An Integrated Approach to Understanding Negative Math Experiences

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ABSTRACT

Despite numerous studies devoted to mathematics aptitude and achievement, research on how individuals experience math has remained relatively fragmented. Here, using a combined theoretical and data-driven approach, we sought to characterize self-reported math experiences, with a particular focus on negative math experiences. An examination of existing literature led to the identification of eight potential facets of math experiences: emotional, cognitive, physiological, behavioral, testing, classroom/social performance, self-efficacy, and attitudinal. We generated survey items intended to probe experiences within each of these facets and constructed a preliminary questionnaire of 107 candidate items, comprising positively and negatively framed statements about one's math experiences, with data from a final analytic sample of N=803 adult participants. Focusing on negative items, four key factors emerged from the data: negative attitudes and avoidance, physiological experiences, testing and educational experiences, and cognitive and emotional experiences. These results point to opportunities for contact between literatures (e.g., between negative attitudes and avoidance behaviors), and toward relatively unexplored topics, such as the importance of negative physiological experiences when facing math. On a practical level, we also provide short subscales with sound internal metrics for each of the four factors identified above. Taken together, this work may prove useful on both a theoretical and a methodological level for those looking to develop a unifying framework of negative math experiences.

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INTRODUCTION

Mathematics concepts and methods are ubiquitous in contemporary society, playing an increasingly important role in formal education, a wide range of professions, and many aspects of everyday life. American students consistently rank worse on tests of numeracy and math skills compared to their counterparts in Europe and Asia (Pew Research Center, 2017). For the past three decades, educational and policy leaders in the United States have enacted efforts to address the consistent underperformance through curriculum changes, teacher education, and high-stakes accountability testing emphasizing knowledge and skills (e.g., Common Core, National Governors Association, 2010). However, the outcomes of these approaches have been mixed, as indicated by national and international assessments (Foley et al., 2017). The COVID-19 pandemic has heightened these changes. For example, the results of the 2019 National Assessment of Education Progress (NAEP, often referred to as the "Nation's Report Card") administered to representative samples of fourth and eighth graders demonstrate that students in the United States have shown little improvement in math since 2009 (NAEP, 2019). While there is an abundance of research highlighting the role of cognitive factors such as ability, intelligence, and prior knowledge for academic success, the educational and psychological research literature has firmly established that academic achievement cannot be explained solely by the cognitive and behavioral factors (e.g., Schiefele & Csikszentmihalyi, 1995). Thus, improvement of math performance may call for understanding the role of non-cognitive factors and subjective experiences (such as emotions, thoughts, feelings, and experiences; Lee & Stankov, 2018; Pekrun et al., 2002).

Over the past several decades, researchers have identified various predictors of math ability and achievement. To be sure, several such predictors focus on cognitive ability and capacity. For instance, cognitive psychology and neuroscience research has identified specific **components of cognitive processing** which underlie successful math learning, such as working memory (Ashcraft & Krause, 2007; Cragg & Gilmore, 2014) and executive function (Bull & Lee, 2014; Cragg & Gilmore, 2014). **Behavioral factors** such as self-regulation strategies related to avoidance, engagement, and achievement orientation toward mathematics have also been highlighted (Ashcraft, 2002; Ashcraft & Krause, 2007). Non-cognitive (or at least less overtly cognitive) factors have also been identified. Perhaps the most well-known of these is **mathematics anxiety** (e.g., Barroso et al., 2021; Dowker et al., 2016; Foley et al., 2017; Hembree, 1990), defined as fear and apprehension towards math characterized by feelings of anxiety, panic, and dread elicited by anticipating or participating in math activities (Richardson & Suinn, 1972). Other important factors include **motivational beliefs** and attitudes about math (Betz & Hackett, 1983; Pajares & Graham, 1999; Lee & Stankov, 2018). For instance, an extensive body of work has also pointed to **math attitudes**, such as self-efficacy, self-concept, and confidence, as predictors of math achievement (Lee & Stankov, 2018; Pajares & Graham, 1999). Neurobiological factors related to math processing, especially those that operate partially outside the central nervous system, have recently gained attention. Based on research on general anxiety (Beck et al., 1988), test anxiety (Roos et al., 2020), and achievement emotions (Pekrun et al., 2002), researchers have surmised that unwanted or overactive **physiological responses** (such as sweaty palms, increased heart rate, shaking hands), may directly impact performance and shape one's present and future experiences with mathematics (Perry, 2004; Roos et al., 2020). Finally, in addition to these individual-level

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factors, researchers have also examined features of **educational contexts** such as testing and classroom situations, finding that characteristics of student educational environments such as classroom quality, classroom emotional climate and student engagement may impact academic achievement (Ames, 1992; Reyes et al., 2012; Schunk, 1991).

Against this backdrop, education and psychology researchers have posited theoretical frameworks that can be utilized for understanding various aspects of an individual's experiences with mathematics, including emotional factors (Baumeister et al., 2007; Pekrun, 2006; Pekrun et al., 2002; Scherer, 2009; Valiente et al., 2012), anxiety-related factors (Beck et al., 1988; Spielberger, 1983), social factors (e.g., Bandura, 1989), attentional factors (Derakshan & Eysenck, 2009), and motivational factors (e.g., Deci & Ryan, 1985). However, much of this work has been done in a relatively siloed manner. As a consequence, how each of these factors relate to – or even reduce to – one another is often obscured, making it difficult to build an integrated interpretation of the existing literature.

To address this difficulty, we posit a unifying theme, that of *math experiences*, such that each of the cognitive and non-cognitive factors briefly discussed above (as well as several others that we discuss below) can all be viewed as particular instances of **math experiences.** We define math experiences as the ways in which people *think about, feel about, engage with, and relate to* mathematics. From this starting point, one can then ask which aspects of math experiences previously examined in various corners of disparate literatures may in fact be highly overlapping or indeed be relatively distinct. A broader unifying framework of this kind may be useful for the same reason that theoretical unification carries value in any scientific field: it allows for translation and comparison between concepts and computations in disparate contexts with minimal friction. Thus, for instance, we can ask whether some facets of math experiences reduce to one another, and which require distinct categories or concepts. As a clarifying note, we do not see reduction in this case in a pejorative light; instead, statistical similarity may be indicative of potential connections between disparate sub-literatures. Similarly, distinctions do not, in our minds, imply impenetrable barriers, but opportunities to consider complimentary aspects of math experiences that may not be evident from a single theoretical perspective or approach.

Candidate Facets of Math Experiences

In the following section, we review in greater detail the different facets, both cognitive and non-cognitive, briefly noted in the section above that prior literature has identified as relevant to how different individuals experience math learning, math performance, and math achievement. Subsequently, we propose an approach – which we execute and report in the present paper – to bring each of these facets together under the common rubric of *math experiences*. This approach allowed us to evaluate the underlying structure of math experiences from the standpoint of which facets are largely overlapping and which facets should be conceptualized as distinct. This approach, in turn, allowed for the development of a survey instrument that systematically assesses a range of math experiences in an efficient, flexible manner.

Furthermore, given the potential breadth of the proposed endeavor, here we focus primarily on *negative* aspects of math experiences – such as negative emotional or physiological responses to the prospect of doing math (Chang & Beilock, 2016), negative attitudes about math that cast it or

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a person's relation to math in a negative light (Hannula, 2018), aspects of cognitive processing that interfere with one's ability to perform well in math (Ashcraft & Moore, 2009) and behavioral and educational factors that might lead a person to avoid engaging in learning behaviors that could otherwise benefit one's math ability or attitudes (Jackson & Leffingwell, 1999). For present purposes, we define a "negative" experience as one that diminishes an individual's capacity to engage with math effectively, whether through reduced motivation, heightened anxiety, or the avoidance of math-related activities. The focus here on negative experiences also reflects the fact that, in several of the facets of math experiences highlighted above, such as emotional, cognitive, and physiological responses to math, the plurality of work has tended to focus on factors that negatively impact math learning and performance.

Hence, many of the above-mentioned facets of math have garnered attention in part because they predict negative math outcomes, something that is imperative for individuals and societies to work to avoid as much as possible (Ashcraft & Moore, 2009). Our hope is that the framework established here might provide a guide for future work that examines the underlying structures of both negative and positive math experiences – for instance, whether they are simply mirrors of one another or distinct. In sum, here we provide a first approximation of what a unified framework linking multiple research areas under the rubric of math experiences might look like, using negative math experiences as an initial test case and basic proof of concept.

Emotional Facets of Math Experiences

Negative emotional experiences related to anticipating or doing math can include feelings of anxiety such as tension (Richardson & Suinn, 1972), fear and apprehension (D'ailly & Bergering, 1992), dread (Fennema & Sherman, 1976), panic, helplessness, and frustration (Tobias & Weissbrod, 1980). These negative experiences have been most extensively studied under the topic of math anxiety (Richardson & Suinn, 1972). Additional aspects of the negative emotions associated with math, such as anger, frustration, shame, or boredom, may also be relevant for characterizing how different individuals might react negatively to math in an emotional manner (Pekrun et al., 2002).

Cognitive Facets of Math Experiences

Research findings in neuroscience and cognition in the last 20 years have significantly increased our understanding of the specific cognitive processes and mental functions that can be compromised in some individuals, leading to poor math learning and performance (Ashcraft & Kirk, 2001; Ashcraft & Ridley, 2005; Beilock & Carr, 2005; DeCaro et al., 2010). These include compromise of critical working memory resources (Ashcraft & Krause, 2007), disruption of attentional resources (Eysenck & Calvo, 1992; Eysenck & Derakshan, 2011), and suboptimal strategy selection (Beilock, 2008). Negative aspects of math experiences related to compromised cognitive functioning thus often pertain to 'on-line' or 'in-the-moment' processing. Examples include feeling one's mind 'go blank', mental freezing, paralysis of thought (Tobias & Weissbrod, 1980), mental disorganization and confusion, mental exhaustion, impaired focus, reduced concentration, and 'zoning out' (Betz, 1978). The common thread is that each of these examples is thought to disturb the underlying cognitive processes that can occur for some individuals in math-related situations.

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Physiological Facets of Math Experiences

In educational research, there has been a growing interest in understanding how physiological responses and experiences may influence emotional states and predict students' academic success. Over the last decade, there has been a steady and growing use of physiological measures (e.g., cardiovascular measures, electrodermal activity, saliva samples, EEG and fMRI), to complement traditional self-report measures of emotions (Avancini & Szűcs, 2019; Roos et al., 2020). Many individuals, however, are not aware of these physiological responses, even if they lead to more overt physical expressions of discomfort. Hence, it is largely unknown whether more explicit awareness of physiological responses forms a meaningful part of some individuals' math experiences. Several math anxiety scales have adapted the emotionality dimension of test anxiety encompassing physiological experiences such as heart rate, upset stomach, and general unease (Liebert & Morris, 1967). For example, Ganley & McGraw 2016, and Harari et al., 2013, have incorporated physiological experiences such as headaches, stomach aches, and fast heart-rate into scales designed for young children, but to our knowledge, a comprehensive understanding for adult populations is missing. Such symptoms might include physical illness such as nausea, stomach pains, headaches, faintness, shortness of breath, the assumption that one's heart is beating faster, hands trembling, and sweaty palms (Dew et al., 1984; Malinsky et al., 2006; Perry, 2004).

Behavioral Facets of Math Experiences

Behavioral experiences and outcomes related to math learning, engagement, and avoidance have received significant attention due to the short-term and long-term consequences of avoidance behaviors for participation and success in STEM-related careers (Ashcraft & Krause, 2007; Ashcraft & Moore, 2009; Dowker et al., 2016). Short-term avoidance behaviors can include making decisions to enroll in fewer math courses and avoiding elective coursework (Ashcraft & Krause, 2007). In the long term, this behavior can transform into a global avoidance pattern across one's lifespan, which has been characterized as "math phobia" (Ashcraft, 2002; Ashcraft & Krause, 2007; Tobias & Weissbrod, 1980). These negative behaviors can include procrastinating, investing less time and effort, inefficiently organizing one's own study environment, actively devoting less concentration and attention to learning, and failing to study regularly may be behaviors associated with negative affective experiences.

Classroom and Social Performance Facets of Math Experiences

Classroom settings are important educational contexts for understanding how individuals experience math and may hold an important developmental significance for the math learning, as classroom context and school engagement are significant predictors of academic achievement (Reyes et al., 2012). This is particularly important when considering aspects related to instructional demands, situational constraints, and psychosocial and environmental characteristics (Ames 1992, Schunk, 1991). Typical classroom situations include performing math tasks (*social performance*) and being evaluated in math in front of others (*social evaluation*) (Ames, 1992). Negative classroom experiences related to *social performance* can include worrying about being called on, dreading going to the board in math class, fearing to ask questions in the math classroom, and avoiding performing math in front of others (Tapia, 1996; Wigfield & Meece, 1988). Experiences related to *social evaluation* include worrying about keeping up with the rest of the class, feeling

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embarrassed about poor math performance, preoccupation with one's classmates' relative performance, and comparing oneself to others (Tapia, 1996; Wigfield & Meece, 1988).

Testing-Related Facets of Math Experiences

The math-testing environment is critical in shaping student perceptions of math and math environments (Henschel & Roick, 2018). High stakes testing environments have become more common over the past 20 years, in part due to accountability legislation intended to increase academic achievement (e.g., the No Child Left Behind Act, 2001). Furthermore, tests and examinations have a unique developmental significance for how students experience math, particularly in light of the research suggesting the phenomenon of "choking under pressure" in high-pressure situations, such as tests and performance assessments (Beilock, 2008). In the testing context, negative math experiences may include feelings of time pressure (Jackson & Leffingwell, 1999), as well as heightened emotions brought on specifically by the testing environment, such as dread (Wigfield & Meece, 1988), worry about failure (Felson, 1984), and fearing of unexpected tests, such as pop quizzes (Alexander & Martray, 1989).

Self-Efficacy Facets of Math Experiences

Self-efficacy, self-concept, and expectancy beliefs, such as confidence are important individual and motivational experiences that may influence math outcomes and the development of math attitudes (Betz & Hackett, 1983; Meece et al., 1990; Olivier et al., 2019; Ramirez et al., 2018). Math self-efficacy is the belief in one's capabilities to carry out a math task, while math self-concept is the belief in one's competence to carry out the math task, and these beliefs are experienced on a spectrum (Betz & Hacket, 1983; Olivier et al., 2019). Experiences consistent with low math self-efficacy and low self-concept include lacking confidence believing that math is "too hard" or that it is one's "worst" subject, feeling stupid when doing math, giving up easily when solving a problem, and second-guessing one's answer through doubt and hesitation (Tapia, 1996; Hendy et al., 2014). Low self-rated math ability has been shown to be negatively related to math performance (Meece et al., 1990; Olivier et al., 2019; Ramirez et al., 2018), and poor perceived math ability has been identified as a predictor of math anxiety (Hembree, 1990).

Attitudinal Facets of Math Experiences

Substantial research has focused on the role and development of attitudes toward mathematics as an important factor related to math achievement, performance, and engagement (Ramirez et al., 2018). In the research literature, attitudes towards math (math attitudes) extend to broad categories of enjoyment (Aiken, 1974), interest (Lee & Stankov, 2018), identity (Good et al., 2012; Necka et al., 2015), value (Luttrell et al., 2010) and motivation (Wang et al., 2015). Several ways that individuals can approach math positively is through motivation-related attitudes, such as enjoyment, liking, interest, and fascination (Aiken, 1974; Luttrell et al., 2010; Tapia, 1996). A related construct, *math interest* denotes positive affective experiences with, and arousal of attention toward, math-related activities (Lee et al., 2014). Concepts of self-identity and belongingness in math have been identified as important components of math attitudes (Good et al., 2012). Conversely, individuals who perceive math negatively often view math as unappealing, dull, boring, and unenjoyable; such individuals often describe math as among their least favorite subjects (Aiken, 1974). In academic achievement, individuals with lower interest in math tend to

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show lower math achievement (Jansen et al., 2016). Similarly, Necka and colleagues (2015) showed that individuals whose sense of self-concept is strongly 'distanced' from math (low self-math overlap) tend to perform more poorly in math, in part because the relation between performance and anxiety tends to be exacerbated among such individuals.

Current Study

The previous section reviewed literature pertaining eight potential facets of math experiences: emotional, cognitive, physiological, behavioral, classroom/social performance, testing, self-efficacy, and attitudes. To date, while these respective literatures do occasionally acknowledge one another, it is often in a somewhat piecemeal manner without much reference to an overarching framework. For instance, various authors working in one or more of these areas may regularly cite one another, but this is often limited to specific pairs of facets [e.g., between the cognitive and emotional facets of math (Ashcraft & Kirk, 2001; Ashcraft & Krause, 2007) or between self-efficacy and math attitudes (Lee & Stankov, 2018; Pajares & Graham, 1999; Necka et al., 2015), to name just two such pairs]. Our point is not to criticize these authors or the rest of the extant literature in this space, but rather to highlight that we are unaware of prior work that explicitly attempts to unify all these facets of math under a single umbrella. Doing so could be of significant benefit in part to use a data-driven approach to test implicit intuitions and assumptions about which of these facets are most closely related to one another. For instance, even in the heavily abridged reviews presented above, the potential for overlap and distinction between the various facets of math should be apparent to even an uninitiated reader, let alone an expert in one of more of the sub-fields briefly described above. Indeed, testing these various hypotheses about where aspects of math experiences might be synthesized or divided is one of the primary reasons for proposing an overarching framework. For example, do the data support the existing pairwise points of communication between sub-literatures when considered in concert with measures taken from the other sub-literatures? Further, might there be connections between facets of mathematics that have heretofore been missed? For these reasons, we believe considering a broad range of sub-literatures on the various facets of how individuals encounter, process and adjust to mathematical situations and stimuli and against the broader backdrop of math experiences can be of theoretical and practical utility to researchers working in a number of domains.

In the current paper, we present an initial step that illustrates the potential for a unified framework of math experiences. In this first attempt, we did so via self-report ratings, as this measurement technique is common to each of the eight facets described above. We first examined the literature for existing scales or measures containing self-report items that specifically and explicitly address a given facet. Wherever possible we used items in their existing form. In some cases, items were modified slightly to address a single facet more explicitly, and in other cases, lack of existing literature (e.g., in the case of many aspects of physiological experiences) led us to generate new items altogether. Further, as noted above, we focused here primarily on negative math experiences. Doing so allowed us to draw from the largest pre-existing literatures and frankly simplified the initial problem space, given the large scope of the proposed project. We generated an initial stimulus set of over 100 items spanning the 8 facets of math experiences described above and collected ratings from over 800 adult participants. We used a factor analytic approach, first confirming a basic distinction between positively versus negatively framed items. We next

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explored in greater detail the underlying factor structure of the negatively valenced items across the 8 candidate facets described above. Rotated factor solutions provided a shortened list of items that can potentially be used as a novel '*Negative Math Experiences'* scale. In this way, we hope to provide a large dataset that contributes to the extant literature on both a theoretical and a methodological level.

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METHODS

Participants

Participants were adults recruited via Amazon's Mechanical Turk (MTurk). 827 participants provided a complete dataset. Data collected on MTurk have been shown to be similar in quality to data samples collected in-lab in college if appropriate quality assurance steps are taken (Buhrmester et al., 2022; Necka et al., 2016; Paolacci et al., 2020;). Excluded from the analysis were 24 participants because of failed attention check items, i.e., items intended to ensure that participants were devoting appropriate attention to the task, such as an item that asked participants to "Please select 'strongly agree'" as their response, gave the same response on all items in a given page, and completed the survey in less than 10 minutes. These quality assurance steps measures were intended to ensure that participants were devoting appropriate attention to the task.

Thus, the quality-controlled sample totaled N = 803 participants. The characteristics of the sample's age between 20-77 years (Mean = 39.9 years, SD = 11.3 years; note: 4 participants were excluded from characterization of age because incomplete date of birth was entered). Participants who reported their gender were primarily male 51.7% (N = 415), there were 47.9% female (N = 385) and 3 individuals preferred not to answer. Participants who reported their race and ethnicity predominantly identified themselves as White/Caucasian (79.0%), with the remaining participants self-identifying as Black or African American (12.7%), Asian (6.1%); 13.0% of participants self-identified as Hispanic or Latino.

Procedure

All procedures and materials were reviewed and approved by the Georgetown University Institutional Review Board (IRB), and all participants gave informed consent prior to the beginning of the study. The study consisted of a main questionnaire composed of 107 candidate items presented in a randomized order, (see Supplementary materials). Several filler questionnaires and basic demographic information were also collected. The order of the main battery of 107 items and the filler questionnaires was randomized; the demographic section was always presented last. Within each questionnaire, item order was randomized; for questionnaires exceeding 10 items, items were presented 10 at a time (i.e., 10 items per page).

For the main battery, participants received the following instructions: "In this section you will be presented with a series of statements about experiences that people can have with mathematics. You will be asked to indicate the extent to which you agree or disagree with the following statements. Read each statement carefully and select the response that you feel most accurately describes you." The study took approximately 15-25 minutes to complete. After completing the series of questionnaires, participants were given a completion code, and were compensated $2 for their time through Mechanical Turk.

Stimuli

Candidate Item Generation

Initially, 107 items were generated to address eight unique facets of math experiences based on our review of the various respective literatures, as described in the Introduction. These facets were: emotional, cognitive, physiological, behavioral, classroom/social performance, testing, self-efficacy, and attitudinal. For each facet, we first examined the literature for existing scales or measures containing self-report items that specifically and explicitly addressed that facet. If possible, we used items in their existing form. In some cases, items were modified slightly to address a single facet more explicitly, and in other cases, lack of existing literature (e.g., in the case of many aspects of physiological experiences) led us to generate new items altogether. For each facet, 12 to 15 items were thus identified or constructed.

Valence and Scoring

Because our primary focus here is on negative math experiences, approximately 70% of items were negatively valenced (e.g., "I feel like crying when I have to do math"), and the remaining 30% were positively valenced (e.g., "I am comfortable doing math"). Item responses were on a 5-point Likert scale (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree), and scored 0-4, respectively. Positive items were reverse coded. See Appendix A (Tables A1-A8) for a complete list of the 107 items, including their source in the literature and any modifications that may have been made.

Emotional Items

The Emotional facet (E) comprised 12 items designed to capture emotional experiences with math: 9 negative items (E01-E09; e.g., "I feel like crying when I have to do math"), and 3 positive items (E10-E12; e.g., "I am comfortable doing math"). These 12 items were obtained and adapted from the State-Trait Anxiety Inventory (STAI; Spielberger al., 1970), Number Anxiety Scale (Dreger & Aiken, 1957); the Math Barriers Scale (MBS; Hendy et al., 2014), the Mathematics Self-Concept, Self-Efficacy and Anxiety Scale (Lee, 2009), the Math Anxiety Questionnaire-Modified (MAQ-M; Wigfield & Meece, 1988), and the Anxiety Symptom Questionnaire (ASQ; Cameron & Nesse, 1986). We created 1 item to capture the absence of feeling overwhelmed when doing math. See Table A1 for full item details.

Cognitive Items

The Cognitive facet (CG) comprised 13 items designed to capture components of cognitive-level experiences with math: 10 negative items (CG01-CG10; e.g., "When I see a math problem I just freeze up"), and 3 positive items (CG11-CG13; e.g., "I find it easy to concentrate on math for long periods of time"). The 13 items were obtained and adapted from the Number Anxiety Scale (Dreger & Aiken, 1957), Math Anxiety Scale (MAS; Betz, 1978), STAI (Spielberger et al., 1970), the Academic Achievement Test (AAT; Alpert & Haber, 1960), and the MBS (Hendy et al., 2014). We created 2 additional items to reflect experiences of mind wandering and mental disorganization. See Table A2 for full item details.

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Physiological Items

The Physiological facet (P) comprised 15 items designed to capture self-awareness of physiological arousal (e.g., nausea, physical illness, heart racing, sweaty palms) related to doing math: 12 negative items (P01-P12; e.g., "I feel like fainting when faced with a math problem"), and 3 positive items (P13-P15, e.g., "I feel calm and relaxed when I do math"). The items were obtained and adapted from the ASQ (Cameron & Nesse, 1986), the Beck Anxiety Inventory (BAI; Beck et al., 1988), and the STAI (Spielberger et al., 1970). Many items in this facet were modified to reflect physiological responses in math-specific situations. We created 3 additional items to reflect one's sense of overall bodily reaction. See Table A3 for full item details.

Behavioral Items

The Behavioral facet (B) comprised 13 items designed to capture self-reports of active adjustments to one's behavior in order to avoid math (or in the positive case, to approach math): 9 negative items (B01-B09; e.g., "I tend to ask others to complete tasks for me if they involve math or numbers of any kind), and 4 positive items (B10-B13; e.g., "I would consider a career that involved complicated math"). Items were obtained and adapted from the MAS (Betz, 1978) and the Fennema-Sherman Mathematics Anxiety Subscale-Revised (FSMAS-R; Mulhern & Rae, 1998). We created 2 additional items to capture (lack of) help-seeking behavior and attentional disengagement. See Table A4 for full item details.

Classroom/Social Performance Items

The 12 items in the Classroom facet (CS) were designed to capture elements of social performance and social evaluation within a math classroom setting: 8 negative items (CS01-CS08; e.g., "I am afraid that others will not approve of me because I am bad at math"), and 4 positive items (CS09-CS12; e.g., "As a student I often volunteered to solve math classes on the board in my math classes"). Items in this facet were obtained and adapted from the MAS (Betz, 1978), Math Anxiety Online Self-Assessment (MA online; Freedman, 2022), Brief Fear of Negative Evaluation Scale (FNES; Leary, 1983), ASQ (Cameron & Nesse, 1986), and the Attitudes Towards Mathematics Inventory (ATMI; Tapia, 1996). We created 1 additional item to reflect receiving feedback. See Table A5 for full item details.

Testing Items

The Testing facet (T) comprised 14 items designed to capture experiences related to being tested on one's math knowledge: 11 negative items (T01-T11; e.g., "As a student, I was terrified of pop quizzes in my math classes"), and 3 positive items (T12-T14; e.g., "As a student, I was usually at ease during math tests"). Items were obtained and adapted from the MA Online (Freedman, 2022), Math Information Processing Scale (MIPS; Bessant, 1997), Test Anxiety Inventory (TAI; Spielberger, 1980), shortened Math Anxiety Rating Scale (sMARS; Alexander & Martray, 1989), AAT (Alpert & Haber, 1960) and the MAS (Betz, 1978). We created 4 additional items to capture high stakes experiences, guessing behavior, and confidence specific to math testing situations. See Table A6 for full item details.

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Self-efficacy Items

The Self-efficacy facet (S) comprised 15 items designed to capture how individuals feel about their math ability, math self-confidence, and math performance: 11 negative items (S01-S11; e.g., “Math is too hard for me”), and 4 positive items (S12-S15; e.g., “I am good at math”). Items in this facet were obtained and adapted from the MAS (Betz, 1978), the Mathematics Value Inventory (MVI; Luttrell et al., 2010), FSMAS-R (Rae & Mulhern, 1998), ATMI (Tapia, 1996); MBS (Hendy, et al., 2014), Math Information Processing Scale (MIPS; Bessant, 1997), and the Mathematics Self-Concept, Self-Efficacy, and Anxiety Scale (Lee, 2009). We created 3 additional items to capture feelings of insecurity and (un)intelligence with math, as well as feelings of confidence without a calculator. See Table A7 for full item details.

Attitudinal Items

The Attitudinal facet (A) comprised 13 items designed to capture broader attitudes about mathematics, such as interest, liking/enjoyment, identity and motivation: 7 negative items (A01-A07; e.g., “Math does not appeal to me"), and 6 positive items (A08-A13); e.g., “I consider myself part of the math community”). Items in this facet were obtained and adapted from the MIS (Hulleman et al., 2010), the ATMI (Tapia, 1996), MVI (Luttrell et al., 2010), the Math Motivational Beliefs Scale (MMBS; Watt et al., 2012), and the Math Sense of Belonginess Scale (MSBS; Good et al., 2012). We created 3 additional items to capture additional aspects of (dis)interest and intrinsic motivation toward math. See Table A8 for full item details.

Analysis Approach

Our primary analysis technique for addressing theoretical questions was exploratory factor analysis (EFA). We ran two separate EFAs: the first included all 107 items, and the second included only the 77 negative items. Both EFAs used maximum-likelihood extraction to allow for correlated factors (1000 iterations). Rotated factor loadings were computed using the Promax algorithm (Delta=0, Kappa=4, 1000 iterations). Inclusion criteria for factor extraction were two-fold: (1) an eigenvalue greater than 1, AND (2) the reduction in eigenvalues to the factor with the next lowest eigenvalue was 15% or greater[1]. (This latter criterion helped avoid running into ‘plateaus’ as one might see on a scree-plot.)

To generate the Math Experiences measurement tool, we used separate confirmatory factor analyses (CFAs) for each subscale in order to identify the optimal items for that subscale. CFAs were limited to a single factor, which made rotation irrelevant; factor loadings in this case were taken from the respective factor matrices.

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[1] $[(I_n - I_{n+1}) / I_n \geq .15]$, where I_n is the eigenvalue for the factor in question and I_{n+1} is the eigenvalue for the factor with the next lowest eigenvalue.

RESULTS

Results are divided into two main sections. In the first (I), we address the theoretical questions laid out in the Introduction: (1) Can we confirm a basic distinction between negatively vs positively framed math experiences; (2) What is the structure of *negative* math experiences? In the second section (II), we describe a potentially useful measurement tool that emerged from addressing question (2) above.

I) Theoretical Questions

1) Positive vs Negative Math Experiences

Our primary focus was on negative math experiences, but in this section, we first sought to test for a core distinction between negatively vs positively framed math experiences. Results from the EFA using all 107 items as inputs revealed 4 factors that met our inclusion criteria (see Methods above). Table 1 shows the first 10 factors, with those selected for inclusion printed in black.

Figure 1 shows the rotated factor loadings. At first glance, the first and second factors appear to separate into negative and positive items, respectively. Indeed, 68 of the 77 negative items (88%) loaded most highly on the first factor, while 30 of the 30 positive items (100%) loaded most highly on the second factor. Of the 9 negative items that did not load most highly on the first ('negative') factor, none loaded most highly on the second ('positive') factor, loading instead on either the third or fourth factor. The positive and negative factors were correlated at r=.402 (Table 1).

These results provide strong support for the notion that self-reported math experiences divide primarily along valence (negative vs positive). In the next section, therefore, we isolate the 77 negative items and pursue our primary theoretical goal of identifying the structure of (self-reported) negative math experiences.

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Table 1

Factor Index	Eigen-value	% Reduction to next Eigenvalue[1]	% Variance	Factor Correlations 1	2	3	4
1	53.643	74.8%	50.1%		.40	.47	.30
2	13.518	81.8%	12.6%	.40		.54	.36
3	2.464	20.5%	2.3%	.47	.54		.09
4	1.959	43.3%	1.8%	.30	.36	.09	
5	1.110	1.5%	1.0%				
6	1.093	5.5%	1.0%				
7	1.033	7.2%	1.0%				
8	0.959	5.3%	0.9%				
9	0.908	6.1%	0.8%				
10	0.853	6.3%	0.8%				

Table 1 shows factor metrics for the first 10 factors when considering all 107 items. The first 4 factors met inclusion criteria. [1]Indicates the percentage reduction in eigenvalues from that of the current factor to that of the next lowest factor in the table (see also footnote 1).

Figure 1

	Factor			
Item	1	2	3	4
E01	.97	-.09	-.16	.07
E02	.57	.10	.02	.01
E03	.80	.04	-.15	.02
E04	.47	.07	-.05	.13
E05	.47	.08	-.04	.17
E06	.63	-.02	-.12	.06
E07	.67	.03	-.10	.10
E08	.54	.04	.02	.02
E09	.68	.07	-.06	-.03
*E10	.14	.78	-.11	-.14
*E11	.12	.76	-.14	-.01
*E12	.10	.63	-.22	-.26
C01	.78	.03	-.13	.02
C02	.69	.00	-.11	.07
C03	.72	.02	-.13	.02
C04	.32	-.07	.05	.13
C05	.51	.14	.03	-.02
C06	.31	.13	.14	.18
C07	.52	.08	.15	.19
C08	.65	.05	-.06	.01
C09	.44	.00	.21	-.05
C10	.60	.00	-.01	.03
*C11	.16	.77	-.19	-.11
*C12	-.10	.74	-.03	.09
*C13	-.09	.65	.01	-.14
P01	1.06	-.03	-.11	.03
P02	1.06	-.18	-.10	.02
P03	1.02	.02	-.05	.01
P04	.98	.13	-.10	-.05
P05	1.02	.01	-.05	-.01
P06	.83	.09	-.15	-.02
P07	1.02	-.14	-.08	.06
P08	1.01	-.05	-.09	.08
P09	.98	-.19	.05	.06
P10	1.11	.15	-.08	-.06
P11	.75	.06	-.08	-.03
P12	.74	.00	.03	-.02
*P13	.37	.69	-.19	-.28
*P14	.18	.75	-.20	-.14
*P15	.05	.76	-.03	-.10
B01	.42	.14	.14	.31
B02	.46	.09	-.04	.29
B03	.49	.11	.07	.25
B04	.32	.20	.09	.30
B05	.62	-.03	-.11	.08
B06	.77	-.05	-.08	.06
B07	.68	-.01	.14	.13
B08	.55	.06	.23	.08
B09	.67	.06	-.02	.21
*B10	.11	.77	-.20	-.01
*B11	-.14	.82	-.02	.16
*B12	.21	.76	-.08	-.08
*B13	-.08	.81	.04	.32

	Factor			
Item	1	2	3	4
CS01	.65	.16	.29	-.01
CS02	.51	.16	.34	.03
CS03	.45	.03	.22	-.05
CS04	.81	-.02	.08	.06
CS05	.60	.01	.21	-.04
CS06	.94	-.15	.06	.02
CS07	.87	-.10	.22	-.06
CS08	.92	.01	.06	-.03
*CS09	-.27	.88	.25	.06
*CS10	-.05	.54	.06	-.23
*CS11	-.08	.82	.18	.08
*CS12	.09	.82	-.03	.05
T01	.35	.10	.20	.15
T02	.48	.14	.31	-.12
T03	.47	.05	.33	-.03
T04	.43	.07	.27	.01
T05	.62	.11	.25	-.05
T06	-.03	-.11	.44	.16
T07	.57	.14	.29	-.01
T08	.55	-.11	.15	-.05
T09	.61	.04	.12	-.02
T10	.48	-.01	.15	.06
T11	.45	-.11	.27	-.04
*T12	.00	.68	-.02	-.15
*T13	-.02	.73	.05	-.15
*T14	-.49	.61	-.05	-.09
S01	.52	-.01	-.10	.10
S02	.21	.06	.08	.29
S03	.39	.08	.32	-.03
S04	.73	-.08	-.04	.03
S05	.46	.06	.18	-.04
S06	.41	.07	.15	.06
S07	.59	-.08	.20	-.06
S08	.56	.07	-.01	.07
S09	.57	.07	.03	.12
S10	.34	.12	.19	.03
S11	.47	-.06	.17	.02
*S12	.04	.75	-.04	-.08
*S13	-.04	.72	-.09	.12
*S14	.17	.81	-.18	-.05
*S15	.17	.77	-.13	-.10
A01	.19	.19	.16	.51
A02	.15	.16	.17	.42
A03	.20	.19	.12	.49
A04	.23	.15	.25	.31
A05	.33	.17	.18	.55
A06	.29	.13	.23	.33
A07	.19	-.27	.34	.19
*A08	-.03	.90	.06	.29
*A09	-.07	.78	.01	.30
*A10	-.06	.83	-.01	.28
*A11	-.01	.90	.01	.23
*A12	-.37	.86	.12	.17
*A13	-.22	.81	.03	.24

Figure 1 shows rotated factor loadings from the EFA using all 107 items. The four factors are the top four factors from Table 1. Abbreviations: E: Emotional, C: Cognitive, P: Physiological, B: Behavioral, CS: Classroom/Social Performance, T: Testing, S: Self-efficacy, A: Attitudinal. Items marked with an asterisk (*) are positively valenced and hence reverse coded; all other items are negatively valenced.

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2) Factor Structure of Negative Math Experiences

In this section, we ran a second EFA, but in this case we included only the 77 negative items. Despite including items from 8 candidate facets as inputs, results revealed just 4 factors that met our inclusion criteria (Table 2).

Overall model metrics for the 4-factor EFA solution were sound: RMSEA=.037 [90% CI: .036-.039], CFI=.955, TLI=.949, $\chi^2(2624)=5580.36$, $p<.001$. Notably, comparable metrics were superior to a CFA with 8 factors based on the 8 a priori facets (i.e., candidate items from a given facet were forced onto the same factor). 8-factor CFA model fit metrics: RMSEA=.056 [90% CI: .055-.057], CFI=.894, TLI=.890, $\chi^2(2821)=9974.92$, $p<.001$. We thus conclude that a solution allowing for some factors to be combined (in particular into the 4-factors identified by the EFA reported here) provided a better overall account of the data than a solution that forced 8 separate factors based on the 8 a priori facets.

Correlations between EFA factors are provided in Table 2, and Figure 2 shows the rotated factor loadings. Note that items in Figure 2 are sorted first based on which factor they loaded most strongly, and then within a given factor based on relative factor loading. This allows one to quickly identify which types of items (in particular which facet they come from) loaded most consistently and strongly on each of the 4 emergent factors. To further provide a sense of what each factor potentially represents in terms of math experiences, Table 3 provides item text for the top 10 items from each factor.

<u>Factor 1: Attitudes and Avoidance Experiences.</u> The first factor appears to merge the Attitudinal (A) and Behavioral (B) facets, comprising 6 of the 7 negative A items and 6 of the 9 negative B items. No other facet contributed a majority of its items to this factor, and 9 of the top 10 items were from the A or B facet. We thus characterize this factor as capturing negative attitudes and avoidance behaviors toward math and refer to it as *Attitudes and Avoidance Experiences (AA)*.

<u>Factor 2: Physiological Experiences.</u> The second factor is dominated by items from the Physiological (P) facet, comprising 10 of the 11 negative P items. No other facet contributed a majority of its items to this factor, and 8 of the top 10 items were from the P facet. We thus characterize this factor as capturing negative physiological responses to math and refer to it as *Physiological Experiences (PH)*.

<u>Factor 3: Testing and Educational Experiences.</u> The third factor was made up primarily of items from the Testing (T) facet, comprising 8 of the 11 negative T items. No other facet contributed a majority of its items to this factor, and 7 of the top 10 items were from the T facet. We thus characterize this factor as capturing negative experiences with math testing performance in educational contexts and refer to it as *Testing and Educational Experiences (TE)*.

<u>Factor 4: Cognitive and Emotional Experiences.</u> The fourth factor appears to merge the Cognitive (C) and Emotional (E) facets, comprising 7 of the 10 negative C items and 5 of the 9 negative E items. No other facet contributed a majority of its items to this factor, and 8 of the top 10 items were from the C or E facet. We thus characterize this factor as capturing negative cognitive and emotional responses to math and refer to it as *Cognitive and Emotional Experiences (CE)*.

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Summary. To summarize, the 8 original facets distilled into just 4 factors, and this solution was superior to one that forced 8 factors based on the original facets. The Physiological (P) and Testing (T) facets emerged as distinct factors. Meanwhile, the Attitudinal (A) and Behavioral avoidance (B) facets merged into a single factor. Similarly, the Cognitive (C) and Emotional (E) facets merged into a (separate) single factor as well. On the other hand, the Self-efficacy (S) and Classroom and Social performance (CS) facets provided less of a coherent picture, with items from each facet seemingly dispersed across the 4 factors. This is not to say these facets are irrelevant, as each contributed some of the top items to several of the 4 factors. In the Discussion, we treat each of the points above in greater detail.

Table 2

Factor Index	Eigen-value	% Reduction to next Eigenvalue[1]	% Variance	Factor Correlations 1	2	3	4
1	46.192	90.4%	60.0%		.63	.68	.80
2	4.422	62.4%	5.7%	.63		.60	.78
3	1.661	24.3%	2.2%	.68	.60		.75
4	1.257	25.5%	1.6%	.80	.78	.75	
5	0.936	4.9%	1.2%				
6	0.890	10.2%	1.2%				
7	0.799	2.5%	1.0%				
8	0.779	8.9%	1.0%				
9	0.710	6.5%	0.9%				
10	0.664	12.3%	0.9%				

Table 2 shows factor metrics for the first 10 factors when considering the 77 negative items. The first 4 factors met inclusion criteria. [1]Indicates the percentage reduction in eigenvalues from that of the current factor to that of the next lowest factor in the table (see also footnote 1).

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Figure 2

Item	Factor 1	2	3	4
A01	1.05	-.09	.03	-.14
A03	.99	-.11	.00	-.05
A05	.94	.06	-.05	-.18
A02	.92	-.17	.12	-.01
A06	.78	.03	.17	-.17
A04	.76	-.04	.30	-.14
S02	.75	-.05	.17	.03
B02	.74	.13	-.11	.15
B04	.73	-.03	.04	.07
B03	.67	.19	.00	.01
B01	.64	.06	-.02	.09
C06	.56	-.10	.17	.22
E05	.54	.08	.03	.31
T01	.52	.03	.37	.04
C07	.51	.12	.13	.15
B09	.49	.38	-.08	.07
E04	.45	.02	.03	.45
S01	.45	.13	-.04	.41
T10	.43	.22	.25	.02
S09	.43	.16	-.02	.30
S06	.38	-.03	.26	.31
B08	.37	.27	.30	-.05

Item	Factor 1	2	3	4
P02	-.05	1.04	-.03	-.16
P07	.02	.99	.00	-.20
P01	.03	.94	-.01	-.09
P09	-.03	.94	.08	-.20
P08	.10	.87	-.01	-.07
P10	-.10	.86	.06	.03
P05	-.04	.83	.07	.01
P03	-.02	.80	.08	.02
E01	.11	.77	-.15	.15
CS06	-.14	.70	.06	.17
CS07	-.29	.65	.29	.07
P04	-.01	.64	.04	.23
B06	.28	.62	-.02	-.02
CS08	-.15	.58	.14	.26
S04	.16	.49	.01	.17
CS04	.10	.47	.03	.21
P12	.10	.47	.17	.14
P06	.13	.46	-.02	.36
E03	.18	.43	-.07	.40
B05	.39	.40	-.05	.10
B07	.30	.35	.04	.12

Item	Factor 1	2	3	4
T02	.09	.07	.60	.18
T03	.18	.16	.58	-.01
S03	.20	-.08	.48	.30
T07	.14	.12	.47	.23
T04	.30	.13	.46	.02
CS02	.24	.05	.45	.19
T11	.00	.34	.41	-.15
CS03	.17	.02	.40	.33
T05	.02	.17	.40	.31
T06	.25	-.07	.40	-.28
S07	.08	.32	.39	.09
C09	.05	.07	.34	.30
T08	.12	.31	.32	.10
CS01	.08	.15	.31	.29
A07	.13	.15	.21	-.15

Item	Factor 1	2	3	4
S08	.29	.02	.01	.62
E02	.20	.03	.11	.61
C02	.27	.22	-.11	.56
E08	.25	.03	.14	.56
C10	.26	.12	.04	.53
C08	.22	.18	.02	.53
CS05	-.09	.10	.24	.52
E06	.32	.21	-.07	.50
E09	.15	.23	.05	.50
C03	.21	.29	-.07	.49
C04	.45	-.11	.09	.48
S05	.18	-.05	.30	.48
C05	.27	.04	.18	.42
P11	.11	.35	.04	.41
C01	.21	.40	-.06	.40
S10	.33	-.15	.34	.39
E07	.33	.29	-.05	.38
T09	.18	.17	.22	.37
S11	.24	.11	.21	.28

Figure 2 shows rotated factor loadings from the EFA using the 77 negative items. The four factors are the top four factors from Table 2. See Figure 1 for abbreviations. Item text for the top 8 items from each factor can be found in Table 3 (full text for all items can be found in Table A-1). The grey line demarcates the top 10 items for a given factor.

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Table 3

Factor	Item	Item Text
Factor 1: *Attitudes & Avoidance Experiences (AA)*	A01	Math does not appeal to me.
	A03	I do not enjoy math.
	A05	Math is dull and boring.
	A02	I am not a math person.
	A06	I only ever took the bare minimum of math classes needed to finish school.
	A04	Math was among my least favorite subjects in school.
	S02	Math is my worst subject.
	B02	I avoid math whenever possible.
	B04	I would never consider a career that would require me to take advanced math courses.
	B03	I try to do as little math as possible in my daily life.
Factor 2: *Physiological Experiences (PH)*	P02	I feel like fainting when faced with a math problem.
	P07	I get indigestion and heartburn when I think about math.
	P01	Knowing that I have to do a math problem makes me feel nauseous and physically ill.
	P09	When doing math, I notice that I have to go to the bathroom more than usual.
	P08	My stomach hurts when I think about math.
	P10	Knowing that I will have to do a difficult math problem makes my hands shake.
	P05	My breathing becomes rapid and shallow when I am faced with a difficult math problem.
	P03	I experience sweaty palms when presented with a math problem.
	E01	I feel like crying when I have to do math.
	CS06	I am afraid that others will not approve of me because I am bad at math.
Factor 3: *Testing & Educational Experiences (TE)*	T02	As a student, I was always worried that I would not be able to finish math tests in time.
	T03	As a student, I often felt rushed during math tests.
	S03	I tend to second guess my work when doing math tasks.
	T07	As a student, I was terrified of pop quizzes in my math classes.
	T04	As a student, I often found that I was unable to do my best work on timed math tests.
	CS02	As a student, I was always worried about being called on in my math classes.
	T11	As a student, I remember math tests where I would only be able to remember the material after the test.
	CS03	As a student, I was afraid I would be unable to keep up with my peers in my math classes.
	T05	During math tests, I would find myself thinking and worrying about what it would mean to fail.
	T06	As a student, I felt much more confident on math tests that allowed a calculator, even if I did not end up needing it.
Factor 4: *Cognitive & Emotional Experiences (CE)*	S08	When I do math problems, I feel stupid.
	E02	I am often nervous when I have to do math.
	C02	When I see a math problem, my mind goes blank.
	E08	I feel anxious when I have to do math.
	C10	My mind feels disorganized whenever I have to do math.
	C08	My thoughts become distracted with worry when I have to do a math task.
	CS05	I feel embarrassed whenever I do not understand something in math.
	E06	I feel helpless when doing math.
	E09	I feel a sense of impending doom when I have to do a difficult math problem.
	C03	I am unable to think clearly when I am faced with a math problem.

Table 3 provides item text for the top 10 items (Figure 2) in the top 4 factors (Table 2) from the 77-item CFA.

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II) Measurement Tool – Negative Math Experiences Scale (NMES)

The previous section identified 4 factors in Table 2 comprising the top subcomponents of negative math experiences: Attitudes & Avoidance (AA), Physiological (PH), Testing & Educational (TE), Cognitive & Emotional (CE). In this section, we generate an abbreviated subscale to measure each of these factors. We did so by running 4 separate confirmatory factor analyses (CFAs). The inputs for a given CFA were the items that indexed most strongly on the relevant factor (Figure 2). For instance, in the first CFA, we included the 22 items that loaded primarily on the Attitudes & Avoidances subcomponent (Figure 2, top left), recoding them as AA01-AA22[2]. For the measurement subscale, we took the 6 items that loaded most strongly on the primary factor characterizing these items when considered in isolation. In theory, these 6 items optimally capture the core aspect of what comprises the AA subcomponent. The same process was then repeated for the other three subcomponents (PH, TE, CE). Factor matrix loadings of the items in each subcomponent are shown in Figure 3, with the top 6 items indicated in black ink above the grey line. Table 4 provides subscale summary statistics. Specificity metrics are given in Figure 4. Together, the four 6-item subscales comprise the 24-item *Negative Math Experiences Scale* (NMES), final text for which is given in Table 5. Note that the underlying factor structure from above (Figure 2, Table 3) was preserved when considering just the 24 items in the shortened scale.

Attitudes & Avoidance Experiences Subscale (AA)

From Figure 3, the top 6 items all loaded highly on the primary AA factor (loadings > .86). From Table 3, summary statistics showed scores that spanned the full range of the subscale (0-24)[3], with a mean score of 11.26 (s=7.66). The distribution showed minimal skew (0.10) with a slightly flattened shape, albeit within acceptable kurtosis limits[4] (-1.33). Internal reliability for this subscale was very good: Cronbach's α = .951. Figure 4 shows that average AA-to-AA correlations were significantly higher than AA-to-Other (PH, TE, CE) correlations (t=5.12, p=1.1E-06), demonstrating acceptable subscale specificity.

Physiological Experiences Subscale (PH)

From Figure 3, the top 6 items all loaded highly on the primary PH factor (loadings > .85). From Table 3, summary statistics showed scores that spanned the full range of the subscale (0-24), with a mean score of 7.26 (s=7.88). The distribution showed acceptable skew (0.67) with a slightly flattened shape, albeit within acceptable kurtosis limits (-0.75). Internal reliability for this subscale was very good: Cronbach's α = .948. Figure 4 shows that average PH-to-PH correlations were significantly higher than PH-to-Other (AA, TE, CE) correlations (t=8.80, p=1.1E-14), demonstrating acceptable subscale specificity.

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[2] Items were recoded according to their rank order in Figure 2 for the relevant subcomponent: AA01-AA22, PH01-PH21, TE01-TE15, CE01-CE19.

[3] Recall that individual items were scored as 0-4.

[4] Here we adopt the general guidelines that acceptable skew is between -1 and 1, and acceptable kurtosis is between -2 and 2 (Hair et al., 2021).

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Testing & Educational Experiences Subscale

From Figure 3, the top 6 items all loaded highly on the primary TE factor (loadings > .81). From Table 3, summary statistics showed scores that spanned the full range of the subscale (0-24), with a mean score of 11.84 (s=7.16). The distribution showed minimal skew (-0.11) with a slightly flattened shape, albeit within acceptable kurtosis limits (-1.20). Internal reliability for this subscale was very good: Cronbach's α = .936. Figure 4 shows that average TE-to-TE correlations were significantly higher than TE-to-Other (AA, PH, CE) correlations (t=4.18, p=5.5E-05), demonstrating acceptable subscale specificity.

Cognitive & Emotional Experiences Subscale

From Figure 3, the top 6 items all loaded highly on the primary PH factor (loadings > .88). From Table 3, summary statistics showed scores that spanned the full range of the subscale (0-24), with a mean score of 10.07 (s=7.41). The distribution showed minimal skew (0.19) with a slightly flattened shape, albeit within acceptable kurtosis limits (-1.28). Internal reliability for this subscale was very good: Cronbach's α = .958. Figure 4 shows that average CE-to-CE correlations were significantly higher than CE-to-Other (AA, PH, TE) correlations (t=8.07, p=6.0E-13), demonstrating acceptable subscale specificity.

Table 4

Subscale	Mean	SD	Skew	Kurtosis	Reliability (α)
Attitudes & Avoidance (AA)	11.26	7.66	0.10	-1.33	0.951
Physiological (PH)	7.26	6.88	0.67	-0.75	0.948
Testing & Educational (TE)	11.84	7.16	-0.11	-1.20	0.936
Cognitive & Emotional (CE)	10.07	7.41	0.19	-1.28	0.958

Table 4 provides metrics for the four subscales, using the final 6 items for each subscale identified in Figure 3, and final text for which is given in Table 5.

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Figure 3

Attitudes & Avoidance

Item	Loading
AA13	.882
AA08	.874
AA17	.873
AA07	.870
AA04	.863
AA01	.862
AA14	.859
AA18	.857
AA02	.848
AA06	.835
AA15	.825
AA21	.819
AA12	.806
AA10	.804
AA09	.791
AA19	.789
AA20	.782
AA05	.779
AA03	.775
AA16	.759
AA22	.744
AA11	.743

Physiological

Item	Loading
PH03	.882
PH05	.874
PH08	.865
PH09	.860
PH06	.854
PH12	.853
PH07	.852
PH01	.839
PH02	.836
PH19	.831
PH18	.830
PH04	.793
PH14	.789
PH10	.788
PH13	.766
PH17	.758
PH15	.746
PH16	.735
PH20	.710
PH11	.689
PH21	.676

Figure 3 shows factor loadings for the four subscales. A separate CFA was run for each subscale. The grey line demarcates the top 6 items for a given subscale.

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Testing & Educational

Item	Loading
TE04	.875
TE01	.859
TE08	.834
TE06	.833
TE02	.826
TE03	.818
TE05	.809
TE09	.799
TE11	.758
TE14	.739
TE13	.729
TE12	.687
TE07	.512
TE15	.288
TE10	.287

Cognitive & Emotional

Item	Loading
CE04	.904
CE05	.890
CE06	.889
CE08	.886
CE03	.885
CE02	.883
CE01	.881
CE17	.858
CE10	.856
CE09	.852
CE15	.852
CE11	.844
CE18	.833
CE16	.826
CE13	.822
CE12	.816
CE14	.813
CE19	.742
CE07	.689

Figure 4

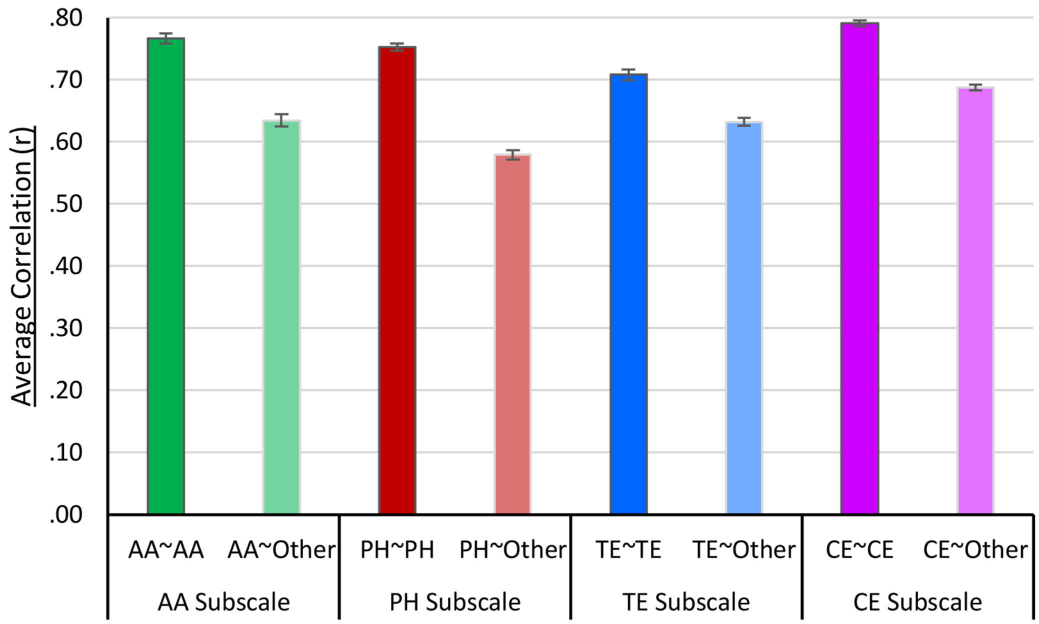

Figure 4 shows specificity of items within each subscale. Darker shaded bars (e.g., AA~AA) show average correlations among items within a given subscale. Lighter shaded bars (e.g., AA~Other) show average correlations between items in a given subscale with items from the other three subscales. Error-bars are standard errors of the mean.

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Table 5

Attitudes & Avoidance Experiences Subscale (AA)
I dread having to do math.
I avoid math whenever possible.
Math makes me feel uncomfortable.
Math is my worst subject.
I am not a math person.
Math does not appeal to me.
Physiological Experiences Subscale (PH)
Knowing that I have to do a math problem makes me feel nauseous and physically ill.
My stomach hurts when I think about math.
I experience sweaty palms when presented with a math problem.
I feel like crying when I have to do math.
Knowing that I will have to do a difficult math problem makes my hands shake.
I can feel my heart racing whenever I have to do math.
Testing & Educational Experiences Subscale (TE)
As a student, I was terrified of pop quizzes in my math classes.
As a student, I was always worried that I would not be able to finish math tests in time.
As a student, I was afraid I would be unable to keep up with my peers in my math classes.
As a student, I was always worried about being called on in my math classes.
As a student, I often felt rushed during math tests.
I tend to second guess my work when doing math tasks.
Cognitive & Emotional Experiences Subscale (CE)
I feel anxious when I have to do math.
My mind feels disorganized whenever I have to do math.
My thoughts become distracted with worry when I have to do a math task.
I feel helpless when doing math.
When I see a math problem, my mind goes blank.
I am often nervous when I have to do math.

Table 5 provides item text for the final 6 items for each of the four subscales. For reference, instruction text read as follows: "In this section you will be presented with a series of statements about experiences that people can have with mathematics. You will be asked to indicate the extent to which you agree or disagree with the following statements. Read each statement carefully and select the response that you feel most accurately describes you." We suggest randomizing item-order across participants (as was done here). Response options were as follows: "strongly disagree, disagree, neither agree nor disagree, agree, strongly agree", and coded 0-4, respectively.

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DISCUSSION

Here we propose a framework for integrating distinct and overlapping aspects of cognitive and non-cognitive factors pertaining to the wide range of negative math experiences that have been reported and studied in the literature. Following an extensive literature review of how previous research has characterized and measured negative math experiences, we posited an initial starting point of eight facets: emotional, cognitive, physiological, behavioral, classroom / social performance, testing, self-efficacy, and attitudinal experiences. An initial proof-of-concept analysis supported a clear distinction between negative vs positive math experiences both within and across facets. We then turned to a more data-driven approach in examining negative math experiences. There we found that the eight original facets coalesced into four main factors: negative attitudes and avoidance, negative physiological experiences, negative testing and education experiences, and negative cognitive and emotional experiences. We also generated individual subscales that capture each of these four factors. In the discussion that follows, we consider each of these factors and how they relate to the broader literature from which the initial eight facets were drawn.

One of the more surprising results was the robustness of the physiological aspect of negative math experiences. From Figure 2, we see that the top 8 items loading on what would come to be dubbed the Physiological factor (PH, factor 2) were all from the Physiological (P) facet, and all but one of the original 12 items from the P facet loaded on this factor. Together this suggests a high degree of conceptual coherence for physiological experiences. Furthermore, looking at Figure 1, we see that P items had many of the highest factor loadings on the primary negative valence factor (factor 1 in that analysis). In sum, despite being relatively overlooked to date in the literature examining math experiences (though see Liebert & Morris, 1967, and Ganley & McGraw, 2016, for notable exceptions), self-reported physiological experiences in math contexts appear to be a central and robust feature of people's negative impressions of math. A related consideration is that the PH subscale had the lowest average rating score, along with a slight positive skew (Table 4). One possibility is that only a relatively small subset of individuals experience negative physiological responses in math contexts, but such experiences are especially salient among those who do. Hence, reports of strong negative physiological experiences with math may be indicative of particularly debilitating cases of math anxiety, for instance. A final point worth considering is that, while the current dataset relies on self-reported physiological experiences, recent work suggests a disconnect between self-report and objective physiological measures of sympathetic responses during math (Daker et al., 2023a; Avancini & Szűcs, 2019). Furthermore, it was self-reported anxiety (and not objective measures) that performed best when explaining the link between math anxiety and math performance (Daker et al., 2023a). In sum, a closer examination of negative physiological experiences surrounding math – even self-reported experiences – may prove to be a fruitful area of future research.

Turning to the Cognitive and Emotional (CE) factor, we found this factor merged emotional experiences like anxiety and helplessness with cognitive experiences like mental disorganization and distraction. Interestingly, this result coincides with leading accounts of how emotional responses such as anxiety interfere with math performance – via disruption of attentional and

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executive control resources that are crucial for understanding complex math concepts and executing complex math procedures (Ashcraft, 2002; Ashcraft & Krause, 2007; Ramirez et al., 2018). Perhaps taking this one step further, the current results suggest that, in terms of how people experience math, anxiety and mental disorganization are in fact two sides of the same coin. To be sure, we are not saying that cognition and affect distill to the same underlying mechanism; rather, for many individuals who may experience math in a negative light, how they feel and their ability to think about math appear to be tightly linked. On a broader level, this view is consistent with the idea that mutual influence between cognitive and affective processes is more the exception than the rule (e.g., Lerner et al., 2015; Ochsner & Phelps, 2007;), and it is in this sense that, at the level of conscious experience, the two are two sides of a single coin.

With respect to the Attitudes and Avoidance factor (AA), it is interesting to see that this factor mainly merged the attitudinal (A) and behavioral avoidance (B) facets. On the one hand, math avoidance has long been hypothesized to be a core implication of negative math experiences (Ashcraft, 2002; Dowker et al., 2016). This has led to dedicated efforts especially in the education community to foster more positive attitudes toward math (e.g., Lim & Chapman, 2015; Suárez-Pellicioni et al., 2018; Werner, 2001; Zan et al., 2006). While the current data cannot speak to a causal link between negative attitudes toward math and math avoidance, they do support the notion that these two facets are – much as we saw with the cognitive and emotional facets – two sides of the same coin. On a broader scale, these data are consistent with the notion that attitudes and behavior are tightly linked in general (Centerbar & Clore, 2006; Gunderson et al., 2018; Melnikoff et al., 2020; Paige & Mansell, 2013). Perhaps another way to frame this is that subjective perceptions of a given domain – say, math – can influence one's tendency to approach or avoid that domain (Daker et al., 2023b). Probing the depth of this connection in the math domain at the level of neural structures that drive approach/avoidance behaviors (Lyons & Beilock, 2012; Aupperle et al., 2010, 2015; Ito & Lee, 2016), may be a fruitful area for future research.

In terms of negative experiences in educational contexts, we found that negative experiences with math testing (along with social comparison) seemed to be most prominent (TE factor). This result is perhaps especially interesting given growing debate about the value of testing in general (e.g., Tindal & Fuchs, 1999; Hart et al., 2015; Hollenbeck, 2002; Lovett, 2010), and in the math domain in particular (Boaler, 2014; Caviola et al., 2017). Here we should be careful to clarify that we are not suggesting the current data provide support for the notion that testing is bad – just that it is a core aspect of negative math experiences. To wit, unpleasant experiences, can often have positive value. For instance, one may not especially enjoy the feelings of muscle ache and exhaustion on a long run, but the various mental and health benefits one receives from such exercise remain despite the negative hedonic experience. Similarly, some have argued that testing can provide substantial benefits for learning and future skill resilience even when the process of taking the test itself is not especially pleasant (Benjamin & Pashler, 2015; Yang, et al., 2019). Regardless, the current data indicate that, when considering negative experiences with math, those in math testing contexts appear to be front and center in many individuals' minds.

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Implications

One of the aims of the current work was to facilitate attempts to provide an organizing framework for thinking about negative math experiences. It is our hope that this work will serve as a jumping off point for future endeavors that may build and improve upon what we have done here.

On a theoretical level, this work provides a template for how one might probe hypotheses about how extant constructs in the literature may or may not be overlapping in terms of the underlying phenomena they aim to describe. For instance, the current work suggests that cognitive disorganization and anxiety may well be two sides of the same underlying coin. Future work may directly test this hypothesis, for instance by examining similarity of neural responses to math anxiety and the feeling of being mentally disorganized when doing math. On the other hand, our data suggest that physiological experiences of math are highly distinctive. Thus, while it may be tempting to talk about math anxiety and physiological stress responses to math in the same breath, the two may not reduce so easily to one another. That said, this is merely a hypothesis born of the current data, and future work is needed to draw firmer conclusions, but that, we argue, is part of the added value of the current work.

On a practical level, Table 5 provides four subscales aimed at measuring the four negative math experiences factors that emerged from the primary EFA. These subscales are each short and should be relatively simple to administer. Despite their brevity, each has sound internal metrics (e.g., internal reliability, distribution metrics, etc.), and despite the fact that the four factors are clearly inter-correlated (Table 2), the subscales provide a degree of discriminability as well (Figure 4).

How might one make use of one or more of these subscales? To drill down on one potentially illustrative example, imagine one is interested in including a scale on math motivation, as well as a scale on math avoidance in a particular study. The current work suggests that these scales are likely to be highly correlated, and so including both in a regression model as predictors would likely to lead to high collinearity. The unique variance in some outcome of interest (say, math SAT scores) captured by either or both scales may tend toward zero, not because math motivation and avoidance are irrelevant for SAT performance, but because the two may cancel each other out in a regression context. One might then ask whether combining motivation and avoidance is justified – at least according to our dataset, the answer is, within reasonable limits, yes. To that end, on a practical level, the AA subscale offers a pre-made measure that does just that: One can be reasonably confident it will capture both (negative) motivation and avoidance-related variance, distilled into a single variable to assuage collinearity concerns, and with sound internal metrics. Conversely, one can be reasonably confident that, if one included two or more of the subscales offered here as predictors in a regression model, while they are not perfectly independent, they are capable of capturing interpretable, non-competing aspects of an outcome variable.

Limitations

We should note that we view this endeavor as but a first step in the direction of using a combined theory- and data-driven approach to unify research on how people experience mathematics. By no means is this paper meant to be the single, definitive work on the topic. First, such a thing is likely impossible. To wit, the current work examines only a single data-collection method, self-report,

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which while valuable, can by definition provide only part of the whole picture. For instance, the characteristics of our adult sample, particularly their accumulated life experiences with math, could have influenced the factor structure we observed. It remains unclear whether this structure would hold in younger populations who may not yet have formed such implicit or explicit associations with math.

We also focus here on negative math experiences, the structure of which may or may not be mirrored by positive math experiences. Another limitation is that, while we believe our review of the relevant literature to be fairly extensive, it is certainly possible that other researchers may see the literature as supporting one or more experiential facets that we did not consider here as part of our initial 8-facet basis set.

With respect to the NMES scale presented in Table 5, one important caveat is that here we do not provide external reliability metrics. On the one hand, we would note that scale development was not our primary motivation, but rather a secondary upshot of our theoretical approach. That said, given that three of the four factors – and hence three of the four subscales – in fact merged items coming from disparate sub-literatures; hence, it isn't altogether clear what measures would provide the best external validation in those cases. In the case of the physiological factor, we note above (1) the relative dearth of extant measures of physiological math experiences in the literature, and (2) there is poor alignment between self-report and objective physiological measures (Daker et al., 2023; Avancini & Szűcs, 2019). Hence, it may be that the optimal means of providing external validation for the subscales in Table 5 is more of a theoretical than a methodological question for future work.

Finally, it is important to point out that important contextual factors – such as race, gender and culture, to name just a few – may moderate some of the results reported here. Despite these limitations, we believe the current work may nevertheless serve as a valuable proof-of-concept for formulating a unified framework of math experiences, illustrating both the theoretical need to do so and a roadmap for how to address that need.

Conclusion

This study sought to unify and operationalize *negative math experiences*. Following an extensive literature review, we posited a framework of eight facets of negative math experiences, both cognitive and non-cognitive. We then sought to use a data-driven approach to unpack overlap and differentiation among these hypothesized facets. Exploratory factor analysis results suggested a distillation of the original eight facets into four distinct factors: attitudinal and avoidance experiences, physiological experiences, testing and educational experiences, and cognitive and emotional experiences. On a practical level, we were then able to provide short (6-item) subscales with strong internal metrics that capture core elements of each of the four types of negative math experiences. In sum, we hope the present paper provides coherent theoretical and practical contributions toward unifying the wide range of past and future research on how individuals may experience mathematics in a negative manner.

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DECLARATIONS

Ethical Approval

All participants provided informed consent and all procedures were approved by the Georgetown University Institutional Review Board (Approval #2017-1293)

Competing Interests

The authors declare no competing interests.

Data Availability Statement

The data supporting this work can be found on the Open Science Framework at the following link: https://osf.io/2rhqz/files/osfstorage

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APPENDIX A

Appendix A provides full item text and source information for all initial items in each facet.

Table A1: Emotional Facet

Item	Valence	Question Text	Concept	Source	Modification
E01	Negative	I feel like crying when I have to do math.	Crying	STAI (Spielberger et al., 1970)	Math-specific
E02	Negative	I am often nervous when I have to do math.	Nervousness	MAT (Aiken, 1974); MAS (Betz, 1978)	--
E03	Negative	I panic when I see math problems.	Panic	ASQ (Cameron & Nesse, 1986)	Math-specific
E04	Negative	Math makes me feel uncomfortable.	Discomfort	MAT (Aiken, 1974)	--
E05	Negative	I dread having to do math.	Dread	MAQ-M (Wigfield & Meece, 1988)	--
E06	Negative	I feel helpless when doing math.	Helpless	Mathematics Self-Concept, Self-Efficacy and Anxiety Scale (Lee, 2009)	--
E07	Negative	I feel frustrated and angry when I have to do math.	Frustration	MBS (Hendy et al., 2014)	Slight reword
E08	Negative	I feel anxious when I have to do math.	Anxiety	STAI (Spielberger et al., 1970)	Math-specific
E09	Negative	I feel a sense of impending doom when I have to do a difficult math problem.	Doom	ASQ (Cameron & Nesse, 1986)	Math-specific
E10	Positive	I feel calm and at ease when presented with a math problem.	Calm/ease	STAI (Spielberger et al., 1970)	Math-specific
E11	Positive	I am comfortable doing math.	Comfort	STAI (Spielberger et al., 1970)	Math-specific
E12	Positive	If someone tells me I have to do math, I rarely feel overwhelmed.	Absence of overwhelmed	Researcher created	--

Table A1 provides full item details for the initial set of Emotional items.

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Table A2: Cognitive Facet

Item	Valence	Question Text	Concept	Source	Modification
C01	Negative	When I see a math problem, I just freeze up.	Freezing up	Number Anxiety Scale (Dreger & Aiken, 1957)	Slight reword
C02	Negative	When I see a math problem, my mind goes blank.	Mind goes blank	MAS (Betz, 1978); FSMAS-R (Mulhern and Rae, 1998)	Slight reword
C03	Negative	I am unable to think clearly when I am faced with a math problem.	Unable to think clearly	MAS (Betz, 1978); FSMAS-R (Mulhern and Rae, 1998)	Slight reword
C04	Negative	Math makes me feel confused.	Confusion	MAT (Aiken, 1974)	Slight reword
C05	Negative	I feel mentally exhausted after doing math problems.	Mental exhaustion	STAI (Spielberger et al., 1970)	Slight reword
C06	Negative	Difficult math looks like a foreign language to me.	Foreign language	Researcher created	--
C07	Negative	My mind tends to wander when people talk to me about math.	Mind wanders	Researcher created	--
C08	Negative	My thoughts become distracted with worry when I have to do a math task.	Distracted with worry	Researcher created	--
C09	Negative	Worrying during important math tasks hinders my performance.	Worry	AAT (Alpert & Haber, 1960)	Slight reword
C10	Negative	My mind feels disorganized whenever I have to do math.	Disorganized	Researcher created	--
C11	Positive	I think clearly when I have to do math.	Thinking clearly	MAS (Betz, 1978); FSMAS-R (Mulhern and Rae, 1998)	Reversed
C12	Positive	I find it easy to concentrate on math for long periods of time.	Concentration	MBS (Hendy et al., 2014)	Reversed
C13	Positive	I rarely have trouble remembering the procedures to solve math problems.	Memory	MBS (Hendy et al., 2014)	Reversed

Table A2 provides full item details for the initial set of Cognitive items.

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Table A3: Physiological Facet

Item	Valence	Question Text	Concept	Source	Modification
P01	Negative	Knowing that I have to do a math problem makes me feel nauseous and physically ill.	Nausea	BAI (Beck et al., 1988)	Math-specific
P02	Negative	I feel like fainting when faced with a math problem.	Fainting	BAI (Beck et al., 1988)	Math-specific
P03	Negative	I experience sweaty palms when presented with a math problem.	Sweaty palms	BAI (Beck et al., 1988)	Math-specific
P04	Negative	I can feel my heart racing whenever I have to do math.	Heart racing	BAI (Beck et al., 1988)	Math-specific
P05	Negative	My breathing becomes rapid and shallow when I am faced with a difficult math problem.	Difficulty breathing	BAI (Beck et al., 1988)	Math-specific
P06	Negative	I can feel my body reacting in an unpleasant way when I have to do math.	Physical reactions	Researcher created	--
P07	Negative	I get indigestion and heartburn when I think about math.	Indigestion	BAI (Beck et al., 1988)	Math-specific
P08	Negative	My stomach hurts when I think about math.	Stomach	BAI (Beck et al., 1988)	Math-specific
P09	Negative	When doing math, I notice that I have to go to the bathroom more than usual.	Physiological response	ASQ (Cameron & Nesse, 1986)	Math-specific
P10	Negative	Knowing that I will have to do a difficult math problem makes my hands shake.	Shaky hands	BAI (Beck et al., 1988)	Math-specific
P11	Negative	I feel physically exhausted when I have to do math tasks.	Exhaustion	STAI (Spielberger et al, 1970)	Math-specific
P12	Negative	I often experience headaches when I have to do math for long periods of time.	Headaches	ASQ (Cameron & Nesse, 1986)	Math-specific
P13	Positive	When I do math, my body does not feel any different than when I do other challenging tasks.	Body feels different	Researcher created	--
P14	Positive	I feel fine when I have to do math.	Feel fine	Researcher created	--
P15	Positive	I feel calm and relaxed when I do math.	Feel calm	STAI (Spielberger et al., 1970)	Math-specific

Table A3 provides full item details for the initial set of Physiological items.

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Table A4: Behavioral Facet

Item	Valence	Question Text	Concept	Source	Modification
B01	Negative	I would rather have someone give me the solution to a difficult math problem than have to work it out for myself.	Avoidance	FSMAS-R (Rae & Mulhern, 1998)	--
B02	Negative	I avoid math whenever possible.	Avoidance	FSMAS-R (Rae & Mulhern, 1998)	Slight reword
B03	Negative	I try to do as little math as possible in my daily life.	Avoidance	FSMAS-R (Rae & Mulhern, 1998)	Slight reword
B04	Negative	I would never consider a career that would require me to take advanced math courses.	Avoidance	MAT (Aiken, 1974)	Slight reword
B05	Negative	I would not fill out an application for a school or program that required me to take a standardized math assessment.	Avoidance	MAT (Aiken, 1974)	Slight reword
B06	Negative	I tend to ask others to complete tasks for me if they involve math or numbers of any kind.	Help-seeking	Researcher created	--
B07	Negative	When I have to do a difficult math task, I wait until the very last minute.	Procrastination	ATMP (Won et al., 2018)	Concept reword; Researcher Created
B08	Negative	As a student, I would often find excuses for putting off my math homework.	Homework	ATMP (Won et al., 2018)	Math-specific
B09	Negative	I stop paying attention the moment someone starts talking about math.	Attention	Researcher created	--
B10	Positive	I would consider applying to a job that required me to take a math assessment.	Decision-making	MAT (Aiken, 1974)	Concept reword
B11	Positive	I would consider a career that involved complicated math.	Decision-making	MAT (Aiken, 1974)	Concept reword
B12	Positive	When I have to do a difficult math task, I try to start it right away.	Career	ATMP (Won et al., 2018)	Concept reword; Reversed
B13	Positive	If given the opportunity, I would definitely take more math classes.	Education	MAS (Betz, 1978)	Slight reword

Table A4 provides full item details for the initial set of Behavioral items.

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Table A5: Classroom / Social Performance Facet

Item	Valence	Question Text	Concept	Source	Modification
CS01	Negative	As a student, I was afraid to raise my hand to ask questions in my math classes.	Help-seeking	MA Online (Freedman, 2022)	Concept reword
CS02	Negative	As a student, I was always worried about being called on in my math classes.	Worry	MA Online (Freedman, 2022)	Concept reword
CS03	Negative	As a student, I was afraid I would be unable to keep up with my peers in my math classes.	Peers	MA Online (Freedman, 2022)	Concept reword
CS04	Negative	I am afraid to ask others questions about math.	Fear	MA Online (Freedman, 2022)	Concept reword
CS05	Negative	I feel embarrassed whenever I do not understand something in math.	Embarrassment	MBS (Hendy et al., 2014)	Slight reword
CS06	Negative	I am afraid that others will not approve of me because I am bad at math.	Fear of others	FNE (Leary, 1983)	Math-specific
CS07	Negative	Sometimes I think I am too concerned with what other people think of my math ability.	Social perceptions	FNE (Leary, 1983)	Math-specific
CS08	Negative	Whenever I do math, I feel like other people are looking at or judging me.	Social perceptions	ASQ (Cameron & Nesse, 1986)	Math-specific
CS09	Positive	As a student, I often volunteered to solve math problems on the board in my math classes.	Social comparison	MA Online (Freedman, 2022)	Concept reword
CS10	Positive	As a student, I was never too concerned with how I performed in math class relative to my peers.	Social comparison	MA Online (Freedman, 2022)	Concept reword
CS11	Positive	As a student, I looked forward to having my graded math exams returned.	Achievement	Researcher created	--
CS12	Positive	I feel comfortable discussing math with others.	Social	ATMI (Tapia, 1996)	Concept reword

Table A5 provides full item details for the initial set of Classroom / Social Performance items.

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Table A6: Testing Facet

Item	Valence	Question Text	Concept	Source	Modification
T01	Negative	As a student, I dreaded math tests more than any other kind of test.	Dread	MA Online	Slight reword
T02	Negative	As a student, I was always worried that I would not be able to finish math tests in time.	Testing	MIPS (Bessant, 1997)	Concept reword
T03	Negative	As a student, I often felt rushed during math tests.	Time pressure	MIPS (Bessant, 1997)	Concept reword
T04	Negative	As a student, I often found that I was unable to do my best work on timed math tests.	Testing	MIPS (Bessant, 1997)	Concept reword
T05	Negative	During math tests, I would find myself thinking and worrying about what it would mean to fail.	Testing	TAI (Spielberger, 2009)	Math-specific
T06	Negative	As a student, I felt much more confident on math tests that allowed a calculator, even if I did not end up needing it.	Calculator	Researcher created	--
T07	Negative	As a student, I was terrified of pop quizzes in my math classes.	Testing	sMARs (Alexander & Martray, 1989)	Concept reword
T08	Negative	As a student, I always lost points for simple numerical mistakes on math tests.	Testing	Researcher created	--
T09	Negative	The higher the stakes on a math test, the worse I would seem to do.	Testing	Researcher created	--
T10	Negative	As a student, I often resorted to guessing on math tests.	Guessing	Researcher created	--
T11	Negative	As a student, I remember math tests where I would only be able to remember the material after the test.	Testing	AAT (Alpert & Haber, 1960)	Concept reword
T12	Positive	To me, a math exam was just like any other exam that I encountered at school.	Testing	MA Online (Freedman, 2022)	Concept reword
T13	Positive	As a student, I was usually at ease during math tests.	Ease	MAS (Betz, 1978)	Slight reword
T14	Positive	As a student, feeling stressed while taking math tests helped me perform better.	Stress	Researcher created	--

Table A6 provides full item details for the initial set of Testing items.

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Table A7: Self-Efficacy Facet

Item	Valence	Question Text	Concept	Source	Modification
S01	Negative	Math is too hard for me.	Self-efficacy	MVI (Luttrell et al., 2010)	Concept reword
S02	Negative	Math is my worst subject.	Self-efficacy	MAS (Betz, 1978)	Slight reword
S03	Negative	I tend to second guess my work when doing math tasks.	Self-efficacy	ATMI (Tapia, 1996)	Concept reword
S04	Negative	I hesitate when doing math calculations, such as determining how much to tip or how to split a restaurant check.	Self-efficacy	ATMI (Tapia, 1996)	Concept reword
S05	Negative	Even when I feel like I know what to do, I still lack self-confidence when performing math tasks.	Self-confidence	STAI (Spielberger et al., 1970)	Math-specific
S06	Negative	When I do math, it is hard for me to be sure that I have the right answer.	Self-efficacy	ATMI (Tapia, 1996)	Concept reword
S07	Negative	As a student, I would often change my answer at the last minute on math tests.	Self-confidence	Researcher created	--
S08	Negative	When I do math problems, I feel stupid.	Self-efficacy	MBS (Hendy et al., 2014)	--
S09	Negative	I give up easily when I am unable to solve a math problem.	Self-efficacy	Researcher created	
S10	Negative	I often doubt my answers when I do math.	Self-doubt	Researcher created	Researcher created
S11	Negative	Although I can remember the general procedures and rules in math, I have difficulty applying them to new problems and situations.	Cognition	MIPS (Bessant, 1997)	Slight reword
S12	Positive	I am confident when performing math tasks without a calculator.	Self-confidence	Researcher created	--
S13	Positive	I am good at math.	Self-efficacy	FSMAS-R (Rae & Mulhern, 1998)	Reversed
S14	Positive	I am confident in my ability to learn new math concepts.	Self-efficacy	ATMI (Tapia, 1996)	Concept reword
S15	Positive	If I do not understand a math problem at first, I am confident that I will get it eventually.	Self-confidence	ATMI (Tapia, 1996)	Concept reword

Table A7 provides full item details for the initial set of Self-Efficacy items.

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Table A8: Attitudinal Facet

Item	Valence	Question Text	Concept	Source	Modification
A01	Negative	Math does not appeal to me.	Interest	ATMI (Tapia, 1996)	Reversed
A02	Negative	I am not a math person.	Identity	MSBS (Good et al., 2012)	Reversed
A03	Negative	I do not enjoy math.	Dislike	FSMAS (Fennema & Sherman, 1976)	Reversed
A04	Negative	Math was among my least favorite subjects in school.	Interest	MAT (Aiken, 1974)	Slight reword
A05	Negative	Math is dull and boring.	Disinterest	ATMI (Tapia, 1996)	--
A06	Negative	I only ever took the bare minimum of math classes needed to finish school.	Avoidance	ATMI (Tapia, 1996)	Reworded and Reversed
A07	Negative	In my math classes, I was motivated by getting good grades rather than by learning the material.	Intrinsic Motivation	Researcher created	--
A08	Positive	It is fun to do math.	Interest	MVI (Luttrell et al., 2010)	--
A09	Positive	I like math.	Interest	ATMI (Tapia, 1996)	Math
A10	Positive	I enjoy solving difficult math problems.	Interest	FSMAS (Fennema & Sherman, 1976)	Slight reword
A11	Positive	I am always interested in learning new math ideas or concepts.	Interest	MAT (Aiken, 1974)	Slight reword
A12	Positive	I consider myself part of the math community.	Identity	MSBS (Good et al., 2012)	Slight reword
A13	Positive	Being good at math is an important part of who I am.	Identity	Researcher created	--

Table A8 provides full item details for the initial set of Attitudinal items.

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