling this and other gaps in our current understanding.

The Meta-Reasoning Framework

Metacognition involves the processes by which learners plan, monitor, evaluate and change learning behaviours to suit tasks (Chauhan & Singh, 2014), and is commonly referred to as 'thinking about thinking' (Flavell, 1979). While metacognitive research within educational contexts is focused on reflection and explicit choice of learning strategies, metacognitive research within cognitive psychology is traditionally grounded in memory and knowledge retrieval. Recently, it has started branching into the more complex issues of problem-solving and reasoning. To that end, Ackerman and Thompson (2017a, 2017b) proposed a meta-reasoning framework (Figure 1) that details the metacognitive processes involved in problem-solving and reasoning, which could also be helpful in answering some questions in research into mathematical reasoning, mathematics learning, and how these are affected by MA (we detail the potential effects of MA on meta-reasoning processes in a separate section below).

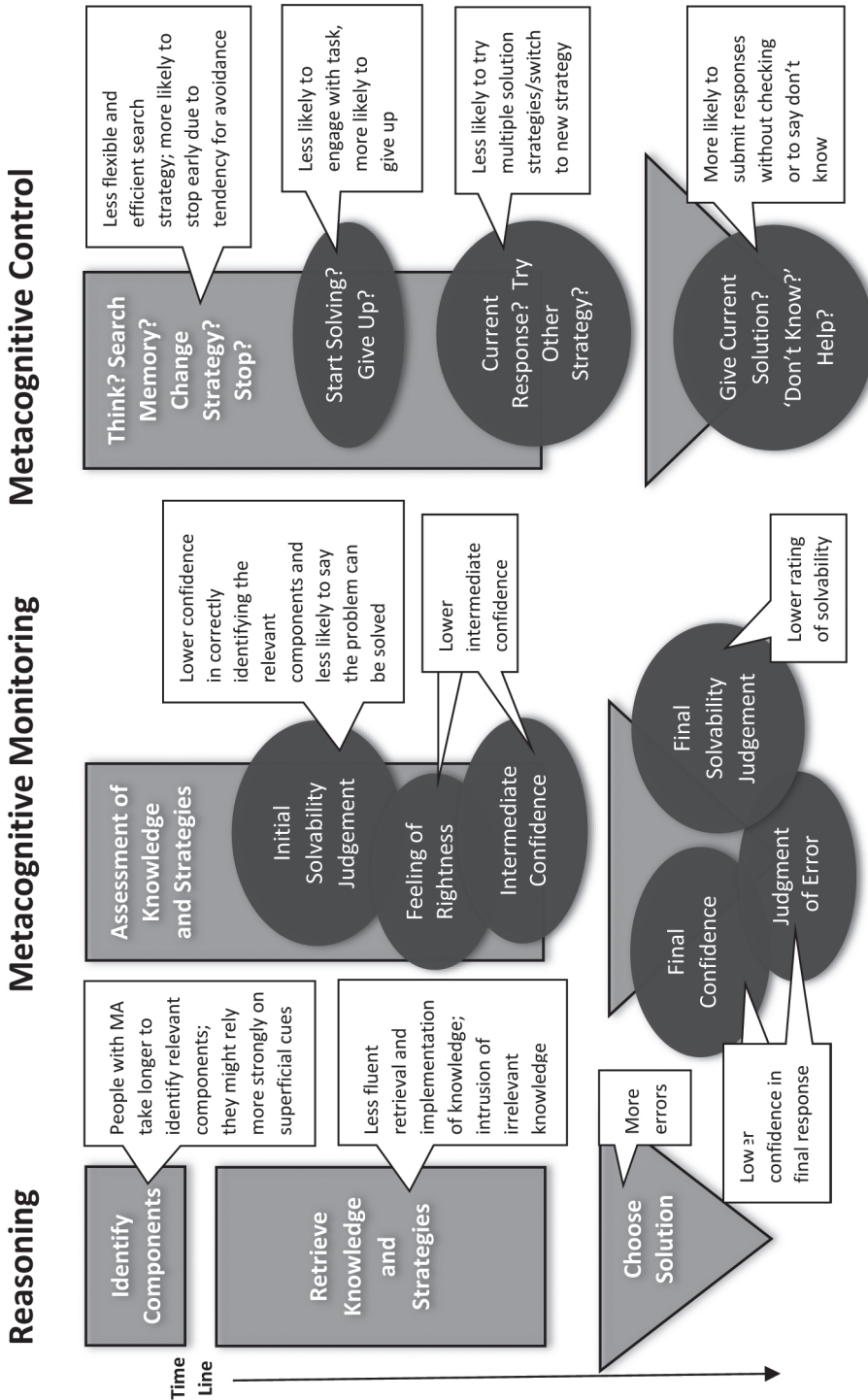


Figure 1. Possible effects of mathematics anxiety on meta-reasoning processes.

In particular, MA research typically focusses on the final outcome and the time taken to generate a response (i.e., response accuracy and reaction times), whereas the meta-reasoning approach breaks down solution and learning processes into their components, including various processes of monitoring and control. Metacognitive monitoring has been defined as the subjective self-assessment of how well a cognitive task will be/is/has been performed (Nelson & Narens, 1990). In the context of meta-reasoning, it involves processes such as judgements regarding the solvability of a task and confidence in reaching a solution (e.g., Ackerman & Beller, 2017). Metacognitive control consists of initiating, changing or terminating the allocation of effort to a cognitive task (see Ackerman & Thompson, 2017a, 2017b, for a review; e.g., initiating search for a new solution strategy, giving up on solving a task). This approach investigates reasoning and problem-solving as it unfolds over time, and it also involves acknowledging that evaluations regarding a task's solvability, as well as people's confidence, fluctuates during the solution process. This fine-grained analysis of changes while working on a task is completely missing from the MA literature.

In addition to analysing the process of generating answers to specific questions, the metacognitive framework has also been used to investigate how learners (e.g., when preparing for a test) set targets, allocate their time, evaluate their knowledge and decide when to stop during self-regulated learning (Ackerman, 2014). A central concept in these models is item-by-item confidence, and even within-item intermediate confidence judgments, which we discuss in the next section.

Metacognitive Research into Confidence

As previously mentioned, confidence and self-efficacy are important concepts in research into mathematics learning and problem solving. Confidence is also a key concept in metacognitive research. Nevertheless, confidence is defined and investigated in different ways in the two literatures. Self-efficacy refers to a person's confidence relating to their ability to solve a particular problem, *before* they actually engage in solving the task. Additionally, general confidence towards mathematics might also be assessed. In this case, the person is not currently engaged in the tasks, but they are asked for an assessment of their past experiences. By contrast, in the metacognitive framework, confidence judgments are generated once the person has actually engaged in the solution process or when they have already solved a particular task item (see Stankov, Kleitman, & Jackson, 2015 for a recent review on different ways of defining and measuring confidence). In this framework, confidence emerges as the output of metacognitive monitoring processes, and it causally determines metacognitive regulation and control (e.g., decisions about whether it is worth attempting a problem and whether a putative response should be accepted as the final solution).

Two interesting concepts, which are completely absent from the MA literature, are calibration and resolution (see Ackerman, Parush, Nassar, & Shtub, 2016;

Lichtenstein & Fischhoff, 1977). Calibration refers to the gap between mean confidence level across items in the task and actual success rates. This measure reveals tendencies for under- or (most commonly) overconfidence. A robust phenomenon in this context is the Dunning-Kruger effect (Dunning, 2011; Pennycook, Ross, Koehler, & Fugelsang, 2017): being ignorant of one's own ignorance. This deficit leads to increased mistakes in a domain and, as a double burden, the lack of knowledge also leaves individuals unaware of when they are making mistakes. Overconfidence can also play a role in terminating the learning process too early (e.g., Ackerman & Goldsmith, 2011). In these cases, learners mistakenly believe that they have already reached their target level of knowledge.

Resolution refers to a learner's ability to discriminate between tasks that they solved successfully or unsuccessfully. Resolution is typically measured by the within-participant correlation between judgment of success on specific items and actual success (Nelson, 1984). Good resolution is important in the regulation of both learning and problem solving. In particular, it could be advantageous to skip particularly difficult items, and to allocate more time to tasks with intermediate levels of difficulty, as these items have a higher chance of improvement when further time is invested (Metcalf & Kornell, 2005). It is important to note that calibration and resolution are independent processes. A learner might be able to correctly judge the relative difficulty of items, but still under- or overestimate their ability to solve them.

A final issue which is worth highlighting is that in the MA literature, when confidence or self-efficacy ratings are collected, a single rating is provided for the entire task. By contrast, the metacognitive framework does not assume that confidence levels remain stable across items or steps within the global task. Indeed, changes in subjective confidence are considered to be important for metacognitive regulation. We discuss these processes in the next section.

Confidence and the Regulation of Cognitive Effort

Many models of problem solving, and self-regulated learning can be classified as discrepancy-reduction models (e.g., Butler & Winne, 1995; Dunlosky & Hertzog, 1997; Nelson & Narens, 1990). In these models, people start by setting a desired level of confidence in their accuracy or their state of learning, before they engage in the process of solving a problem or learning some materials. Once they engage in the cognitive task, they continuously monitor how well they are progressing. If they reach or exceed the desired level of confidence, they terminate cognitive effort. However, if they are not sufficiently confident in their solution or level of learning, they continue to invest effort until the perceived discrepancy between the current and desired states of confidence reaches zero.

The Diminishing Criterion model (Figure 2), put forward by Ackerman (2014), substantially modifies this framework by proposing that although people tend to initially set a high target level of confidence, as time passes while working on an item, they are willing to compromise on this target. The model also proposes that

people apply a time limit, reflecting the maximum time they are willing to invest in each item. People stop investing effort once they reach this limit (Undorf & Ackerman, 2017). Another phenomenon that the model illustrates is that people's level of confidence tends to increase with the time spent on cognitive tasks. Nevertheless, the subjective experience of the solution or learning process substantially differs between easy and difficult items. In the case of items perceived to be easy, people start with a high level of confidence, which then quickly reaches the target level. In the case of items perceived to be difficult, people start with a low level of confidence, which slowly increases over time, leading to a feeling of disfluency and effort. In these cases, due to the feeling that additional effort might not lead to substantially improved outcomes, a person might decide to submit their current response or give up, by not providing a response, or responding "I don't know" (Ackerman, 2014; Ackerman & Goldsmith, 2008; Koriat & Goldsmith, 1996).

Overall, research into metacognitive monitoring and control offers well-established models of problem solving and learning. It offers several potential ways to extend investigations into mathematics learning and problem solving and the effects of mathematics anxiety. We outline some hypotheses and proposals for potential research directions in the next section.

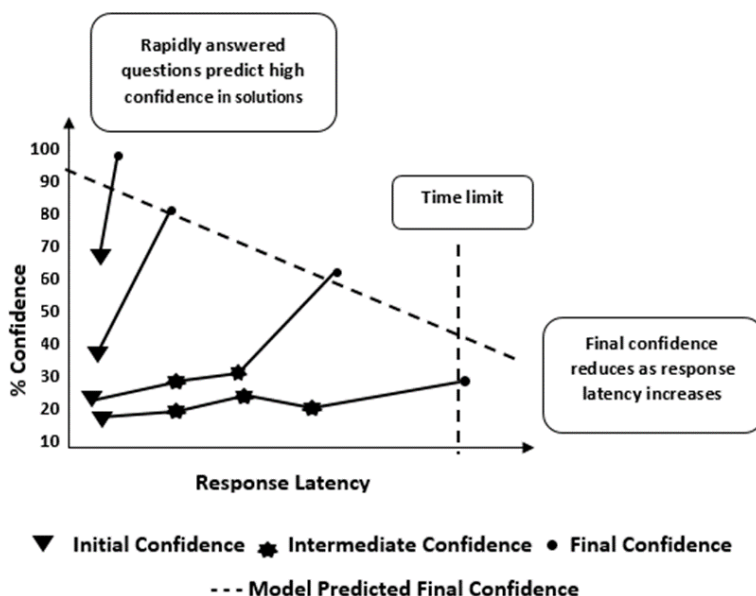


Figure 2. The Diminishing Criterion Model (Ackerman, 2014).

Hypotheses and Possible Research Avenues

Although MA has not previously been studied using the metacognitive approach developed by cognitive psychologists, some metacognitive studies on reasoning and problem-solving have included tasks with numerical content (e.g., Ackerman, 2014; Fernández-Cruz, Arango-Muñoz, & Volz, 2016; Jackson, Kleitman, Howie, & Stankov, 2016; Payne & Duggan, 2011). These studies have focused on a variety of tasks, and various metacognitive processes, and thus provide a good starting point for combining the two research fields. Specifically, Ackerman (2014) used response patterns on the cognitive reflection test to support the Diminishing Criterion Model. Fernández-Cruz et al. (2016) studied the number bisection task (i.e., presenting participants with three numbers and asking them to decide whether the middle number is the arithmetic mean of the other two numbers). These researchers used this task to investigate, whether participants detect when they give incorrect responses on the task. Jackson et al. (2016) used the cognitive reflection test, as well as some other tasks from the heuristics and biases literature, and investigated the effect of monitoring confidence and control thresholds on participants' performance. Finally, Payne and Duggan (2011) investigated performance on the water jar problems, which are multi-step mathematical problems where participants should describe how they would use three jars with differing capacities to measure out a particular amount of water. Payne and Duggan (2011) focussed on the factors that affect people's decisions to give up on unsolvable versions of these problems.

Previous studies have already established that performance on most of these tasks is affected by mathematics anxiety (e.g., Beilock & DeCaro, 2007; Morsanyi et al., 2014; Pletzer, Kronbichler, Nuerk, & Kerschbaum, 2015)¹. Consequently, it is also possible that the metacognitive processes of maths anxious and non-anxious participants also differ when they perform these tasks. For example, Payne and Duggan (2011) found that when people were informed that there was a high chance that the problem that they were working on was unsolvable, they tended to spend less time on it before giving up. If we assume that maths anxious participants are less confident in their ability to solve problems, we can predict that they might be more likely to give up on trying to solve difficult problems than participants with lower levels of anxiety, even when they have similar levels of mathematics knowledge. In the following sections, we outline several additional hypotheses regarding how MA might affect the metacognitive processes involved in learning and problem solving.

¹ The relation between mathematics anxiety and performance on the heuristics and biases tasks used by Jackson et al. (2016) has not been investigated yet.

The Effects of Mathematics Anxiety on Metacognitive Monitoring and Control

Given the well-established negative relationship between MA and test performance, we can expect that MA hinders the efficiency of metacognitive monitoring and control. According to processing efficiency theory (Eysenck & Calvo, 1992) and its successor, attentional control theory (Eysenck, Derakshan, Santos, & Calvo, 2007), anxiety impairs the functioning of the goal-directed attentional system, and, at the same time, increases the processing of low-level cues and stimuli, especially when these are threat-related. Indeed, Pletzer et al. (2015) provided neuroimaging evidence for this effect in the case of the number comparison (i.e., when participants should quickly indicate which of two numbers is numerically larger) and number bisection tasks. We can expect that such reduction in inhibitory processes might result in participants' defaulting to quick-and-dirty strategies (e.g., judging the difficulty of a task based on superficial characteristics of the stimuli, such as the roundness of numbers or how large or small the numbers are).

Figure 1 provides an overview of how metacognitive monitoring and control might be affected by mathematics anxiety. In brief, differences between anxious and non-anxious participants might occur at every stage of the problem solving process and could affect any or all aspects of monitoring and control. In particular, we can expect less flexibility in trying out multiple strategies, lower target levels, lower confidence at all stages of the solution process, and, as a result of a tendency for avoidance, a higher likelihood of terminating the problem solving process too early or giving up after a lengthy solving attempt, and submitting suboptimal solutions.

Nevertheless, to a certain degree, people may be able to compensate for anxiety-related processing inefficiencies through increased cognitive effort (Eysenck et al., 2007). Thus, especially in the case of tasks with low- or medium level of difficulty, anxiety might be associated with more stringent monitoring and control processes (e.g., spending a longer time on problems or double-checking responses before submitting them). Similar proposals have been made in relation to allocating time and effort to learning and exam preparation (Birenbaum & Eylath, 1994; Macher et al., 2015). Given the well-replicated finding that MA has a more negative effect on performance on difficult than on easy tasks, we might predict that whether maths anxious people allocate more resources to solving a problem or to learning than less anxious participants depends on the perceived difficulty of the cognitive task. In the case of relatively easy tasks with a high perceived chance of success, anxious individuals might allocate more resources, aiming to reach a high level of confidence, whereas they might invest less effort in trying to solve difficult tasks than non-anxious participants, as they are more likely to judge that their chances of success are low.

Maths anxious people might also differ in their metacognitive behaviour immediately after generating their final response. For example, due to their lower confidence in their responses, they might be more likely to judge that they submitted

an incorrect response than non-anxious participants (see next section for a more detailed analysis of this issue). They can also be expected to be less inclined to ask for help when they cannot solve a problem (see e.g., Baloğlu, 2003). These are metacognitive control decisions which are rarely studied in the metacognitive literature. Thus, investigations into this topic could offer novel insight for researchers from both the metacognition and maths anxiety fields.

Calibration and Resolution in MA

With regard to metacognitive monitoring processes, it is interesting to consider whether MA might affect calibration and resolution. Given that most people are overconfident in their performance, the fact that maths-anxious participants typically display lower levels of confidence could lead to the hypothesis that their metacognitive judgments might be better calibrated, as they might display a weaker tendency for overconfidence. The critical question in this respect is whether their confidence reflects a reliable assessment of their lower performance, or they suffer from the Dunning-Kruger effect — lower confidence than better performers, but not low enough. Although no studies have focussed on this question specifically, there are at least two existing studies which have reported relevant findings (Erickson & Heit, 2015; Morsanyi et al., 2014). In both cases, the findings suggest that both maths anxious and non-anxious participants were overconfident (although participants with higher levels of anxiety were less confident in their performance in general, they also performed more poorly than less anxious participants). Erickson and Heit (2015) also compared statistically the discrepancy between perceived and actual performance among people with higher and lower levels of MA. They reported a non-significant trend toward reduced overconfidence in maths anxious individuals. This finding leaves open the possibility that although maths anxious individuals display a tendency for overconfidence, this trend is at least reduced, compared to non-anxious participants (i.e., their judgments are somewhat better calibrated). Another important issue in this context is the fine line between low confidence that discourages people from further effort investment and low confidence as an encouraging factor with a belief that additional effort might be fruitful. Thus, a question in place is under what conditions maths anxious people might benefit from their low confidence.

Regarding resolution, there are some relevant findings available as well, at least regarding the relationship between general anxiety and error monitoring. In their meta-analysis, Moser, Moran, Schroder, Donnellan, and Yeung (2013) reported that anxiety, and especially anxious apprehension and worry, were moderately related to enhanced error monitoring, as reflected in increased amplitudes of error-related negativity in EEG studies. A potential explanation is that anxiety increases sustained attention to internal sources of threat (i.e., worry), which reduces the availability of resources dedicated to the active maintenance of task rules and goals. As a result, anxious individuals rely on reactive (instead of pro-active) control as a compensatory strategy (cf., Yeung & Summerfield, 2012). Suárez-Pellicioni, Núñez-Peña, and

Colomé (2013) replicated the finding regarding enhanced error-related negativity in the case of participants with mathematics anxiety using the numerical Stroop task (in which there is a conflict between the numerical and physical size of numbers). It should be noted that in this context, the detection of error has been considered as a constant source of distraction, which necessitates compensatory re-focus (cf., Moser et al., 2013). In other words, instead of offering some advantages, the enhanced processing of errors further drains the already limited cognitive resources of anxious participants.

On the basis of these findings, we might hypothesize that resolution could be better in the case of anxious individuals, at least in the case of incorrectly answered items. However, as a limitation of the available evidence, we should note that these EEG studies exclusively focussed on simple tasks where participants generate responses quickly. Apart from the lack of investigations regarding error monitoring in the case of complex tasks, there is also no research evidence regarding whether anxious participants are more likely to mistakenly judge correct responses as incorrect. An issue recently raised in the metacognitive literature is whether confidence in accuracy of an answer is the other end of the same continuum as judgment of error (Duyan & Balci, 2018; Fernández-Cruz et al., 2016; Gangemi, Bourgeois-Gironde, & Mancini, 2015; see Figure 1). Potentially, research into this continuum among MA people may shed light on the commonalities and differences between these two judgments. Overall, investigations into calibration and resolution could offer novel insight into metacognitive monitoring processes in maths anxious individuals.

Maths Anxiety and the Diminishing Criterion Model

The Diminishing Criterion Model (Ackerman, 2014) offers some interesting questions for research into MA. Key components of this model include the initial target confidence set by participants, and the time limit to produce a response or complete a learning task. This model offers a novel approach to investigating the phenomenon of local avoidance in MA (i.e., the tendency to rush through tasks to escape the anxiety-inducing situation of having to deal with maths). It is possible that anxious participants start off by setting a lower level of target confidence, have a steeper diminishing criterion slope, and/or set a shorter time limit to solve tasks. Another possibility is that they set similar targets to non-anxious participants, but err in estimating their progress during the solution process, which bias their decisions in the association between the ongoing confidence and the two stopping criteria.

This framework could also be used to investigate whether MA can lead to improved outcomes in the case of very difficult or unsolvable tasks. When facing such items, anxious participants might be faster in recognizing that it is not worth investing further resources in the solution process, saving their effort for more promising items. Process analysis based on the Diminishing Criterion Model can promote understanding on what basis these decisions are made.

Summary and Conclusions

In this paper, we provided an overview of some important gaps in the maths anxiety literature that highlight outstanding questions regarding the causal links between MA and maths performance, confidence, and learning behaviour. We reviewed some concepts and models from the metacognition literature, and especially from the recently developed meta-reasoning framework, that could be used to address these questions by offering a fine-grained analysis of the processes involved in mathematical problem solving and learning. Although, clearly, not all outstanding questions in the literature on maths anxiety that we reviewed could be answered using a metacognitive approach, we have outlined a number of suggestions for specific hypotheses that could be tested, and highlighted some easy-to-use measures (e.g., calibration and resolution) and models (e.g., the Diminishing Criterion Model) that could be particularly useful in this context. There might also be various other directions for further research that we did not consider here.

Apart from the benefits that the metacognitive approach could offer for understanding the effects of MA, investigations into mathematical reasoning and mathematics learning could also significantly expand the scope of metacognitive investigations. Additionally, this approach can provide novel insights by focussing on individual-difference variables, such as MA and maths-related confidence, and how these might determine the metacognitive regulation of learning and problem solving. Overall, we believe that both the metacognition and maths learning fields could be enriched by the proposed investigations. This line of work could also have important implications for educational design. Specifically, it could help to optimize learning settings and materials for anxious students.

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