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Measuring mathematics anxiety: Paper 1 - Developing a construct model

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Abstract
The motivation for this paper was a growing need to better understand the manifestation of mathematics anxiety in different situations, at different times and for different persons. Such an understanding is important for those who teach mathematics, study mathematics or use mathematics in everyday life. Implicit in the notion of a better understanding is the systematic application of investigative techniques to both qualify and quantify this phenomenon.

The first section presents common accounts of experiencing mathematics anxiety and some of the consequences of these experiences. Then, possible causes or determinants of mathematics anxiety are examined. This is followed by a series of expository discussions commencing with clarification of the construct using a four-function model of construct specification which leads on to consideration of how to define the construct operationally. Next, these qualitative explanations are built upon to examine how Modern Measurement Theory can inform development of a construct model of mathematics anxiety. The final section operationalises theoretical and measurement issues by proposing an eight-domain construct model.

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Mathematics anxiety

The manifestation and significance of mathematics anxiety

The psychological indicators of mathematics anxiety include feelings of tension (Richardson & Suinn, 1972), fear and apprehension (D'Ailly & Bergering, 1992), low self confidence, a negative mind-set towards mathematics learning (Jain & Dowson, 2009), feeling threatened (Zohar, 1998), failing to reach potential (Perry, 2004) and a temporary reduction in working memory (Ashcraft & Kirk, 2001). Mathematics anxiety is physiologically exhibited by sweaty palms, nausea, heart palpitations and difficulty in breathing (Malinski, Ross, Pannells & McJunkin, 2006; Perry, 2004). It interferes with the manipulation of numbers and the solving of mathematical problems in academic, private, and social environments (Richardson & Suinn, 1972; Suinn, Taylor & Edwards, 1988).

While the phenomenon is most often associated with formal mathematics instruction and testing in elementary schools, secondary schools, colleges and universities, (Suinn, Taylor & Edwards, 1988), it is also a common occurrence in daily life and work. For example, it can be seen in the avoidance of environments and careers that require application of mathematical skills (Hopko, 2003). Within classrooms, this form of anxiety is not restricted to students. Teachers have reported nervousness or lack of confidence when required to teach or use mathematical operations (Malinski, Ross, Pannells & McJunkin, 2006).

Mathematics anxiety is often viewed from a deficit perspective through which it explains a lack of demonstrable mathematical ability. For example, it is defined as a restrictive influence on successful working with numbers and problem-solving (Furner & Berman, 2003; Suinn, Taylor & Edwards, 1988). Indeed, there is a well established negative correlation between mathematics anxiety measures and performance on tests of mathematical ability (Ma, 1999; Jain & Dowson, 2009; Satake & Amato, 1995). Consequently, research has concentrated on understanding the causes of mathematics anxiety on the assumption that if anxiety levels are decreased, there will be improvements in cognitive, behavioural and attitudinal aspects of mathematics learning. For example, by manipulating instructional variables such as teacher behaviours, task structure and classroom context (Perry, 2004; Jain & Dowson, 2009).

The antecedents of mathematics anxiety

The sources of mathematics anxiety are varied, inter-related and inconsistent in their effects (Furner & Berman, 2003; Jain & Dowson, 2009). For example, Baloglu and Kocak (2006) noted that some studies have reported gender influences whereas others have failed to substantiate such influences. Furner & Berman (2003) qualified the influence of gender by noting a further complication - the relative levels of mathematics anxiety of boys and girls changes with age, neither boys nor girls have been shown to have a consistently higher level. Similarly, Jackson and Leffingwell (1999) reported that student perceptions of anxiety-causing teacher behaviours differed significantly between the elementary, high school level and college levels of education – students at different levels identified teacher effects specific to their level of education. Notwithstanding these uncertainties, the causes can be broadly classified as attributes of the student, the family, the teacher and instruction, peers, and the nature of mathematics (Baloglu & Kocak, 2006). Student attributes include dispositional causes that are personality-related internal characteristics of the individual student (Baloglu & Kocak, 2006). The effect of family can be illustrated by anxiety increasing when parents have limited or negative experiences with mathematics (Furner & Berman, 2003). The types of teacher behaviour that cause and reinforce mathematics anxiety in students were investigated by Jackson & Leffingwell (1999). Students reported they experienced mathematics anxiety as a result of the difficulty of the material, competing with peers, teacher hostility towards students, teacher gender bias, teacher anger, teacher insensitivity, and lack of remediation. With regard to the influence of peers, Buckley (2008) noted the increased significance of peer relationships in adolescence which is a time of life also frequently characterised by increased mathematics anxiety. Finally, while student perceptions of the nature of mathematics are affected by classroom experiences and attitudinal factors, the intrinsic abstractness, symbolism and rules of mathematics may also present difficulty to certain students (Berebitsky, 1985).

The construct of mathematics anxiety

In the preceding sections, mathematics anxiety was explained in terms of how it is manifest and the factors, which influence its development. While this form of information is useful in understanding the nature of a phenomenon, it is insufficient for precisely defining a psychological construct or a latent trait. Specification of crucial aspects of a latent trait typically requires development of a construct model. A construct model can describe:

- The componential/internal structure of the construct;
- It's relationship to other constructs;
- Incumbent developmental assumptions - levels of proficiency; and
- Incumbent cognitive processing assumptions - cognitive activities and states (Wolfe and Smith, 2007).

These four dimensions are usually *a priori* considerations in the design of investigations of latent traits. However, they also have utility for *a posteriori* assessment of previous research and theorising. Mathematics anxiety has been studied for at least 50 years. For example, in 1957, Dreger and Aitken investigated number anxiety. Since then, numerous theories have been proposed and a variety of instruments have been developed and administered. Notwithstanding this effort, there are still uncertainties and contradictions in how mathematics anxiety is conceptualised resulting in no commonly accepted construct model (Kazelskis, Reeves, Kersh, Bailey, Cole, Larmon, Hall & Holliday, 2000). In the following sections, the above four functions of a construct model will be used as a theoretical framework to assay the literature on mathematics anxiety with the intention of clarifying the construct.

1. The componential structure of mathematics anxiety. This aspect of construct definition centres on two issues - differentiating between mathematics anxiety and test anxiety, and the dimensionality of mathematics anxiety.

First, the correlation of data from measures of mathematical anxiety with that from measures of test anxiety is often interpreted as evidence of similarity between the two anxieties. Alternatively, another interpretation is that mathematics anxiety is a form of test anxiety (Kazelskis et al., 2000). Resolving this inconsistency empirically is difficult. The data from measures of mathematics anxiety are weakly correlated. Hence, the extent of correlation between data from mathematics anxiety instruments and that from test anxiety instruments is confounded by the low correlation between data from the mathematics anxiety instruments. The strength of the association between mathematics anxiety and test anxiety is dependent on the measure used.

Second, analysis of data from the different anxiety measures provides evidence of both uni-dimensionality and multi-dimensionality. Studies confirming a uni-dimensional structure within the data include Beasley, Long and Natali's (2001) administration of the *Mathematics Anxiety Scale for Children* (MASC) to 278 sixth grade students; and Prieto and Delgado's (2007) administration of a Spanish version of the *Mathematics Anxiety Rating Scale* (MARS) to 627 Spanish 13 and 14 year-old students. Multi-dimensionality was found in *Revised Mathematics Anxiety Rating Scale* (RMARS) data from 805 college students (Baloglu & Zelhart, 2007); *Mathematics Anxiety Rating Scale Revised* (MARS-R) data from 815 college students (Hopko, 2003); *Mathematics Anxiety Rating Scale for Elementary* Children (MARS-E Japanese version) data from 154 fifth and sixth grade students (Satake & Amato, 1995); and *Mathematics Anxiety Rating Scale for Adolescents* (MARS-A) data from 1780 secondary school students (Suinn & Edwards, 1982).

In the cases of multi-dimensionality, different factorial structures have been confirmed for different measures. In MARS-A data, two factors, *Numerical Anxiety* and *Test Anxiety*, accounted for 91% of the variance in all test items (Suinn & Edwards, 1982). Similarly, in MARS-R data, a two-factor solution was validated by confirmatory factor analysis. The factors were *Learning Math Anxiety* (LMA - anxiety about the process of learning), and *Math Evaluation Anxiety* (MEA - related to testing situations) (Hopko, 2003). Baloglu & Zelhart, (2007) confirmed three factors in RMARS data – *Numerical Task Anxiety*, *Mathematics Test Anxiety* and *Mathematics Course Anxiety*. The *Mathematics Course Anxiety* factor included worry about the choice of mathematics course. Satake & Amato (1995) found four factors in MARS-E (Japanese version) data – *Mathematics Calculation/Problem Solving Anxiety*, *Mathematics Test Anxiety*, *Mathematics Classroom Performance Anxiety*, and *Mathematics Application Anxiety*. All these multi-dimensional measures of mathematic anxiety include a test anxiety dimension.

Kazelskis (1998) administered three mathematics anxiety instruments to 323 undergraduate college students. The instruments were the 25-item RMARS (*Revised Mathematics Anxiety Rating Scale*), the 11-item MAQ (*Mathematics Anxiety Questionnaire*) (Betz, 1978), and the 12-item MAS (*Mathematics Anxiety Scale*). A principal components factor analysis with oblique rotations revealed six factors that accounted for 60.7% of the total variance. These were *Mathematics Test anxiety* (15 items), *Numerical anxiety* (five items), *Negative Affect Towards Mathematics* (six items), *Worry* (four items), *Positive Affect Towards Mathematics* (eight items), and *Math Course Anxiety* (five items). The dimensions tended to be specific to the respective instruments and the study did not provide evidence to support a single higher order mathematics anxiety construct.

2. The relationship of mathematics anxiety to other constructs. As was noted previously, measures of mathematics anxiety negatively correlate with measures of mathematical ability, particularly when the ability is assessed in tests or examinations. This relationship requires qualification. It is curvilinear because low levels of anxiety are associated with higher performance but then as anxiety increases, performance decreases (Ma, 1999). D'Ailly & Bergering (1992) administered the *Maths Avoidance Behaviour Test* (MABT) and two 15-item scales from the original MARS – *Math Test Anxiety* (MTA) and *Numerical Anxiety* (NA) to 112 university students. The correlations between mathematics avoidance behaviour and the two mathematics anxiety scales were small yet significant. Jain & Dowson (2009) applied structural equation modelling to data from 232 eighth grade Indian students obtained from the *Motivated Strategies for Learning Questionnaire* (MSL0) and ten-item *Mathematics Anxiety Scale* (MAS) (Fennema & Sherman, 1976). The MSLO is a 55-item questionnaire consisting of scales measuring self-efficacy, test anxiety, cognitive and metacognitive strategies. There was good data fit to a model in which self-regulation and self-efficacy were directly related and there was an inverse relation between self-efficacy and maths anxiety. Ashcraft & Kirk (2001) investigated the relationship between data from the *Short Mathematics Anxiety rating Scale* (sMARS) and *Listening Span* (L-span) and *Computation Spa*n (C-span) tasks to assess working memory. There was an inverse relation between the C-span scores and the mathematics anxiety scores. Wigfield and Meece (1988) found significant correlations between Mathematics Anxiety Questionnaire (MAQ) data and measures of mathematical ability perceptions, mathematics task demands, mathematics interest and mathematics performance.

These positive and negative associations substantiate theorised similarities and differences between mathematics anxiety and related constructs. They provide external points of reference for the construct model.

3. *Developmental assumptions.* Latent traits such as cognitive abilities often have a developmental aspect in recognition of the changes and growth of the ability over time. Implicit in this developmental view is a hierarchical model with descriptors of stages of development or of levels of proficiency. For example, a developmental continuum that shows how a child's learning in a particular area of the curriculum progresses through sequential stages as the child masters increasingly difficult knowledge and skills.

Examination of the mathematics anxiety literature revealed a paucity of research or construct models incorporating developmental models. One exception is the construct model underpinning the 18-item Math Anxiety Scale developed by Prieto & Delgado (2007). The 18 self-report items indicating mathematics anxiety presented students with varying levels of affirmativeness –some items were easily affirmed by many students while other items were more difficult to affirm. For example, Item 15 (Before taking a math exam I feel nausea), was more difficult to affirm than Item 12 (My mind goes blank when taking maths exams). The developmental model of mathematics' anxiety applied here specifies that experiencing nausea indicates a higher level of anxiety than having a blank mind. Another example of developmental model can be found in the *Attitudes Towards Mathematics and its Teaching Survey* (ATMAT) (Ludlow & Bell, 1996). Attitudes towards teaching junior primary students were more positive than towards teaching upper-secondary students. The data showed that only the students with the highest attitude scores affirmed their confidence to teach at the upper-secondary level.

The modelling of levels of proficiency/developmental stages is necessary for qualifying the extent of the presence of the construct in different persons. The difference between persons needs to be in degrees of the same qualities and not in the types of qualities. If the types of qualities differ, then it is likely that different combinations of qualities will indicate different constructs. Similarly, mapping the development of a person's ability also requires a collection of data on the same characteristics over time. For these reasons, it is important to build developmental or proficiency level models of mathematics anxiety.

4. Cognitive processing assumptions. Because mathematics anxiety is a latent trait, the psychological manifestations of this trait are governed by cognitive process and cognitive states. While these aspect of the construct are not directly observable, the construct model can include theorising on the assumption that confirmatory evidence will be forthcoming. For example, the Jain & Dowson (2009) study tested a model of motivational strategies and mathematics anxiety. This was based on the assumption that "… perceived self-regulatory competence is a necessary but not sufficient condition for reduced mathematics anxiety because self-regulation operates substantially within the cognitive domain whereas anxiety operates substantially within the affective domain (Jain & Dowson, 2009, p. 243). They also theorised that internalised efficacy would counteract the negative effect of anxiety. Specification of these internal processes enables an understanding of the construct by providing reasons for observations based on cognitive theory. This is in contrast to *post hoc* identification of sources of anxiety from observations and analysis of associations within data.

Sherman and Wither (2003) researched the issue of causality between mathematics achievement and mathematics anxiety in conjunction with the possibility of a third underlying factor. When data from a five-year longitudinal study were analysed by cross-lagged panel analysis, they concluded "…the data do not support the hypothesis that mathematical anxiety causes a lack of mathematical achievement, but that either the lack of mathematical achievement causes mathematical anxiety, or there is a third factor which causes both" (Sherman & Wither, 2003, p. 148). This causal relationship has implications for how cognitive aspects of mathematics anxiety are modelled.

Recount. The theorising and research into mathematics anxiety is characterised by several tensions. First, is the uncertainty about the theoretical relationship between mathematics anxiety and test anxiety. Second is the dimensionality of the construct. Third is the variety of factorial structures in data from different instruments. Fourth, most of the construct models and instruments do not have a developmental structure. Fifth, theoretical specification of cognitive processing models including causality is much less common than empirical identification of 'influences' on mathematics anxiety.

Operationally defining mathematics anxiety

Creating a detailed description of a construct is an initial stage in instrument design. The construct model can then be applied to identify the ways the construct will be behaviourally manifest. The construct is operationalised "… by identifying a universe of potential indicators of the construct … numerous ways in which we could potentially observe evidence relating to the construct" (Wolfe & Smith, 2007, p. 106). For example, by examining the components and relationships within the construct model to choose appropriate tasks that elicit confirmatory data. This also requires consideration and specification of data analysis processes and tools to test that the data performs as expected.

As was noted earlier, different types of indicators have been utilised in mathematics anxiety measures. These can be classified as physiological hyperarousal (e.g. shaking), cognitive (e.g.

poor test performance) or affective (e.g. lack of confidence). If these indicators all provide evidence of the same construct, then a construct model that explains why this is to be expected is required. Alternatively, a multi-dimensional model, which specifies multiple factors, might be more appropriate. The nub of this dilemma is whether a multi-dimensional componential structure is appropriate for a construct that delineates a unique latent trait. A related issue is choosing an analytic procedure (measurement model) that requires observations to fit a particular type of construct model. For example, a confirmatory factor analysis tests that data fit a multi-factor model whereas a Rasch Rating Scale model analysis (Andrich, 1978a, 1978b) requires data fit a uni-dimensional model.

An operational definition of mathematics anxiety needs to be conceptually consistent with the components and structure of the construct model, and specify instrumentation to observe the indicators and techniques to test data to model fit. With these matters in mind, the following section explores the implications of applying modern Measurement Theory (MMT) (Osterlind, 2006), specifically the Rasch model (Rasch, 1960) to construct an objective measure of mathematics anxiety.

The objective measurement of mathematics anxiety

Modern Measurement Theory

Modern Measurement Theory (MMT) utilises measurement models including Item Response Theory (IRT) and Rasch models. A major difference between these models and those based on Classical Test Theory is analysis of the properties of data from individual items in contrast to aggregating data from multiple items and then analysing the aggregation (Bond & Fox, 2007). In the case of tests of performance or ability, IRT models require that the test items are measuring a *single continuous latent variable*. Also, the item responses are assumed to be independent of one another, the only relation between items is explained by the conditional relationship with the latent variable – the requirement for *local independence*. In particular, the Rasch model requires *specific objectivity*. That is, comparison of two items' difficulty parameters are assumed independent of any group of subjects studied; and comparison of two subjects' trait level does not depend on any subset of items being administered. The Rasch model defines the relation between *subject ability and item difficulty* - the probability of endorsing an item is a function of the difference between a person's level on the underlying trait and the difficulty of the item. Both person ability estimates and item difficulty estimates are measured in logits. Raw scores are tested against the Rasch model and when the data fit the model, *interval person ability estimates* and *interval item difficulty estimates* are produced.

Modern Measurement Theory has the potential to resolve some of the difficulty in explaining and operationally defining the construct of mathematics anxiety. The first resolution concerns the uni-dimensionality requirement. Analyses confirming a multi-dimensional structure in mathematics anxiety data usually identified a mathematics test anxiety factor in addition to other factors such as numerical anxiety (Baloglu & Zelhart, 2007; Hopko, 2003; Kazelskis, 1998; Satake & Amato, 1995; Suinn & Edwards, 1982). This finding suggests mathematics test anxiety should be treated as a separate yet related construct to other forms of mathematics anxiety. Distinguishing between anxiety constructs could use a typology comprising different instructional, assessment and application activities – situational types of mathematics anxiety or domains of mathematics anxiety. For example, working independently, working individually, working in groups, or working in a class group; summative assessment through written examinations and in-class written tests, and formative assessment through quizzes and exercises; and using mathematics outside of the mathematics class in other subjects, at home or for work. Psychological measures of anxiety distinguish between state anxiety and trait anxiety. State anxiety is situationally and temporally dependent, whereas trait anxiety is a function of personality and is stable over time (Barnes, Harp & Jung, 2002; Gros, Antony, Simms & McCabe, 2007). The notion of situational types of mathematics anxiety is similar to that of state anxiety. Measuring the situational types would require multiple measurements because the respective levels of the types of anxiety are likely to vary between individuals. For example, between a student who experiences high anxiety when working with others, and low anxiety when working individually, and another student who experiences low anxiety when working with others, and high anxiety when working alone.

Second, the situational specificity of the constructs enables each to be measured more precisely than a general mathematics anxiety construct comprising multiple dimensions. Aggregation of scores across multiple dimensions can lead to students with markedly different qualities gaining similar overall scores. This inaccuracy can affect the relations of multi-dimensional anxiety measures to other constructs and weaken criterion-related evidence of construct validity.

Third, for each type of anxiety, the observations that indicate anxiety need to be sensitive to the different levels of anxiety within the population. That is, some indicators will be observable in many persons including those with low anxiety, while other indicators will characterise only those persons with high anxiety. A developmental model or proficiency level model assists in specification of indicators and observations that function this way. For example, the Prieto and Delgado (2007) and the Ludlow & Bell (1996) studies showed students found it easier to affirm the cognitive dimension of their anxiety than to affirm the somatic dimension by reporting physiological hyperarousal. This inference is consistent with the Theory of Reasoned Action (TRA) (Fishbein & Azjen, 1975) which proposes behavioural intentions, attitudes, and subjective social norm influences can predict behaviour. Applying this terminology to a developmental construct model incorporating these dimensions and hierarchies would specify attitudinal and cognitive indicators as precursors to somatic indicators in all domains of mathematics anxiety.

Fourth, from a psychological perspective, arousal of the emotions that accompany state anxiety can be viewed as a cognitive process (Lazarus, 1991). According to this cognitive processing model, the level of threat is cognitively appraised and an affirmative appraisal stimulates the emotional experiences that exemplify anxiety. The implication for objective measurement of mathematics anxiety is that mathematics anxiety construct models need to incorporate the threat appraisal process to ensure data are gathered on this process. In addition, when a measurement model is applied to analyse data on different types of mathematics anxiety, presence of the threat appraisal process is expected to indicate all types of mathematics anxiety.

A construct model of mathematics anxiety

The following model of mathematics anxiety (see Table 1) comprises the components and processes discussed in the preceding discussion of mathematics anxiety. The horizontal dimension portrays three types of anxiety – mathematics instruction anxiety when being taught mathematics, mathematics assessment anxiety when mathematics learning is assessed, and mathematics application anxiety when mathematics knowledge and skills are applied outside the mathematics classroom. The order of the situations is arbitrary and relations between the three types are likely. In each of these situations, a person's anxiety will depend on attributes of the person as well as the demands of the situation. For example, in the case of instruction anxiety, a self-conscious student panicking when asked to answer a question in front of the whole class. For assessment anxiety, a highly ambitious student sitting a high-stakes examination that will determine entry to university. For application anxiety, an inexperienced sales assistant with weak number skills calculating change at a super-market checkout counter. In each case, the level of anxiety is a function of the person's capabilities in conjunction with the task requirements of the situation. Table 1 identifies eight potential domains of anxiety but this list is not exhaustive.

Table 1.
Situational model of mathematics anxiety

		Situational types of mathematics anxiety							
		Instruction			Assessment		Application		
Level	**Domains**	Independent work	Group work	Working in a class group	Formal - examinations and tests	Informal - quizzes and worksheets	Other subjects	Home	Work
Extreme anxiety ↑	Somatic indicators								
	Cognitive indicators								
Low anxiety	Attitudinal indicators								

The vertical dimension shows levels of anxiety. Extreme anxiety is characterised by somatic indicators such as heart palpitations, abnormal breathing, and sweaty palms; high anxiety by cognitive indictors such as confusion, a blank mind, and loss of control; and low anxiety by attitudinal indicators such as worry, expectations of difficulty and lack of confidence. The criteria for differentiating between cognitive and attitudinal indicators were that the cognitive indicators concerned mental process stimulated by the situation, whereas attitudinal indicators were attitudes towards the situation. The indicators are cumulative – a person experiencing extreme anxiety will also present the lower level indicators although these could be less obvious due to over-shadowing by the extreme indicators or have been experienced previously.

Conclusion

Many of the instruments developed to measure mathematics anxiety demonstrate application of Classical Test Theory in instrument construction and the analysis of anxiety data. The use of factor analytic techniques for instrument design and validation has led to acceptance of multi-dimensional representations of mathematics anxiety but these differ in content and structure. Alternatively, application of Modern Measurement Theory requires clear specification of uni-dimensional construct models and design of instrumentation that produces data fitting an IRT or Rasch model. The use of Modern Measurement Theory necessitates careful and early attention to construct model specification since data are required to fit with this theoretical model in addition to fitting the measurement model.

It was argued that the lack of consistency in prevailing mathematics anxiety theory is rectifiable by using Modern Measurement Theory for measure construction. This approach negates modification of the construct model (model to the data fit) by focussing on constructing the measure (data to model fit)..

Further research will include pilot testing of a self-report ‘situational mathematics anxiety’ instrument and Rasch Rating Scale model analysis of resulting data (see the accompanying paper - *Measuring mathematics anxiety: Paper 2 - Constructing and validating the measure*). The availability of interval measures of situational mathematics anxiety will enable investigation of associations with other instructional constructs such as motivation and engagement.

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