



Conceptions of Disciplinary Anxiety across Science, Technology, Engineering, and Mathematics (STEM) Contexts: A Critical and Theoretical Synthesis

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Abstract: Education policy is currently calling for wholistic reform towards the integration of Science, Technology, Engineering, and Mathematics (STEM). However, much of the calls lack practical advice or application to aid classroom and teaching professionals in this venture. Of particular interest should be how properties, such as barriers, of the individual disciplines may change in an integrated form. One such barrier that should be considered is that of anxiety. This review develops a novel framework for STEM anxiety in the educational context. This is accomplished through a review of anxiety literature within the individual disciplines, with reference to related psychological constructs. Literature was reviewed for definitions of anxiety within the disciplines, ways that disciplinary anxiety has been measured, and what antecedents were identified. Antecedents were taken from those that were explicitly identified, as well as those that were inferentially indicated in the definitions or the measurement instruments. The antecedents, or contributors, to the individual disciplinary anxieties were cross-referenced to generate a single list of potential antecedents that may impact learning within the integrated STEM space.

Keywords: Anxiety; Disciplinary Anxiety; STEM; STEM Anxiety; Theoretical Synthesis

Introduction

Science, Technology, Engineering, and Mathematics (STEM) education encompasses highly diverse student outcomes (Honey et al., 2014; Moore et al., 2020) ultimately hoping that students achieving these outcomes will meet the growing need for informed citizenry and a STEM-oriented workforce. While these outcomes are best achieved by anchoring instruction in real-life phenomena (Bybee, 2010; Moore et al., 2020; Talanquer, 2014), it can be a daunting task for classroom teachers due the individualistic nature of disciplinary instruction and the ill-defined concept of integrated STEM (Moore et al., 2020). Some argue that integrated STEM is integration of two independent disciplines in the same instructional space. Others posit that STEM integration is only achieved by conceptual and theoretical integration of each of the disciplines driving the instruction (Brown & Bogiages, 2019). Regardless of the definition, the push to integrate STEM into classroom instruction is a challenge.

As the focus of education policy and practice shifts from the individual disciplines to integrated STEM, there is the potential for emergent difficulties or barriers as a result. One of these potential barriers is the anxiety that often arises around STEM content in both teachers and students. Disciplinary anxieties are supported by decades of research in their respective fields. However, these disciplinary research agendas have been conducted in isolation from one another without consideration of anxiety manifestation in cross-curricular or integrated settings, such as in STEM. With the proposition of a more integrated curricular model of STEM, there is the potential for a novel

integrated STEM anxiety to arise as an emergent property of these reform efforts. This literature review aims to explore similarities and differences in STEM disciplinary anxieties' research literatures through a review and synthesis model. We then discuss the antecedents that lead to disciplinary anxiety and how these may overlap when considering integrated STEM anxiety as a construct. This will provide an attempt to understand the potential causes of STEM anxiety.

Anxiety in Educational Contexts

Educational settings can be anxiety-inducing in both students and teachers presenting any number of symbolic, uncertain, or anticipatory threats as defined by Lazarus & Averill (1972). Learning in a classroom context can be an example of a symbolic threat to a student, the difficulty of connecting new and old information, as well as a potentially uncertain threat, the perception of what difficulty may look like to peers in a social situation. Additionally, there are several examples of anticipatory threats in classrooms; students identifying as a racial or socioeconomic (SES) minority may be subject to stereotype threat as a form of anticipatory threat. Students may also experience a range of trait and state anxieties (Spielberger & Rickman, 1990) when engaging with disciplinary content, such as simply being in a mathematics or science classroom.

Clearly, numerous aspects of a STEM classroom could serve as potential threats and induce various types of state and/or trait anxiety for both students and teachers. Educational research has explored these ideas in various contexts, but as we note above, these studies have often been siloed under disciplines with little cross-disciplinary or interdisciplinary considerations. The following sections outline our methods for the literature search to explore how each of these disciplines define, measure, and explore antecedents to disciplinary anxiety. The broad guiding questions for this synthesis were:

1. How has anxiety been conceptualized in education research within the STEM disciplines?
2. How has disciplinary anxiety been measured in education research?
3. What moderating antecedents have been shown to relate to disciplinary anxiety?

Methods

Literature Search Procedure

This literature search was conducted using both Google Scholar and the university library database using with basic Boolean search terms (*Psychological Anxiety, Science Anxiety, Technology Anxiety, Computer Anxiety, Engineering Anxiety, Statistics Anxiety, and Mathematics Anxiety*). There were no date limitations placed on the searches.

Inclusion Criteria

The following list defines the inclusion criteria for studies found as part of the literature search.

1. Studies were empirically-based, peer-reviewed, in a STEM education context, and had to have somehow defined anxiety within the article.
 - a. Articles were categorized based upon the explicitness of their anxiety definitions. The study: 1) used the term anxiety without an explicit definition. Studies in this category were eventually excluded; 2) provided a definition of anxiety by referencing other studies, or 3) provided a novel definition for anxiety.
2. Studies were found in one of the aforementioned databases or were cited by studies found through this search protocol.
3. Primary studies from peer-reviewed journal articles, dissertations/theses were included, as well as chapters from edited volumes or professional reports.

Exclusion Criteria

The following list defines the exclusion criteria for studies found as part of the literature search:

1. Studies that were not in STEM fields (e.g., literacy or reading anxiety) were excluded from this review.
2. Studies that were in the STEM disciplines fields but were in non-educational (e.g., business or laboratory management) contexts were excluded.

Selection Process

Included studies were reviewed for anxiety definitions and methodological information, such as sample size and description, and validation steps for measurement instruments, if applicable. An original sample size of $n = 130$ studies was collected utilizing this method (Figure 1). All articles were categorized by their respective disciplines. There is a literature base for Statistics Anxiety as well that the author felt would provide an important perspective on the development of this framework, so this category was included in addition to the traditional STEM fields.

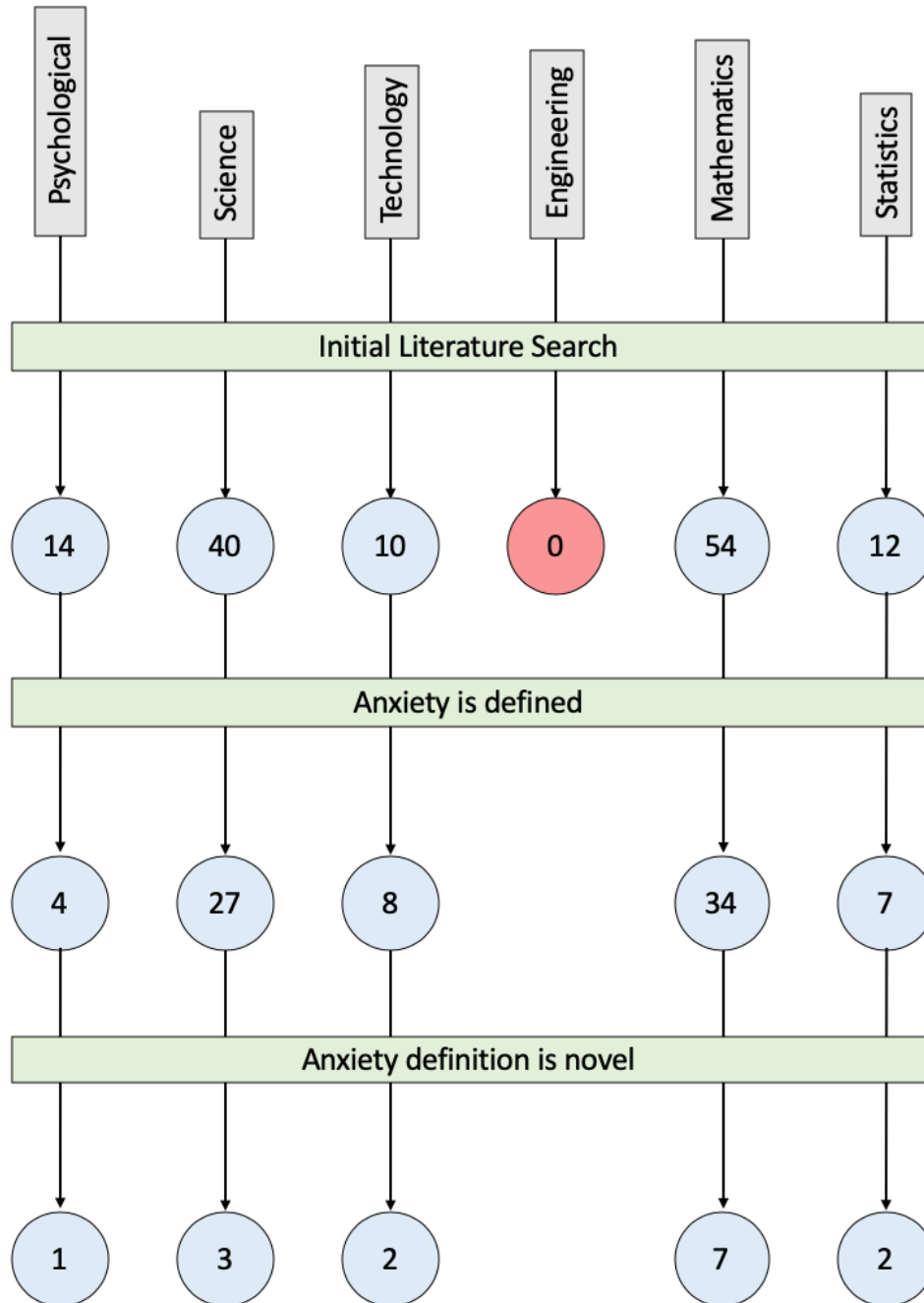
Results and Discussion

The results from the literature search are presented as STEM sub-disciplinary anxiety (e.g., science anxiety, technology anxiety). Within each of the subsections below, the results are further organized by the research questions stated earlier. Of note however, there was no literature base found for engineering anxiety using the methods previously described.

Science Anxiety

How has it been conceptualized?

Science anxiety was originally presented as the fear that students exhibit in response to learning science (Greenburg & Mallow, 1983). In 1986, Mallow detailed different hypothesized causes of science anxiety, potential treatments, and logistical information on science anxiety clinics. This definition recognized the importance of both self-efficacy and the learning environment, paralleling the concepts of state anxiety and anticipatory threats as defined in previous psychological research.

Figure 1*Literature Search Workflow*

Note: Circles indicate the number of articles at each of the filters (green).

How has it been measured?

The original Science Anxiety Questionnaire, adapted from Alvaro (1979), was a survey where students were asked to rate “how much [the student is] FRIGHTENED BY IT NOWADAYS” (Mallow, 1986, pg. 62). The statements

aimed to delineate anxieties toward everyday tasks, science tasks, and arts tasks. For example, one item reads “studying for a final exam in Chemistry, Physics, or Biology” and could be compared to the anxiety that results from “studying for a midterm exam in a History course.” These statements evaluate both the effect of course content and the effect of exams on student anxiety levels. While these items are certainly useful ways to delineate potential variables of interest related to science anxiety, there are concerns with psychologically priming the recipient with the use of the term “frightened”. Additionally, the instructions for the questionnaire were done with entirely capitalized words, which could also prime students in that to read the text as shouting at the participant in today’s context.

There are general science anxiety instruments that have been developed for different populations. Alvaro’s original instrument was designed for work with university students. Additional scales were developed for elementary-aged students (Güzellar & Doğru, 2012), middle and secondary grades (Mehtar & Singh, 2018), and pre-service elementary teachers (Bursal, 2008). These studies each reported the validity evidence for their respective scales.

What are the antecedents?

Numerous studies have identified different contributors or antecedents to science anxiety. Some studies have explored the relationship between teachers, and curriculum by proxy, and their influence on their students’ science anxieties (Beisel, 1991; Gottlieb, 1983; Mallow, 1986). This includes both the implicit and explicit actions taken by teachers, including the perceived difficulty of science. Further, gender was also identified as a contributor when Udo et al. (2004) found that women tended to exhibit higher science anxiety levels than men. Mallow (1986) also attributed science anxiety to the representation of science and scientists in the media, indicating that these representations are foundational to science anxiety. Additionally, Mallow (1986) also names societal norms as an antecedent to science anxiety, explaining that social and societal expectations make it unacceptable to receive a failing grade in a liberal arts course, but students who fail chemistry or physics may present the failing grade favorably to peers.

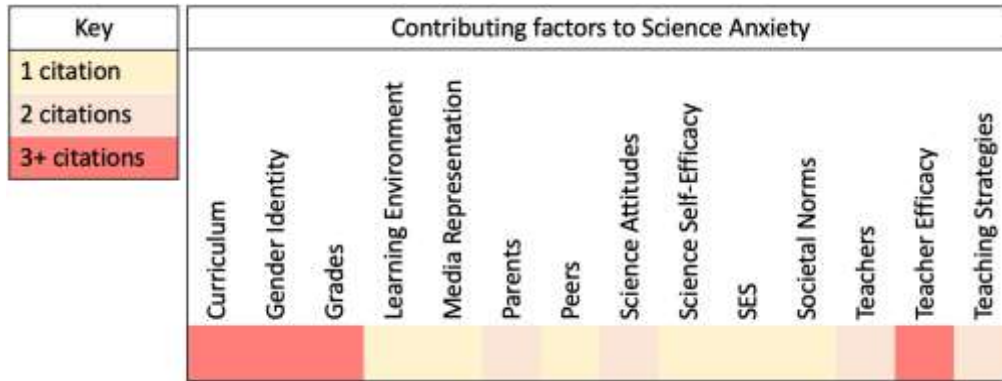
Mallow (1986) also hypothesized the influence of both peers and parents on the development of science anxiety. Though no literature was found that discussed the influence of peers further, Meissner (1988) studied the influence of parents, finding that they can contribute to the science anxiety of their children. Other studies also explored the effects of intrinsic factors, such as science attitudes and self-efficacy (Cox & Carpenter, 1989; Greenberg & Mallow, 1989).

Aside from Mallow (1986), there are other studies that have presented novel mediators of science anxiety. Multiple studies have examined the potential for the contribution of teaching strategies on science anxiety (Oludipe & Awokoy, 2010; Ural, 2016). These studies examined the effect of different teaching strategies, specifically cooperative learning and guided-inquiry respectively, as ways to alleviate students’ anxieties related to science laboratory courses. Kaya and Yildirim (2014) report that there is an inverse relationship among student grades and science anxiety; students with higher grades seem to have lower levels of science anxiety.

There is a final component that may influence science anxiety that has been studied in a very specific population. Anxiety for teaching science has been studied in teachers in terms of alleviation measures (Cox & Carpenter, 1989), and more generally to define and refine the construct (Westerback, 1982, 1984). All of the antecedents discussed above are included in Figure 2 (below).

Figure 2

Science Anxiety Antecedents



While excellent groundwork has been laid to initially determine the different antecedents described above, no documented potential interactions between or among them. For instance, science teacher self-efficacy could influence the teaching strategies being used or the learning environment itself more broadly that then impacts student anxiety. More research is needed to evaluate potential interactions effects of the antecedents to science anxiety.

Technology Anxiety

How has it been conceptualized?

In STEM education, the term technology can have numerous broad definitions (Koehler & Mishra, 2009; Pea, 1985; Quinn et al., 2020). Therefore, this review will focus on research in computer anxiety as computers and computer technology are ubiquitous in educational environments (Dosi & Grazi, 2010). The author recognizes that using the term *computer anxiety* is a limit, however this is the most researched focal anxiety that both falls under the term technology and does not seem to be implicitly cross-disciplinary, as in the case of calculators and their technological application to mathematics (Idris, 2006; Waxman, 1994; Wilson, 1997). Additionally, those studies that use technology anxiety as a construct were all discussing it as caused by continued and increasing interfacing with computer technology (Johnson et al., 2012; Meuter et al., 2003; Yang & Forney, 2013).

Raub (1981) first conceptualized computer anxiety as a series of consequential emotions when computers are perceived as threatening. This description is an instance of state anxiety via anticipatory threat. This led Russell and Bradley (1997) to evaluate the impact of computer anxiety in teachers, finding that many teachers who had negative feelings towards computers were avoiding their use in classroom instruction. Many of the studies that also provided

novel definitions of computer anxiety were published prior to 2000. It is unclear why the definitions do not seem to have progressed, though the research has continued, considering computer technology becoming so ubiquitous. Though this finding does seem to echo Worthington and Zhou's (1999) sentiment that there is something more to be found related to student computer anxiety.

How has it been measured?

The original measure of computer anxiety, the Computer Anxiety Scale (CAS; Marcoulides et al., 1985), was evaluating state anxiety by focusing on contextual anxiety related to the use of computers. Factor analysis indicated that the responses clustered in general computer anxiety and the equipment factor (Arigbabu, 2009). General computer anxiety was defined as anxiety that emerged because of experience with computer technology use, while the equipment component is related to the anxiety surrounding equipment operation.

Marcoulides (1988) evaluated the effect of computer anxiety on student achievement related to computer skills by using both the CAS and the Computer Aptitude Literacy and Interest Profile (CALIP; Poplin et al., 1984). This study found that computer skills was a significant predictor of computer anxiety, more so even than previous experience with computers. A study by Cohen and Waugh (1989) provided additional evidence for this claim. Additionally, the internal reliability was calculated at 0.97. The Mathematics Anxiety Rating Scale (MARS; Richardson & Suinn, 1979) was also used for this study, though no additional psychometrics were reported for this instrument.

The different scales that have been described above are well designed in order to identify potential antecedents to an individual's computer anxiety, while also being broad enough to determine potential additional factors, such as experience with computers that might influence anxiety (Powell, 2013). However, as the author has stated, it is possible that using this narrow concept of computer anxiety as an analog for technology anxiety could skew the results of this search. Therefore, more research is needed to evaluate if updating the construct of technology anxiety could be used to potentially reevaluate portions of the model being proposed throughout this review.

What are the antecedents?

There are numerous identified antecedents to computer anxiety, such as previous experience with computers. Prior experience seems to mediate computer anxiety (Arigbabu, 2009; Cambre & Cook, 1985; Fariña et al., 1981; Raub, 1981), with prolonged exposure to and experience with computers leading to higher self-efficacy; which in turn would lead to lower anxiety. Possibly related to this were some studies finding that students in non-computer science or technology majors had higher computer anxiety than those in computer science, technology, or computer-integrated majors (Cambre & Cook, 1985; Maurer, 1994; Raub, 1981; Rosen et al., 1987). Related to a previous statement regarding self-efficacy, Marcoulides (1988) studied the effect of both computer attitudes, the feelings of an individual towards computer technology, and computer self-efficacy, the individual's perceived likelihood of successful interactions with computer technology (Poplin et al., 1984; Powell, 2013).

Another important component to consider is how people deal with the actual hardware, termed the equipment factor (Marcoulides, 1988). This is defined as the knowledge of procedures that are necessary to successfully use computer technology. Having a low procedural knowledge here correlates to a higher chance of computer anxiety (Arigbabu, 2009; Cohen & Waugh, 1989; Marcoulides, 1988). Fariña et al. (1991) also evaluates the perceived societal impacts of computers and technology as a potential factor to produce computer anxiety. They theorize that computers have such a wide-ranging potential for influence across disciplines and industries, that people's perceptions of these impacts could lead to them developing computer anxiety. They found that those that viewed computers as a tool that could improve or streamline their life or work were less likely to develop computer anxiety. Powell (2013) subsequently reviewed all the antecedents described above (also Figure 3) and developed a categorization scheme, using personal and interactive as the broadest categories. However, in the educational setting, technology as a subject is becoming more prevalent, and there needs to be research moving towards the development of a concept of technology anxiety equivalent to science or mathematics that have been evaluated for individual disciplinary anxieties.

Figure 3

Technology Anxiety Antecedents

Key	Contributing factors to Computer Anxiety								
1 citation	Academic Major	Age	Computer Attitudes	Computer Self-Efficacy	Ethnicity	Gender Identity	Prior Experience	Procedures/Mechanics	Societal Impacts
2 citations									
3+ citations									

Mathematics Anxiety

How has it been conceptualized?

Mathematics anxiety is the oldest disciplinary anxiety in terms of research, first being proposed by Feierabend (1960). However, the original definition, tense feelings interfering with mathematics tasks, was not published until 1972 (Richardson & Suinn, 1972). This definition highlights the importance of both the context and the negative emotions that precede the anxiety and would be an example of a situational or state anxiety. The original definition was subsequently expanded to include the effect of panic and helplessness on an individual's mental capacity (Tobias & Weissbrod, 1980). There were also attempts to include mathematics anxiety under the umbrella of mathematics attitudes (Schoenfeld, 1985), though McLeod (1992) argued that the term attitudes was not descriptive enough for what studies were finding in relation to mathematics anxiety. Another extension was made by Brady and Bowd (2005) saying that mathematics anxiety is based upon unpleasant past experiences with mathematics that can

impede future learning. This psychological phenomenon was also found to be socially transmissible to students from either teachers or parents (Beilock et al., 2010; Maloney et al., 2015).

How has it been measured?

While there are numerous instruments used to study mathematics anxiety, this review will focus on those that are derived from the original mathematics anxiety instrument (MARS, Richardson & Suinn, 1979). Plake and Parker (1982) were the first to amend the initial MARS instrument to produce the MARS-short in order to identify math-type anxiety among students in a statistics course. Suinn and Edwards (1982) then developed the MARS-A for use with adolescents. These are just a few of the numerous alterations to the original MARS instrument, many of them to adapt to a new population. There are a few described above, though there are others where either the psychometrics or the study reporting the psychometrics was unavailable to the authors of this review. Those that are described above rarely make large-scale alterations to the content of the items in the MARS, which implies a robust instrument.

What are the antecedents?

Rubinstein and Tannock (2010) grouped the contributors to mathematics anxiety into three broader categories: cognitive, personal, and environmental factors. Cognitive factors are learner-intrinsic, including things like innate appraisals of mathematics ability. Personal factors are things like low self-esteem and a lack of confidence. Environmental factors are things like previous experiences with mathematics learning or specific teachers. Though these are discussed in isolation, each of the factors described by Rubinstein and Tannock (2010) can mediate each of the other factors in the production of mathematics anxiety. Another study (Chang & Beilock, 2016) further refined these categories to personal and environmental factors, where cognitive and intellectual, and personal and personality were all included as personal contributors.

The personal contributors to mathematics anxiety include mathematics self-efficacy, gender, age, mathematics attitudes, SES, and prior experience. Numerous studies have described the impact of mathematics self-efficacy, an individual's perceptions of their own mathematical ability (e.g., Rubinstein & Tannock, 2010). The studies that have reported on this variable have shown that students that exhibit higher levels of mathematics anxiety are more likely to have lower mathematics self-efficacy. Gender is also often studied in the context of mathematics anxiety, though many of the results seem to be contradictory or context specific. Some studies report that females tend to be more math anxious than males (e.g., Reilly, 1992), while others report that males exhibit higher math anxiety than females (e.g., Bernstein, 1992). Finally, there are some studies that report that there is not a significant difference in males and females in terms of math anxiety (e.g., Lussier, 1996). It is also important to note that these findings may be skewed in terms of students' self-efficacy based upon assumptions that males or females are naturally better at mathematics (Beilock et al., 2010; Furner & Berman, 2003).

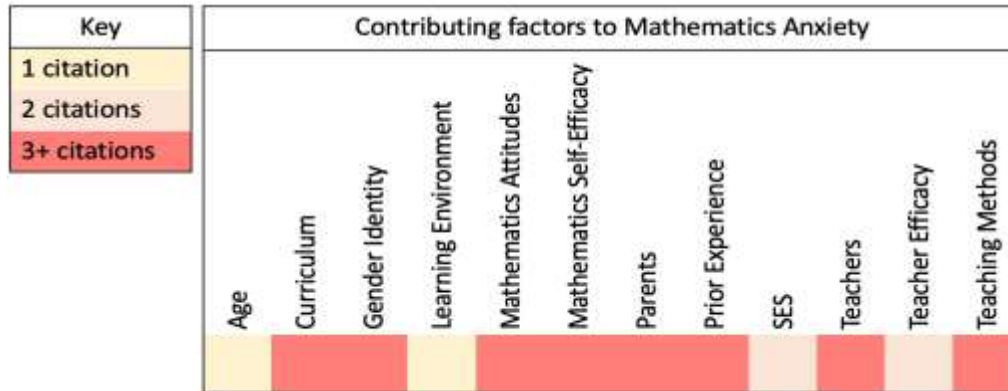
Only one study was found that described the effect of age on mathematics anxiety. Bernstein (1992) reported that mathematics anxiety was more common in males until age 14, when females become more math anxious. Finally, prior experience has been studied by multiple research groups (Betz, 1978; Brady & Bowd, 2005; Rubenstein & Tannock, 2010) which all indicate that negative prior experiences with mathematics, which could ultimately be attributed to other factors, predispose students toward the development of mathematics anxiety. These negative prior experiences can also lead students to have poor math attitudes, which is also indicative of higher potential for math anxiety (Akin & Kurbanoglu, 2011; Çathoğlu et al., 2014). SES was not a topic that seemed to be explicitly discussed in any of the studies cited, however there was inferential evidence that lower SES correlated with high mathematics anxiety due to parental involvement and the learning environment (Betz, 1978; Rubenstein & Tannock, 2010).

Environmental contributors to mathematics anxiety include teachers, teaching methods, teacher efficacy, parents, the learning environment, and curriculum. Teachers and parents have both been studied as sources for mathematics anxiety in their students/children, particularly in the cases where the teachers or parents themselves identify as math anxious (Beilock et al., 2010; Fiore, 1999; Furner & Berman, 2003; Heydari et al., 2013; Kutner, 1992; Rubenstein & Tannock, 2010; Sepehrianazar & Babae 2014). Teachers who exhibit low efficacy have students that have higher probabilities of being math anxious (Gresham, 2009; Jaggernaut, 2010), while teaching methods that emphasize procedural understanding over conceptual understanding tend to produce math anxious students (Akhter et al., 2016; Greenwood, 1984; Hughes, 2016; Kidd, 2003). Curriculum was also found to predispose students to mathematics anxiety. Many studies cite that mathematics anxiety is more likely in upper middle and secondary grades (Harper & Daane, 1998; Ma & Kishor, 1997; Zientek et al., 2010). Interestingly, this corresponds to when mathematics disciplines differentiate in the classroom (e.g., Algebra I, Geometry, Algebra II), though presently mathematics in the secondary grades is taught more as integrated subjects. The learning environment has also been discussed as a contributor to math anxious students in the sense that it can influence students' mathematics attitudes (Vandecandelaere et al., 2012). Figure 4 shows the synthesized contributors described above.

Statistics Anxiety

How has it been conceptualized?

Though statistics is not explicitly included in STEM, the author feels that it is a discipline that permeates most, if not all, of the STEM disciplines and that the research done in this field will serve to improve the conceptions being developed throughout this review, and ultimately the proposed model.

Figure 4*Mathematics Anxiety Antecedents*

One of the first conceptions of statistics anxiety was published by Onwuegbuzie et al. (1997) as an apprehension that occurs when someone is presented with statistics in any form or educational level, framing it as a subset of state anxiety due to its contextual specificity. Much of the research in statistics anxiety uses this definition with very little variation. Earp (2007) analyzed decades of statistics anxiety research in terms of definitions, instruments, and relation to statistics attitudes. Through this analysis, six broad domains were found to influence statistics anxiety: general anxiety, fearful behavior, attitude, expectation, history, and performance. Each domain will be explained in more detail below. Through reviewing the literature on statistics anxiety, the authors note that there are many that seem to equate mathematics anxiety and statistics anxiety, though there are also publications that describe the differences between the two disciplinary anxieties (Baloglu, 2004; Paetcher et al., 2017).

How has it been measured?

The original instrument designed to measure statistics anxiety was the Statistics Attitude Survey (SAS; Roberts & Bilderback, 1980). A later scale was published by Wise, called the Attitudes Towards Statistics (ATS; 1985), to compensate for what Wise interpreted as low content validity for the SAS. The Statistics Anxiety Rating Scale (STARS; Cruise et al., 1985) identified six dimensions related to statistics anxiety: worth of statistics, interpretation anxiety, test and class anxiety, computational self-concept, fear of asking for help, and fear of statistics teachers. The original publication could not be found to evaluate the methods that produced these dimensions, but the dimensions are cited in other studies (Earp, 2007; Onwuegbuzie, 2004; Onwuegbuzie & Wilson, 2003; Williams, 2010). After the publication of the STARS, Zeidner (1991) published the Statistics Anxiety Inventory (SAI) saying that the statistics anxiety construct was comprised of two dimensions: statistics content anxiety and statistics test anxiety, though the distinction is made that statistical test anxiety is different than general test anxiety. Most recently, Earp (2007) developed the Statistics Anxiety Measure (SAM). The measures discussed above all report some level of reliability and validity evidence, however Earp (2007) noted that some of these instruments were developed as alternatives to each other due either minimal or contested evidence.

What are the antecedents?

This portion of the review will draw upon the work done by Earp (2007), who produced a statistics anxiety model comprised of six domains that were all taken from the historical statistics anxiety literature. The anxiety domain is comprised of statistics content anxiety, statistics test anxiety, class anxiety, interpretation anxiety, test anxiety, math anxiety, math test anxiety, numerical anxiety, and lack of mathematical foundations. For the purposes of this review, due to the contextual nature of these constructs, statistics content anxiety, statistics test anxiety, and interpretation anxiety are being pooled into curriculum; and math anxiety and math test anxiety are being pooled into math anxiety. Numerical anxiety is also being pooled into math anxiety because numerical anxiety, as a construct, is evaluated as part of the MARS. Math anxiety is recognized as a contributor, but as a construct it has already been discussed. Therefore, the components being discussed below are curriculum, class anxiety (termed learning environment), and lack of mathematical foundation (termed background knowledge).

Background knowledge, particularly in mathematics, was found to be correlated to statistics anxiety (e.g., Burton & Russell, 1979), though there were no studies found that evaluated the effect of statistical foundational knowledge. This same logic could also be extended to curriculum by discussing the amount and frequency of statistics content in the curriculum (e.g., Fishbein & Ajzen, 1975). The connection to the learning environment (Earp, 2007) is a similar link as in science anxiety wherein the classroom ecology, including peers, the teacher, and norms, can lead to the development of statistics anxiety.

The fearful behavior domain is comprised of fear of asking for help, fear of statistics teachers, extensive worry, intrusive thoughts, mental disorganization, tension, and behavioral responses. For this portion, extensive worry, intrusive thoughts, mental disorganization, tension, and behavioral responses are being pooled into a category termed trait anxiety, the psychological term for these mental and physical responses to anxiety and stress. The contributors being discussed for this section are fear of asking for help (termed self-efficacy), fear of statistics teachers (termed teachers), and trait anxiety. As in the other disciplines, self-efficacy seems to be inversely proportional to anxiety (e.g., Cruise & Wilken, 1980). The influence of the teacher can mediate the feelings of anxiety of students.

The attitude domain encompasses math attitudes, perceived worth of statistics, affect, and psychological arousal. Math attitudes were discussed prior, though it is recognized as a contributor to statistics anxiety. Affect and psychological arousal refer to the emotional response and will be discussed with trait anxiety. Perceived worth of statistics as described by Cruise and Wilken (1980), will be discussed under statistics attitudes. The contributors being discussed for this segment are statistics attitudes and trait anxiety. As discussed in other disciplines, attitudes are often seen as correlational to anxiety, meaning that those with negative statistics attitudes would more likely exhibit statistics anxiety (e.g., Chew & Dillon, 2015).

The expectation domain is made of subjective norms, motivation to continue learning, steps in information processing, cognition, social expectations, parental or peer pressures, pressure to succeed in mathematical solving situations, past experiences, and low levels of mathematical reasoning ability. Subjective norms will be discussed as curriculum. Motivation for learning, information processing, and cognition will be pooled as cognitive demand. Social expectations and pressure to succeed in mathematical solving situations will be pooled under societal norms. Low level of math reasoning will be discussed under background knowledge. The contributors for this domain are curriculum, which was discussed in a prior section, cognitive demand, societal norms, prior experience, and background knowledge. Cognitive demand refers to those situations that are mentally grounded, such as mental computation or information processing, (e.g., Eagly & Chaiken, 1993), and although motivation for learning is included in this term, the author recognizes that there are often extrinsic motivators as well. The societal norms are those extrinsic factors that are either intrinsic or extrinsic that often dictate interactions (Earp, 2007). Finally, although prior experiences and background knowledge seem nearly identical, the author is delineating them as previous lived experiences and previous academic learning, respectively. Negative prior experiences can predispose individuals towards the development of statistics anxiety (e.g., Benson & Bandalos, 1989). Background knowledge was described in the context of a previous domain.

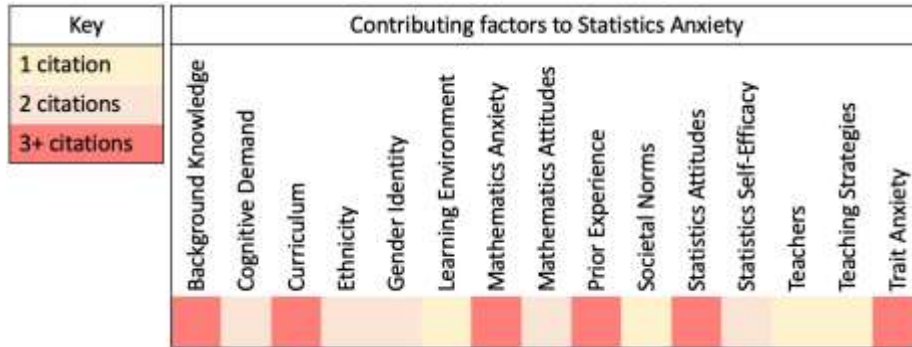
The history domain contains low mathematics self-esteem, prior mathematics class experiences, self-concept, motivation to learn, and instructional situations. Low mathematics self-esteem will be grouped under math attitudes. Prior math class experiences will be grouped with prior experience. Motivation to learn, like the previous section, will be grouped under cognitive demand. The contributors attributed to this domain are prior experience, cognitive demand, learning environment (such as instructional situations) and self-efficacy (self-concept), all of which have been discussed within previous sections.

Finally, the performance domain is solely the self-appraisal of statistics ability, which will be discussed as self-efficacy. From the numerous identified contributors described as falling under the domains, the pooled contributors to be discussed are curriculum, learning environment, background knowledge, self-efficacy, teachers, trait anxiety, statistics attitudes, cognitive demand, societal norms, and prior experience. Additional contributors from other sources are declared major (Onwuegbozie & Wilson, 2003), gender (Benson, 1987; Benson & Bandalos, 1989), and ethnicity (Onwuegbozie, 1999).

Earp (2007) does an excellent job of reviewing the literature on the antecedents of statistics anxiety. Although, it should be noted that statistics anxiety is the only of the disciplinary anxieties that includes another discipline, specifically mathematics anxiety, as an antecedent. Figure 5, below, shows a summary of the antecedents discussed through statistics anxiety.

Figure 5

Statistics Anxiety Antecedents

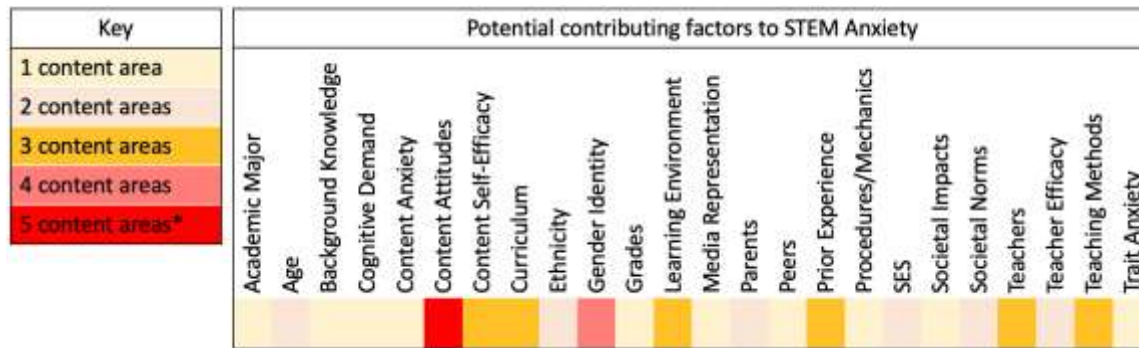


STEM Anxiety Framework

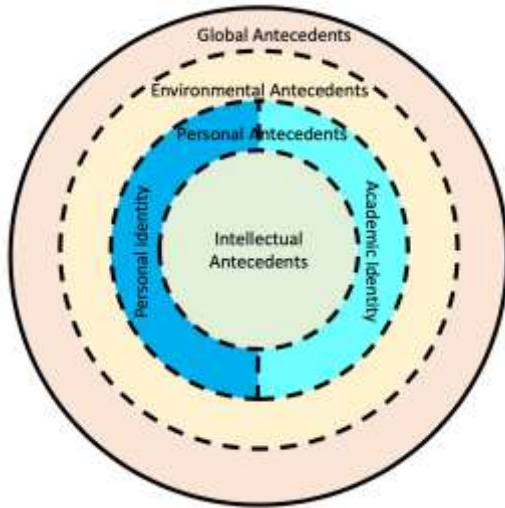
Recent studies have proposed integrated STEM frameworks for the purpose of furthering research on STEM integration. Ortiz-Revilla et al. (2020) proposed a model that focuses on the epistemology of the STEM disciplines, which could also function as an analytical framework for STEM integration research. Kelley and Knowles (2016) developed a conceptual framework designed to resemble a pulley-system that is linked together by the thread of a community of practice and grounded in situated learning (Lave & Wenger, 1991). The individual pulleys in this model are science inquiry, engineering design, technological literacy, and mathematical thinking, all of which imply the importance of a practical and conceptual knowledge grounded in authentic contexts. These frameworks are excellent initial thoughts on the practical integration of STEM in classroom settings. However, none of these frameworks discuss potential barriers to learning or teaching that could exist within the individual STEM fields. This review developed such a framework around one such barrier to both STEM teaching and learning – STEM content anxiety. Figure 6, below, gives an overview of the antecedents to the individual disciplinary anxieties discussed throughout prior sections. These different antecedents were then grouped by the author into four domains: global, environmental, personal, and intellectual (Figure 7).

Figure 6

Potential STEM Anxiety Antecedents



Note: Mathematics attitudes was included in both mathematics and statistics anxiety, and therefore there were a total of 5 instances of content attitudes counted.

Figure 7*STEM Anxiety Domains*

These domains were developed to organize the antecedents that have been described throughout this review and will be described below alongside those antecedents that have been categorized within each domain. The models presented here (Figures 7, above, & Figure 8, below) are in reference to any individual, so this can be used in reference to a teacher, student, parent, administrator, etc. Those antecedents that are categorized as intellectual or personal are intrinsic to the individual, while environmental and global are extrinsic. Figure 7 gives a broad overview of the different domains that were identified as part of this review, while Figure 8 includes the domains as well as the antecedents within each domain.

The overall model presented in Figure 8 identified four categories of antecedents: Global, Environmental, Personal, and Intellectual. These will be discussed below moving from intrinsic to extrinsic factors.

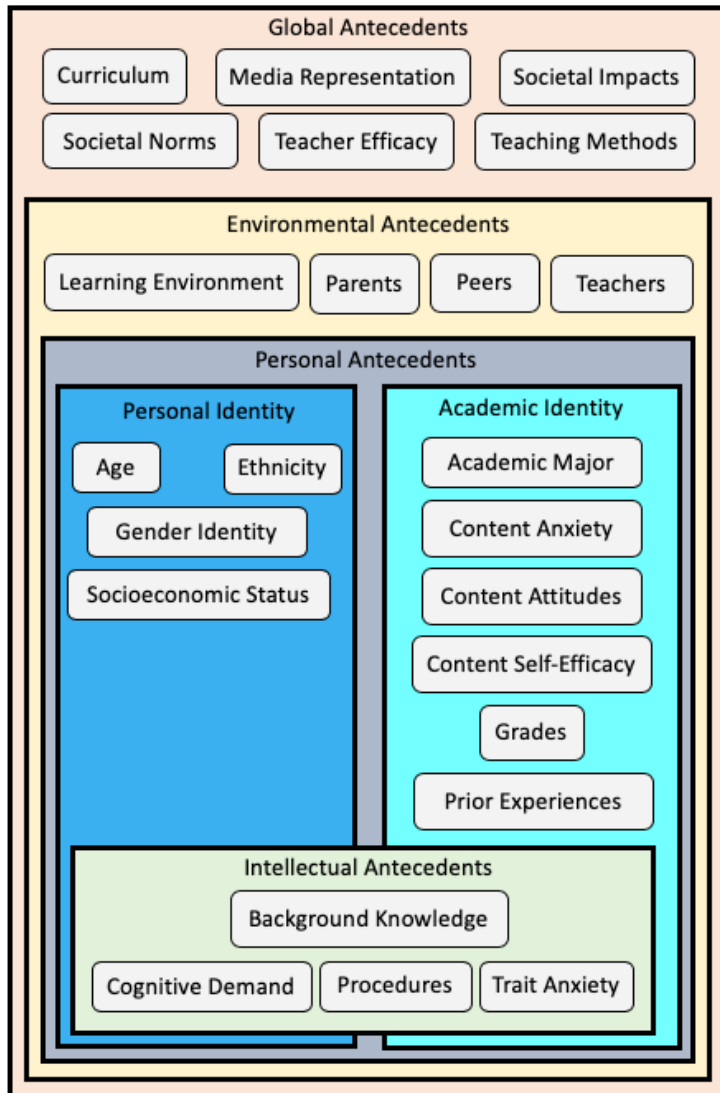
Intellectual antecedents are those that are entirely cognitive in nature, including background knowledge, the cognitive demand of the STEM tasks, the procedures necessary to utilize their background knowledge to be successful within the discipline, and the trait anxiety of the individual.

Personal antecedents were further grouped into personal and academic identities. The personal identity follows a model proposed by Galliher et al. (2017) with age, ethnicity, gender identity, and SES in the personal identity domain. Age, ethnicity, and SES are present in two disciplinary anxieties, as indicated in Figure 6. However, gender identity was included as an antecedent in each of the individual disciplinary anxieties reviewed previously. The academic identity domains were identified using Chan (2016) as a model. Chan (2016) describes academic subject identity as how students can find themselves and develop in their chosen fields. For this model, the antecedents in the academic identity are academic major, the presence of other content anxieties, attitudes and self-efficacy related to the content, and the past academic performance as measured by grades. As shown in Figure 6, academic major,

other content anxieties, and grades are only presented in one disciplinary anxiety. Attitudes, however, was indicated in each of the disciplinary fields (science attitudes, mathematics attitudes, computer attitudes, and statistics attitudes), while mathematics attitudes were also listed in statistics anxiety.

Figure 8

The STEM Anxiety Framework



The environmental antecedents are those in direct contact with but are extrinsic to the individual. This category includes the learning environment, including the peers and the teacher. Because of this, parents are included as an environmental antecedent because of their potential presence in the learning environment outside of the formal school (sometimes called the studying environment in the literature). Finally, global antecedents are those that have an indirect impact on the individual but can mediate the interactions with other levels of this model; likewise, contact with these antecedents can be viewed as mediated by others. For instance, societal norms and societal

impacts are included in this category because the individual may not be aware of these antecedents, but society can mediate the interactions that an individual has with those in the environmental level. Society can also have a mediating effect on the curriculum being taught, which can impact the teaching methods and teacher efficacy within the teacher. An individual would not necessarily have direct contact with curriculum or teaching methods or teacher efficacy as the contact would be through the teacher as a mediator.

Conclusions & Future Directions

As the call for integrated STEM throughout K-16 education proceeds, there needs to be more specific focus on both practical and theoretical ways that this integration can be achieved while also managing the affective responses from both teachers and students. In addition to the studies theorizing integration, other studies have theorized the number of disciplines being integrated. Lonning and DeFranco (1997) established the continuum model for the integration of mathematics and science as five points along a continuum. At the extremes are independent mathematics and independent science, moving inward are points where one discipline is the focus, but activities and concepts of the other are used as support. In the middle is balanced integration. This example, however, is in the context of the integration of two disciplines. Theoretically, integrating the STEM disciplines fully should result in a classroom observer being unable to differentiate the individual content disciplines due to complete integration.

As these calls for STEM reform towards STEM literacy and both practical and theoretical integration of the STEM disciplines increase, many are proposing frameworks for integration (Kelley & Knowles, 2016; Ortiz-Revilla et al., 2020). However, as noted by Kelley & Knowles (2016), very little is being theorized in relation to potential barriers to learning in an integrated STEM classroom. The framework developed throughout this literature review provides a theoretical approach to one potential barrier that has been studied in each of the individual STEM disciplines: anxiety. Anxiety has detrimental effects on both students and teachers and has been found to be socially transmissible in the learning environment. Though this theoretical framework was designed as a framework for the potential anxiety in an integrated STEM setting, there are numerous instances of overlap in antecedents across the independent STEM disciplines. Therefore, this could also be considered an expanded model for use in each of the individual disciplines as well and could serve as a source of new research on these antecedents within the individual disciplines.

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