education sciences

MDPI

Article

Thriving, Persisting, or Agonizing: Integrated Math Anxiety Experiences of University Students in Introductory Geoscience Classes

Julie Sexton [1,*], Dina London [2], Molly M. Jameson [3] and Jennifer M. Wenner [4]

[1] Environmental Studies Department, University of Colorado Boulder, 97 UCB, 4001 Discovery Drive, Boulder, CO 80303, USA
[2] Educational Studies, University of Northern Colorado, McKee Hall, Campus Box 94, Greeley, CO 80639, USA
[3] School of Psychological Sciences, University of Northern Colorado, McKee Hall, Campus Box 94, Greeley, CO 80639, USA
[4] Geology Department, University of Wisconsin Oshkosh, 800 Algoma Blvd., Oshkosh, WI 54901, USA
* Correspondence: julie.sexton@colorado.edu

Abstract: Many factors may contribute to women being underrepresented and marginalized in college-level geoscience majors. Limited research has examined students' math anxiety as a possible factor. To address the dearth of research, we conducted a qualitative study to explore the math anxiety experiences held by students in college-level geoscience classes. Through analysis of students' written math narratives, we identified three themes capturing students' integrated math anxiety experiences (IMAEs), which integrated students' feelings, physiological reactions, and thoughts. Students with Thriving IMAEs liked math and had positive assessments of themselves in math. Students with Agonizing IMAEs had negative feelings and thoughts about math and experienced negative physiological reactions. Students with Persisting IMAEs had positive and negative feelings and thoughts, but thought that, ultimately, they could persist in math. A higher percentage of women than men held Agonizing IMAEs, and a lower percentage of women than men held Thriving IMAEs. Students in introductory geoscience classes had a range of IMAEs, which may have an important role in their success in class and in their decisions to take additional geoscience classes.

Keywords: math attitudes; math anxiety; geoscience; qualitative research; gender differences

Citation: Sexton, J.; London, D.; Jameson, M.M.; Wenner, J.M. Thriving, Persisting, or Agonizing: Integrated Math Anxiety Experiences of University Students in Introductory Geoscience Classes. *Educ. Sci.* **2022**, *12*, 577. https://doi.org/10.3390/educsci12090577

Academic Editors: James Albright and Gavin T. L. Brown

Received: 15 June 2022
Accepted: 19 August 2022
Published: 24 August 2022

1. Introduction

Geoscience is the study of earth processes and materials [1]. Geoscientists study natural disasters like earthquakes, volcanoes, and flooding; energy and mineral resources; and the connections between physical and biological systems. Geoscientists also study Earth's history to understand past life (e.g., dinosaurs) and landscapes. Though often perceived as less quantitative than other sciences like physics and chemistry [2,3], geoscience regularly draws on and incorporates math skills and knowledge [4], including high-level math (e.g., calculus) [5]. Geoscience educators report that their students struggle with math in their geoscience courses, particularly introductory courses [6–10]. Math-averse students may be drawn to geoscience courses because of their misperception that this science is less "math-heavy" than other natural and physical sciences. Due to this misperception and the regular use of math skills in geoscience courses, students' math skills can serve as a barrier to success in class and to the recruitment and retention of higher education geoscience majors [5,11,12]. Students' math anxiety experiences may also influence students' success in geoscience classes and their decisions to select and persist in a geoscience major. Understanding math anxiety experiences can help inform intervention tools that may improve student math success in geoscience classes [13].

1.1. Math Attitudes and Their Impact on Students

Student anxiety towards math often develops at a young age [14–17] and persists from primary school through secondary school, higher education, and into the professional workforce [18]. Math anxiety exists on a continuum from not present to high levels anxiety. High levels of anxiety can be unproductive for students and even influence students' academic interests and choices [19]. Low to non-existent levels of math anxiety are related to increased learning in mathematics [20,21] and in science disciplines [13,22,23]. Low to non-existent levels of math anxiety are also related to students enrolling in elective math courses and selecting math and science majors in college [18,24–26].

Students with higher levels of math anxiety do not necessarily lack math ability; however, their math anxiety may be associated with decreased math performance [27,28]. While lower performance could be related to a lack of foundational math skill [29], in students with high math anxiety, it is more likely related to the thoughts and behaviors (e.g., avoidance of math) [30] associated with that anxiety. For instance, students with higher levels of math anxiety, a fear-based reaction to completing or thinking about math in academic or non-academic settings [31–33], tend to experience decreased working memory capacity, which negatively impacts performance [29,31,34]. Decreased math performance likely relates to lower levels of math self-efficacy, and confidence in one's competence to successfully complete specific math tasks [35]. Students with higher levels of math self-efficacy do not typically see the performance deficit experienced in highly math anxious students [35]. However, students with lower levels of self-efficacy often experience lower math motivation and are less likely to pursue math-intensive majors, like natural and physical sciences [26,27]. This is potentially one reason why there are fewer women than men in natural and physical sciences, as women may more likely have higher levels of math anxiety than men [36], even when measured using implicit measures [37,38].

1.2. Math Attitudes in Geoscience

There has been extensive work to understand how students' science and math attitudes, like science interest and self-efficacy, are associated with students' selecting science majors overall [39–42]; however, there has been little research exploring math attitudes, and math anxiety specifically, for students in geoscience classes. Recently, Jameson et al. [43] showed that students with high math anxiety and low math self-efficacy had more negative attitudes toward geoscience. Jameson et al. [43] also found that women's geoscience interest was partially predicted by their math self-efficacy, while men's interest was not. Holding positive math attitudes may be critical for students' success in geoscience classes and as a factor supporting their selection of geoscience courses and majors; however, more research is needed.

1.3. Study Focus

The Jameson et al. [43] finding that women's math attitudes, including math anxiety, are associated with their geoscience interest is important. Women are underrepresented and marginalized in geoscience [44,45]. There has been little research exploring what barriers affect women's success in geoscience and what barriers exist for women in pursuing a geoscience major [46]. With the emerging findings about math attitudes in geoscience, we are interested in exploring the math attitudes held by students in introductory geoscience classes. We used the following questions to guide this study: What are university geoscience students' experiences with math anxiety? How do students' experiences vary for women and men?

2. Methods

2.1. Study Design

We conducted a qualitative study using a basic qualitative study design, the most common design in education research [47]. Basic qualitative studies focus on how participants "make sense of their lives" [47] (p. 25). Therefore, we selected the qualitative design to

allow students' voices to guide our understanding of their math anxiety while enrolled in introductory geoscience courses.

2.2. Context and Participants

We conducted this study in introductory geoscience classes at two public, four-year universities: one in the Mountain West and one in the Midwest of the United States. The Mountain West university had about 10,000 students and a Basic, Doctoral/Professional University Carnegie Rating [48]. The Midwest university had about 15,000 students and a Basic, Doctoral University—High Research Activity Carnegie Rating [48].

These sites were involved in a larger intervention study we are conducting related to student success in geoscience courses. In that larger study, we implemented six interventions, including an intervention in which students learned about math anxiety and wrote short narratives about their math anxiety. All students enrolled in introductory geoscience courses at the Mountain West site during spring 2020, fall 2020, and spring 2021 semesters (n = 107) were invited to participate. All students enrolled in introductory geoscience courses at the Midwest site during the fall 2021 semester (n = 73) were invited to participate. Students who provided consent and had complete data for the math anxiety intervention provided the final dataset. This includes 77 undergraduate students (Mountain West n = 53, Midwest n = 24). Student demographic data are provided in Table 1.

Table 1. Participant demographic information (n = 77).

Characteristics		N	%
Gender Identity	Man	29	38%
	Non-binary	1	1%
	Woman	45	58%
	No Response	2	3%
Race/Ethnicity	American Indian	1	1%
	Asian American	2	3%
	Black/African American	3	4%
	Latinx/Hispanic	10	13%
	Middle Eastern/North African	1	1%
	White/European American	48	62%
	Multi-Ethnic	10	13%
	No Response	2	3%
International student	No	74	96%
	Yes	3	4%
First-Generation College Student [a]	No	56	73%
	Yes	19	25%
	No Response	2	3%
Year in School	First-year	31	40%
	Second-year	23	30%
	Third-year	14	18%
	Fourth-year	8	10%
	Other	1	1%

[a] In the United States, this refers to a student whose biological or adoptive parent(s) have not successfully completed a four-year college degree when the student is in college.

2.3. Data Collection

As part of a larger study, we developed and implemented a math anxiety lesson for introductory geoscience classes. The lesson was taught during the first eight weeks of class, with the specific week dependent on each instructor's schedule. In the lesson, students read about the definition of math anxiety, the role math anxiety has in learning in geoscience classes, and about strategies to reduce math anxiety (e.g., practicing relaxation techniques and journaling about their anxiety) and improve their success in geoscience classes. Students also completed a formative assessment gauging their understanding of

the reading. Lastly, students completed an application assignment to practice the strategies they learned in the reading. In the math anxiety application assignment, students wrote a short narrative about their thoughts and emotions using the following prompt: "Reflect on your level of math anxiety. Regardless of your previous experiences and level of anxiety, it is helpful to write about your experiences and emotions. In your writing, let yourself go and explore your emotions and thoughts. You might relate your current thoughts to the way you have felt during other similar situations at school or in other situations in your life. Take the next 2 min to write a couple of sentences about your thoughts and feelings (positive, neutral, or negative) about math." Students wrote narratives to this prompt either during the laboratory section of their geoscience class (in 2020, prior to the impacts of COVID-19) or online through their university's learning management system (in fall 2020, spring 2021, and fall 2021). Student narratives ranged in length from a couple of short phrases to a paragraph. We also collected demographic information with a questionnaire administered at the beginning of the semester.

2.4. Analysis

We used an inductive, two-cycle coding approach described by Miles et al. [49]. We conducted inductive coding to allow students' voices to guide our understanding of their math attitudes while enrolled in introductory geoscience courses. The first cycle of coding was descriptive. In this cycle, we found that students described feelings, physiological reactions, and thoughts associated with math; therefore, we developed codes to capture those comments. In addition, students described their feelings, physiological reactions, and thoughts as negative, neutral, and positive; therefore, we coded their feelings, physiological reactions, and thoughts into those dimensions. In the second coding cycle, we conducted pattern coding [49] to synthesize descriptive codes into categories representing students' math anxiety experiences. Based on recommendations by MacQueen et al. for team research [50], we had one lead qualitative researcher, Sexton. The other team members and authors served as peer reviewers of the coding and analysis process as recommended by Merriam and Tisdell [47] for addressing the trustworthiness of the findings, specifically, the consistency and dependability of the findings. Sexton developed an initial set of first and second cycle codes with a subset of data from the Mountain West university. Then, London conducted a peer review, and the coding was revised based on negotiations and a consensus agreement based on guidelines by Merriam and Tisdell [47] for addressing consistency and dependability. London then expanded coding to a larger data set for the Mountain West university. Sexton provided peer review and modified coding based on discussion consensus agreement. Sexton then completed the first and second cycle coding of the rest of the data from both universities. Jameson and Wenner provided an additional peer review of a sample of data and codes. Jameson and Wenner approved the coding and found no areas of modification needed.

In addition to qualitative coding, we conducted content analysis to identify the number and percentage of students coded into the first cycle and second cycle codes [49]. We also conducted content analysis and chi-square analysis to explore gender similarities and differences related to math anxiety experiences.

2.5. Trustworthiness

Several strategies were used to address the trustworthiness of this study [47]. We incorporated data triangulation by collecting data from multiple sites and across multiple semesters to evaluate emerging findings. We used investigator triangulation and peer review by having a team of researchers who analyzed the data and engaged in a peer review process to evaluate coding and emerging findings. We provided descriptions of our data collection sites and demographic information for our participants as a form of thick description. Finally, here we provide our researcher positions. All authors are from the United States. Sexton is a white woman and a geoscience education researcher. London is a white woman and education researcher. Jameson is a white and American Indian woman

and educational psychology researcher. Wenner is a white woman and geoscientist. We hold constructivist perspectives and believe that students develop math anxiety experiences when interacting with societal norms and systems. We also believe that societal norms and systems are designed to better support majority identity students in geoscience. We realize that our perspectives may influence our research approach and how we interpret our results.

3. Results

Students' anxiety experiences when thinking about or doing math had three components: feelings, physiological reactions, and thoughts. Those components intersect to create integrated math anxiety experiences. We first describe the three components and how they vary. Second, we describe how the intersection of feelings, physiological reactions, and thoughts define three integrated math anxiety experiences. Finally, we describe how the integrated math anxiety experiences vary by gender identity.

3.1. Components and Dimensions

Students described feelings, physiological reactions, and thoughts when reflecting on and engaging in math. Students' feelings and thoughts were negative, neutral, or positive (Table 2). Although feelings and thoughts are usually thought to be only positive or negative, students identified some of their thoughts and feelings as neutral; therefore, we included a neutral dimension to feelings and thoughts when students stated they experienced neutral feelings or thoughts. Students only described negative physiological reactions; therefore, there was only one dimension for physiological reactions.

Table 2. Number and percentage of students coded in each component and dimension.

Components and Dimensions		Count (n = 77)
Feelings	All [a]	69 (90%)
	Negative	54 (70%)
	Neutral	7 (9%)
	Positive	33 (43%)
Physiological Reactions	All [a]	6 (8%)
	Negative [b]	6 (8%)
Thoughts	All [a]	74 (96%)
	Negative	54 (70%)
	Neutral	3 (4%)
	Positive	52 (69%)

The total number of students was 77; therefore, all percentages are calculated using 77 as the total. [a] All refers to the total number of students reporting Feelings, Physiological Reactions, or Thoughts. Some students reported more than one category of Feelings and Thoughts; therefore, the sum of Negative, Neutral, and Positive may be higher than the total for All. [b] Only Negative Physiological Reactions were reported by students.

3.1.1. Feelings

Almost all students (69 out of 77) reported math-related feelings (Table 2). Feelings were defined as students' expression of their emotions (i.e., happy, anger, sad). Those feelings were negative, neutral, and positive. Expressions of negative emotions, like anger and fear, were categorized as negative feelings. Negative feelings were more frequently expressed than positive and neutral feelings (Table 2). Fifty-four students (70%) described negative feelings about math including anger, anxiety, boredom, confusion, dislike, dread, embarrassment, fear, frustration, helplessness, lack of motivation, stress, and wariness (Tables 2 and 3). Statements by students that they had neither positive or negative feelings or statements by students that they had neutral feelings were categorized as neutral feelings. Seven students (9%) said that they had either no feelings or felt neutral when engaging in math (Tables 2 and 3). Expressions of positive emotions, like happiness and enjoyment, were categorized as positive feelings. Thirty-three students (43%) described positive feelings

about math. Those feelings included amazement, confidence, enjoyment, excitement, and overall positive feelings (Tables 2 and 3).

Table 3. Examples of student quotes for the feeling dimensions.

Feeling Dimensions	Examples from Student Narratives [a]
Negative	"I have high anxiety and have a hard time with math." "I do find [math] extremely boring" "I don't really enjoy math" "Throughout high school I absolutely dreaded math" "The concern and fear are ever-present [when a math test is coming up]" "I absolutely hate math." "It makes me mad [when] I'm doing [math]" "I still get a little nervous when I do math"
Neutral	"I don't feel anything in particular when I see math problems." "I feel incredibly neutral when it comes to all things math-related." "I have neutral feelings about math."
Positive	"I'm confident that I am able to work through most math problems within reason." "I have high confidence [doing math]." "I actually really enjoy math" "When I understand how to do it, I get really excited because there is always only one right answer, which pleases me." "I have felt positively about completing math problems." "It amazes me how beautifully the world can be explained with simple algorithms and equations."

[a] Student quotes modified for grammatical errors and clarity.

3.1.2. Physiological Reactions

Physiological reactions were identified as changes to a student's body (e.g., headache, crying). Six students described physiological reactions when thinking about or engaging in math; all reactions were negative (Table 2). Negative physiological reactions were identified by interpreting the context in which students described their reactions. Those reactions included crying, fidgeting or restlessness, unable to think clearly, headaches, mind racing, a sense of locking up or shutting down, and sweating (Table 4).

Table 4. Examples of student quotes for the physiological reaction dimension.

Physiological Reaction Dimension	Examples from Student Narratives [a]
Negative	"I sometimes get to the point where I break down in tears of frustration because I cannot solve a problem." " [I have] restlessness when doing things involving math." "I cannot think clearly." "Many times [math] would leave me with headaches." "When I attempt a math problem, my mind starts to race." "I can't do quick math because I 'lock up'" "If the problems become challenging and do not make sense even with an explanation, I break down . . . and I will shut down." "I do have physical reactions like sweating when doing things involving math."

[a] Student quotes modified for grammatical errors and clarity.

3.1.3. Thoughts

We defined thoughts as students' ideas, perceptions, opinions, and beliefs about themselves and the world. Most students (74 out of 77) communicated negative, positive,

and/or neutral math-related thoughts (Table 2). About the same number and percentage of students described negative and positive thoughts (54 and 52, respectively, Table 2). Three students described neutral thoughts (Table 2). Negative thoughts were negative opinions, assessments, or beliefs about math, math performance, and identity. These thoughts included things like: I do not understand math, I cannot remember math, math is a struggle, I will fail, math is hard, I am not good at math, I am stupid, and doing math is a terrible experience (Table 5). Positive thoughts were positive assessments, affirmations, and beliefs about math and math abilities. Positive thoughts included: I am capable, I am good at math, I can do math if I try, I understand math, and math is easy for me (Table 5). Neutral thoughts were students' assessment that they had neutral thoughts about math. Students communicated neutral thoughts by explicitly stating that they were neutral or describing math as something they needed to do without attaching a judgment to it (Table 5).

Table 5. Examples of student quotes for the thought dimensions.

Thought Dimensions	Examples from Student Narratives [a]
Negative	"I don't grasp the concepts at all." "I never felt like I fully understood the material." "I, like many others I'm sure, tend to have a negative opinion of math." "Even when I recognize the problem in front of me, I forget how to solve it." "I don't retain the information." "I know I will struggle with [math]." "I have always struggled with numbers and still do." "If I had to take another math class in college, I'm sure I would fail it." "I usually don't succeed as well as other students do in math." "It is so hard to learn the math problems for me and how to do them." "Math has always been hard for me." "I have never really been good at math." "I have always said, 'I am bad at math'." "It makes me feel like I'm not smart because I can't do math." "I remember algebra 2 was the worst time of my life in high school."
Neutral	"Math is simply another task for me to complete." "I'm pretty neutral when it comes to math."
Positive	"I have to remind myself that I am capable of it." "I actually feel I am quite good at [math]." "I have always gotten good grades in my math classes in high school." "I am actually very smart in math." " [Math] has always come easy to me, so long as I practiced it." "With enough time and practice I feel capable of solving even complex equations." "I feel like I can understand math." "I have always felt like I understand math concepts when taught." "For the most part, I find math pretty easy." "I loved using numbers rather than words, it always came easy to me."

[a] Student quotes modified for grammatical errors and clarity.

3.2. Integrated Math Anxiety Experience Themes

We found that students' feelings, physiological reactions, and thoughts across the dimensions intersect to describe three integrated math anxiety experiences: Thriving, Persisting, and Agonizing. Integrated math anxiety experiences are abbreviated as IMAE for the remainder of the paper. A student's IMAE is not defined by a single feeling,

physiological reaction, or thought, but by integrating all of their feelings, physiological reactions, and thoughts. The three IMAEs are on a continuum. Students with Thriving IMAE like math and have positive assessments of themselves in math. Persisting students have positive and negative feelings and thoughts, but ultimately the students think that they can persist in math. Agonizing students primarily have negative feelings and thoughts about math and experience negative physiological reactions. As Persisting IMAEs combine aspects of Thriving and Agonizing IMAEs, we describe Thriving and Agonizing IMAEs before describing Persisting IMAEs.

3.2.1. Thriving

Students with a Thriving IMAE primarily had positive feelings and thoughts about math, and no negative physiological reactions associated with math (Table 6). When describing their feelings, Thriving students said that they enjoy math, love math, and have little or no math anxiety (see the underlined phrases in students' statements in Table 7). When describing their thoughts, Thriving students said that they understand math, can figure it out even if it is challenging, and have positive assessments of their skills (assessing themselves as being good at math) (see the bolded phrases in students' statements in Table 7).

Table 6. Counts and percentages of students in each IMAE category across the components and dimensions.

Components and Dimensions	Thriving (n = 10)	Persisting (n = 36)	Agonizing (n = 31)
Feelings	9 (90%)	33 (92%)	27 (87%)
Negative	2 (20%)	27 (75%)	25 (81%)
Neutral	0 (0%)	6 (17%)	1 (3%)
Positive	7 (70%)	22 (61%)	4 (13%)
Physiological Reactions	0 (0%)	2 (6%)	4 (13%)
Negative	0 (0%)	2 (6%)	4 (13%)
Thoughts	10 (100%)	35 (97%)	29 (94%)
Negative	0 (0%)	25 (69%)	29 (94%)
Neutral	0 (0%)	3 (8%)	0 (0%)
Positive	10 (100%)	30 (83%)	12 (39%)

All percentages in each IMAE column were calculated using the total number of students holding the IMAE for that column. For example, all percentages for the Thriving IMAE were calculated using 10 as the denominator.

Table 7. Example quotes for students with a Thriving IMAE.

Example #	Student Quote [a]
1	"I love math; I've **always been good at math**, and it really doesn't scare me. **I learn new concepts pretty quickly, and I feel like I have a pretty good understanding of the more abstract ideas**. There are obviously **some concepts that I might not ever fully understand, but for the most part, I find math pretty easy**."
2	"Ever since I was little, math was always my favorite class. I loved using numbers rather than words, **it always came easy to me**. Even when it [math] got hard, I always asked my teacher for help because I wanted to know it. Because I loved math so much, I would help those who didn't understand it like I did. **This showed me that even when things do get hard, there are so many ways to make it better**."
3	"I have low math anxiety. This is **because I have always gotten good grades** in my math classes in high school, specifically with subjects that give you the equations to use, like in science related mathematics. I have never really been worried or nervous about doing math and think that it can even be fun sometimes. Now that I am in college, I am still not nervous about math in geology because **I know that I will be able to figure it out with a bit of diligence**. I have never been told I was bad at math and have never had physical symptoms that relate to math anxiety, so I have high confidence."

Table 7. *Cont.*

Example #	Student Quote [a]
4	"My math anxiety is almost non-existent. I had a good math program in high school and took some college level math courses there. All the math we have done in class is math I have seen before and **know how to do well with a little refresher**."
5	"**Math has always been rather easy for me. The ideas and concepts always came easy**. I do have really bad test anxiety when it comes to math tests though."
6	"**I have very positive thoughts about math. I have always been a "math" person. In high school, I was consistently in the highest possible math course**. In addition, I was a part of the math team, **and I was actually one of the best members on it. I did really well at competitions where we took timed tests . . .** [In AP Calculus] I did experience some feelings of nervousness during the class on test days. **I was able to overcome this stress and do well in the class**."

The quotes include students' full narrative. [a] Student quotes modified for grammatical errors and clarity. Underlined text indicates feelings. Bolded text indicates thoughts.

Two Thriving students described only negative feelings associated with math, and specifically with taking math tests (students 5 and 6 in Table 7). The two students were categorized as Thriving because the anxiety was specific to test-taking and because they had very positive thoughts about math.

3.2.2. Agonizing

Students with an Agonizing IMAE primarily had negative feelings and thoughts about math and negative physiological reactions associated with math (Table 6). Agonizing students had strong negative feelings and said things like they hate math, have math anxiety, feel dumb, feel embarrassed, and feel stressed (see the underlined phrases in students' statements in Table 8). Agonizing students primarily wrote about having strong negative thoughts (see the bolded phrases in students' statements in Table 8). For example, they said they always struggle, do not understand math, and are bad at math. In addition, Agonizing students described experiencing a range of negative physiological reactions including headaches, sweating, crying, and restlessness (see the italicized phrases in students' statements in Table 8).

Table 8. Example quotes for students with an Agonizing IMAE.

Example #	Student Quote [a]
1	"**I have always struggled with numbers and still do. I was always placed in 'special learning' math groups in HS to try to get me up to the level of my classmates but I still struggle with it**. My feelings about math tend to be negative because I have had more negative experiences than positive. Playing simple games with adding or subtracting puts me into a negative mood. *I do have physical reactions like sweating and restlessness when doing things involving math.*"
2	"**I just have never been able to understand math and numbers it's not my strong suit**. A math class gives me anxiety because **I know I will struggle with it**."
3	"I have moderate anxiety **about thinking about or doing math because it takes me a while to do problems usually and for some reason, I always have trouble asking for help**. I think because I don't want to look stupid or embarrass myself for not knowing something, especially if it's simple."
4	"**I have always said, 'I am bad at math**.' Which, now I see that is more my anxiety coming out. **I have always been in the lowest level of math and even would get pulled out of extra help**. It was something I was always embarrassed by. So, I have never enjoyed a math class **even when I feel like I am trying the hardest in the class and I am still getting a B**. I know I have bad math anxiety and I am trying to work on it."

Table 8. *Cont.*

Example #	Student Quote [a]
5	"**I like many others I'm sure tend to have a negative opinion of math.** I'm not sure if it's 100% just math anxiety but I just tend **to avoid things that involve math as to not stress me out**. That's even part of the reason why this [assignment] is turned in late and didn't do it yesterday... I don't hate math but I definitely don't like 'abstract' math."
6	"I was always great in history and English classes, **but I was never the best in my math courses, sometimes many of the problems were easy and I just had to work my way with it**, *but many times it would leave me with headaches* and not want to do it. **I remember algebra 2 was the worst time of my life in high school and made me legit, not even want to live anymore, that's how horrid I am at math and trying to excel in it**. I am a history major which doesn't involve math but I know that I will still have to endure that pain and still have to struggle in some math courses, but hopefully it will pay off."
7	"I do not like math. **I like it when it is explained in a way that I can understand it and be able to explain it to someone else. I cannot and do not understand most math problems in any form. Unless numbers and the equation are given to me without any content or context clues, I cannot understand the problem**. It makes me feel dumb. I feel overwhelmed. *I often cry to my sister and friend* about how **much I want to drop out of college**. I am not being dramatic; they can both testify that. *I once cried doing a 10-question math quiz in 6th grade. Actually, I've cried multiple times over math problems.* **The issue is that I often do not get the context clues and word problems. I like being directly given the numbers and equations and what to do with them**."
8	"I absolutely hate math. **I don't grasp the concepts at all and have always strived to get better, but I always just end up doing worse. One positive thing is that I can add simple problems. One neutral thing is I can walk away from the problem when I need to**."
9	"**The last time I truly remember being good at math was in my sophomore year in high school**. When I got to my junior and senior is when my math anxiety really began. **Things do get more abstract and my efforts shut down**. I got discouraged because **I went from being at the top of the class to being average**.Ever since then I get really nervous before entering a lesson that has math."

The quotes include students' full narrative. [a] Student quotes modified for grammatical errors and clarity. Underlined text indicates feelings. Bolded text indicates thoughts. Italicized text indicates physiological reactions.

Although students with Agonizing IMAEs primarily hold negative thoughts and feelings, some students described positive thoughts and feelings. Those positive thoughts and feelings fall into two categories: (1) students had positive thoughts or feelings when they did simple math problems or (2) students had positive thoughts or feelings associated with their previous middle school or high school experiences, but they no longer have those positive feelings or thoughts. Four students described positive thoughts or feelings when they did simple math problems. For example, student 8 in Table 8 said that a positive thing for them was that they could do simple math problems. However, student 8's one positive thought is overshadowed by the student stating that they "absolutely hate math" and "always end up doing worse" when they have tried to do better. Twelve students described positive thoughts or feelings associated with their previous middle school or high school experiences, but they no longer have those positive feelings or thoughts. For example, student 9 in Table 8 has memories of being good in math earlier in high school. However, as they progressed in school, they developed math anxiety. They became discouraged and now they get nervous about math lessons. Although they had positive memories, their current emotions and thoughts are negative.

3.2.3. Persisting

Thriving students had predominantly positive feelings and thoughts and no physiological reactions related to math. Agonizing students had predominantly negative feelings and thoughts and negative physiological reactions. Persisting students are distinguished from Thriving and Agonizing by having both negative and positive feelings and thoughts. Persisting students expressed negative and positive feelings and thoughts about math (Tables 6 and 9). They also described neutral feelings and thoughts. A small number had negative physiological reactions associated with math (Table 6).

Table 9. Example quotes for students with a Persisting IMAE.

Example #	Student Quote [a]
1	"**I have never been good at math**, but I have always liked it. If I work hard, math tends to be more fun. But when I get stressed and anxious, **it can get hard to keep working at it**."
2	"I actually really enjoy math, **I took AP Calculus my senior year of high school and did rather well!** However, other math classes such as Stats (though I got in A in it) and physics causes more anxiety for me. **I am fine when I am working on my own because I can take my time**, the anxiety really only settles in when there's a quiz/exam or if I'm called on in class."
3	"I like math when it makes sense. **Usually, most questions are not too difficult to learn and/or review and I can catch on quite quickly with the proper examples and explanations**. However, *if the problems become challenging and do not make sense even with an explanation, I break down*. My anxiety will skyrocket and *I will shut down.*"
4	"I don't necessarily dislike math; **I actually feel I am quite good at it**. However, I do find it extremely boring and uninteresting, and for me when I find something boring, I tend to not care about it and don't enjoy it, which makes me kind of mad I'm doing it."
5	"I feel incredibly neutral when it comes to all things math-related. **I'm not very math-minded**, or very interested in math, but **I've never had massive problems with it**, nor have I suffered from any math anxiety. **Math is just another thing to do in school**, and I've never been very worried about how I perform. I don't really feel anxious in general over anything, but **definitely not toward anything as unimportant to me as math**."

The quotes include students' full narrative. [a] Student quotes modified for grammatical errors and clarity. Underlined text indicates feelings. Bolded text indicates thoughts. Italicized text indicates physiological reactions.

The student in example 1 in Table 9 always liked math and even enjoyed math. However, student 1 also experiences stress and anxiety sometimes with math and considers themselves not to be a math student. This blend of positive and negative feelings (enjoyment doing math, but also experiencing stress and anxiety) and a personal belief that they have never been good at math is common for Persisting students. They do not have predominantly positive or negative feelings and thoughts, but a mixture (Table 9).

In addition to a mixture of positive and negative feelings and thoughts, more Persisting students than Thriving and Agonizing students expressed neutral feelings and thoughts. For example, student 5 in Table 9, says "I feel incredibly neutral when it comes to all things math-related" which is categorized as a neutral feeling as defined by the student. Similarly, student 5 says, "Math is just another thing to do in school," which is categorized as a neutral thought. The student does not say math is something they enjoy doing or hate doing; rather, the student states that math is just something to do in school.

3.3. Gender Differences

We are interested in understanding the role of math as a potential barrier for female students in geoscience compared to the role of math for male students, who are the traditional majority in geoscience [51]. Therefore, we examined if there were gender differences in IMAEs (Table 10). The lowest percentage of women and men had Thriving IMAEs. Comparing across gender, a lower percentage of women than men had Thriving IMAEs. The highest percentage of women and second highest percentage of men had Agonizing IMAEs. Comparing across gender, a higher percentage of women than men had Agonizing IMAEs. The percentages of women and men with Persisting IMAEs were similar. The percentages of women and men were different for the IMAEs; however, a chi-square analysis showed no significant difference between men and women in their IMAEs: χ^2 (2, N = 74) = 2.9367, p = 0.230311.

Table 10. Percentage of women and men in each IMAE category.

IMAEs	Women (n = 45)	Men (n = 29)
Thriving	9%	21%
Persisting	44%	48%
Agonizing	47%	31%

4. Discussion

This study aimed to identify math anxiety experiences of students in introductory geoscience classes and to determine if and how those experiences varied by gender identity. We identified three integrated math anxiety experiences of students enrolled in introductory geoscience classes at two universities. The IMAEs occurred at the intersection of students' feelings, thoughts, and physiological reactions and how those feelings, thoughts, and physiological reactions varied across dimensions (positive, neutral, negative). Additionally, the three IMAEs occurred on a continuum from Thriving (predominantly positive feelings, physiological reactions, and thoughts); to Persisting (a mix of positive and negative feelings, physiological reactions, and thoughts); to Agonizing (predominantly negative feelings, physiological reactions thoughts). The conceptual framework in Figure 1 summarizes how the dimensions of students' feelings, physiological reactions, and thoughts intersect to define the integrated math anxiety experiences across the continuum.

	Thriving	Persisting	Agonizing
Feelings	Positive	Positive and Negative	Negative
Physiological Reactions	None	None or Negative	Negative
Thoughts	Positive	Positive and Negative	Negative

Figure 1. Conceptual framework depicting the intersection of the three components (feelings, physiological reactions and thoughts) to define the three IMAEs.

In our study of introductory geoscience students, 40% of all students and nearly 50% of female students held an Agonizing IMAE, defined as having mostly negative feelings, physiological reactions, and thoughts. Although our study did not examine how IMAEs are associated with students' success in class and students' academic and career choices, other researchers have found that math anxiety can negatively affect students' performance [18,52,53]. Additionally, students with math anxiety are less likely to select science academic and career paths [19,54]. More research is needed to identify how Agonizing IMAEs are associated with students' success in class and their academic and career choices.

Persisting was the second most frequently held IMAE for women and the most frequently held IMAE for men in our study. Students with a Persisting IMAE had a mix of positive and negative feelings and thoughts and some had negative physiological reactions. This finding can be partially explained by the findings of Palestro and Jameson [35] who found that math self-efficacy mediates the relationship between math anxiety and performance; as such students with Persisting IMAE may experience some negative attitudes (e.g., high anxiety) and some positive attitudes (e.g., high self-efficacy), which work together to enhance their performance and motivation.

Students with more positive math experiences and attitudes are more successful in math-related activities and more likely to pursue science academic majors, and career paths [18,19]. For example, students with a Thriving IMAE in our study had positive feelings and thoughts and no physiological reactions; therefore, they might be more successful with math-related tasks in their geoscience classes and more likely to pursue geoscience.

5. Limitations

We identified several limitations in this study. Students in this study participated in an instructional intervention before writing the math narrative that we collected. In the instructional intervention, students learned about math anxiety, its role in learning, and strategies to reduce math anxiety. Learning about math anxiety before completing their math narrative may have primed students to focus more strongly on negative feelings, physiological reactions, and thoughts in their math narratives. This possible emphasis on negative feelings, physiological reactions, and thoughts could influence the construction of integrated math anxiety experiences. Future work should consider having students complete a math narrative before learning about math anxiety. The math narratives in this study were short and some students' feelings, physiological reactions, and thoughts might not have been captured in the short narratives. Future work should also consider prompting students to write longer narratives and include interviews with students to capture more in-depth descriptions of students' math anxiety experiences.

6. Conclusions and Future Work

While significant work has been completed on math anxiety in other natural and physical sciences, this is one of the first known studies to explore math anxiety of students in introductory geoscience classes. We conducted an exploratory qualitative study and found that students in introductory geoscience classes had integrated math anxiety experiences defined by their combination of feelings, physiological reactions, and thoughts. A higher percentage of women had Agonizing IMAEs than did men, although the finding was not statistically significant. Having Agonizing IMAEs may be associated with student success in geoscience classes and may be one reason that women are marginalized and minoritized in geoscience programs. Future work should explore if students in introductory geoscience classes at other institutions have similar IMAEs and how the IMAEs are associated with students' success in their geoscience class. Future work should also explore if geoscience majors have similar IMAEs and what role the IMAEs have on students' decisions to select and persist in geoscience majors, particularly female students. Math anxiety is often examined using quantitative surveys. Our study examined students' written narratives and identified novel themes describing students; integrated math anxiety experiences. Future mixed methods research should examine how the qualitative IMAE themes connect with students' math anxiety as measured in quantitative surveys.

Author Contributions: Conceptualization, J.S., D.L., M.M.J., J.M.W.; methodology, J.S., D.L.; validation, J.S., D.L., M.M.J., J.M.W.; formal Analysis, J.S., D.L.; investigation, J.S., D.L., M.M.J., J.M.W.; resources, J.S., M.M.J., J.M.W.; data curation, J.S., D.L.; writing–original draft preparation, J.S., D.L., M.M.J., J.M.W.; writing–review & editing, J.S., D.L., M.M.J., J.M.W.; supervision, J.S., M.M.J.; project administration, J.S., D.L., M.M.J., J.M.W.; funding acquisition, J.S., M.M.J., J.M.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research was partially funded by the National Science Foundation, Improving Undergraduate Science Education grant #1834666 and grant #1949737.

Institutional Review Board Statement: The study was approved by the Institutional Review Board at the University of Northern Colorado (protocol #1295891, 16 September 2019) and University of Colorado Boulder (protocol #19-0478, 21 August 2019).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Due to the nature of this research, participants of this study did not agree for their data to be shared publicly in a data set, so supporting data are not available.

Acknowledgments: We thank the geoscience departments and faculty who graciously served as data collection sites for this study. We also thank the students who participated in this study.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. American Geosciences Institute. What Is Geoscience? Available online: https://www.americangeosciences.org/critical-issues/faq/what-is-geoscience (accessed on 3 February 2017).
2. Corbett, R.G. Should we support establishment of advanced placement geology courses? *Prof. Geol.* **2000**, *37*, 17.
3. Shea, J.H. Mathematics in physical-geology textbooks. *J. Geosci. Educ.* **1990**, *38*, 138–148. [CrossRef]
4. Wenner, J.M.; Baer, E.A.; Manduca, C.; Macdonald, R.H.; Patterson, S.; Savina, M. The case for infusing quantitative literacy into introductory geoscience courses. *Numeracy* **2009**, *2*, 4. [CrossRef]
5. Stokes, P.J.; Levine, R.; Flessa, K.W. Choosing the Geoscience Major: Important Factors, Race/Ethnicity, and Gender. *J. Geosci. Educ.* **2015**, *63*, 250–263. [CrossRef]
6. Fratesi, S.E.; Vacher, H.L. Using spreadsheets in geoscience education: Survey and annotated bibliography of articles in the journal of geoscience education through 2003. *Spreadsheets Educ.* **2005**, *1*, 190–216.
7. Hancock, G.; Manduca, C.A. Developing quantitative skills activities for geoscience students. *EOS* **2005**, *86*, 355. [CrossRef]
8. Manduca, C.A.; Macdonald, H.; Feiss, G. Education: Preparing students for geosciences of the future. *Geotimes* **2008**, *53*, 59.
9. McFadden, R.R.; Viskupic, K.; Egger, A.E. Faculty self-reported use of quantitative and data analysis skills in undergraduate geoscience courses. *J. Geosci. Educ.* **2021**, *69*, 373–386. [CrossRef]
10. Wenner, J.M.; Baer, E.M.D. The Math You Need, When You Need It (TMYN): Leveling the playing field. *Numeracy* **2015**, *8*, 5. [CrossRef]
11. Jameson, M.M.; Sexton, J.M. "Math Sucks!": The role of mathematics in undergraduate geoscience programs. In Proceedings of the University of Northern Colorado Annual Academic Excellence Week Conference, Greeley, CO, USA, 30 April 2017.
12. Miranda, R.J.; Hermann, R.S.; Hurley, K.P.; Moore, J. Motivations for pursuing and challenges to completing geoscience majors at a public university. *J. Geosci. Educ.* **2021**, *69*, 300–312. [CrossRef]
13. Harackiewicz, J.M.; Smith, J.L.; Priniski, S.J. Interest matters: The importance of promoting interest in education. *Policy Insights Behav. Brain Sci.* **2016**, *3*, 220–227. [CrossRef] [PubMed]
14. Ganley, C.M.; McGraw, A.L. The development and validation of a revised version of the math anxiety scale for young children. *Front. Psychol.* **2016**, *7*, 1181. [CrossRef] [PubMed]
15. Geist, E. Math anxiety and the "math gap": How attitudes toward mathematics disadvantages students as early as preschool. *Education* **2015**, *135*, 328–336.
16. Jameson, M.M. The development and validation of the Children's Anxiety in Math Scale. *J. Psychoeduc. Assess.* **2013**, *31*, 391–395. [CrossRef]
17. Jameson, M.M. Contextual factors related to math anxiety in second-grade children. *J. Exp. Educ.* **2014**, *82*, 518–536. [CrossRef]
18. Barroso, C.; Ganley, C.M.; McGraw, A.L.; Geer, E.A.; Hart, S.A.; Daucourt, M.C. A meta-analysis of the relation between math anxiety and math achievement. *Psychol. Bull.* **2021**, *147*, 134–168. [CrossRef]
19. Levy, H.E.; Fares, L.; Rubinsten, O. Math anxiety affects females' vocational interests. *J. Exp. Child Psychol.* **2021**, *210*, 105214. [CrossRef]
20. Awofala, A.O.; Lawal, R.F.; Arigbabu, A.A.; Fatade, A.O. Mathematics productive disposition as a correlate of senior secondary school students' achievement in mathematics in Nigeria. *Int. J. Math. Educ. Sci. Technol.* **2022**, *53*, 1326–1342. [CrossRef]
21. Kusmaryono, I.; Suyitno, H.; Dwijanto, D.; Dwidayati, N. The effect of mathematical disposition on mathematical power formation: Review of dispositional mental functions. *Int. J. Instr.* **2019**, *12*, 343–356. [CrossRef]
22. Smith, J.L.; White, P.H. Development of the domain identification measure: A tool for investigating stereotype threat effects. *Educ. Psychol. Meas.* **2001**, *61*, 1040–1057. [CrossRef]
23. Wang, Z.; Shakeshaft, N.; Schofield, K.; Malanchini, M. Anxiety is not enough to drive me away: A latent profile analysis on math anxiety and math motivation. *PLoS ONE* **2018**, *13*, e0192072. [CrossRef]
24. Daker, J.R.; Gattas, S.U.; Sokolowski, M.H.; Green, A.E.; Lyons, I.M. First-year students' math anxiety predicts STEM avoidance and underperformance throughout university, independently of math ability. *NPJ Sci. Learn.* **2021**, *6*, 17. [CrossRef] [PubMed]
25. Ma, X. A meta-analysis of the relationship between anxiety toward mathematics and achievement in mathematics. *J. Res. Math. Educ.* **1999**, *30*, 520–540. [CrossRef]
26. Samuel, T.S.; Warner, J. "I can math!": Reducing math anxiety and increasing math self-efficacy using a mindfulness and growth mindset-based intervention in first-year students. *Community Coll. J. Res. Pract.* **2021**, *45*, 205–222. [CrossRef]
27. Beilock, S.L.; Maloney, E.A. Math Anxiety: A factor in math achievement not to be ignored. *Policy Insights Behav. Brain Sci.* **2015**, *2*, 4–12. [CrossRef]
28. Foley, A.E.; Herts, J.B.; Borgonovi, F.; Guerriero, S.; Levine, S.C.; Beilock, S.L. The math anxiety-performance link: A global phenomenon. *Curr. Dir. Psychol. Sci.* **2017**, *26*, 52–58. [CrossRef]
29. Ashcraft, M.H.; Ridley, K.S. Math anxiety and its cognitive consequences. In *Handbook of Mathematical Cognition*; Psychology Press: New York, NY, USA, 2005; pp. 315–327.
30. Feldhaus, C.A. How pre-service elementary school teachers' mathematical dispositions are influenced by school mathematics. *Am. Int. J. Contemp. Res.* **2014**, *4*, 91–97.
31. Ashcraft, M.H. Math anxiety: Personal educational, and cognitive consequences. *Curr. Dir. Psychol. Sci.* **2002**, *11*, 181–185. [CrossRef]

32. O'Leary, K.; Fitzpatrick, C.L.; Hallett, D. Math anxiety is related to some, but not all, experiences with math. *Front. Psychol.* **2017**, *8*, 2067. [CrossRef]
33. Richardson, F.C.; Suinn, R.M. The Mathematics Anxiety Rating Scale: Psychometric data. *J. Couns. Psychol.* **1972**, *19*, 551–554. [CrossRef]
34. Ramirez, G.; Gunderson, E.A.; Levine, S.C.; Beilock, S.L. Math anxiety, working memory, and math achievement in early elementary school. *J. Cogn. Dev.* **2013**, *14*, 187–202. [CrossRef]
35. Palestro, J.J.; Jameson, M.M. Math self-efficacy, not emotional self-efficacy, mediates the math anxiety-performance relationship in undergraduate students. *Cogn. Brain Behav.* **2020**, *24*, 379–394. [CrossRef]
36. Else-Quest, N.M.; Hyde, J.S.; Linn, M.C. Cross-national patterns of gender differences in mathematics: A meta-analysis. *Psychol. Bull.* **2010**, *136*, 103–127. [CrossRef] [PubMed]
37. Morrissey, K.; Hallett, D.; Bakhtiar, A.; Fitzpatrick, C. Implicit math-gender stereotype present in adults but not in 8th grade. *J. Adolscence* **2019**, *74*, 173–182. [CrossRef] [PubMed]
38. Rubinstein, O.; Bialik, N.; Solar, Y. Exploring the relationship between math anxiety and gender through implicit measurement. *Front. Hum. Neurosci.* **2012**, *6*, 279. [CrossRef]
39. Lent, R.W.; Lopez, F.G.; Bieschke, K.J. Mathematics self-efficacy: Sources and relation to science-based career choice. *J. Couns. Psychol.* **1991**, *38*, 424–430. [CrossRef]
40. Lent, R.W.; Brown, S.D.; Sheu, H.-B.; Schmidt, J.; Brenner, B.R.; Gloster, C.S.; Wilkins, G.; Schmidt, L.C.; Lyons, H.; Treistman, D. Social cognitive predictors of academic interests and goals in engineering: Utility for women and students at historically black universities. *J. Couns. Psychol.* **2005**, *52*, 84–92. [CrossRef]
41. Lent, R.W.; Sheu, H.B.; Miller, M.J.; Cusick, M.E.; Penn, L.T.; Truong, N.N. Predictors of science, technology, engineering, and mathematics choice options: A meta-analytic path analysis of the social–cognitive choice model by gender and race/ethnicity. *J. Couns. Psychol.* **2018**, *65*, 17. [CrossRef]
42. Lin, L.; Lee, T.; Snyder, L.A. Math self-efficacy and STEM intentions: A person-centered approach. *Front. Psychol.* **2018**, *9*, 2033. [CrossRef]
43. Jameson, M.M.; Sexton, J.M.; London, D.R.; Wenner, J.M. Math attitudes in undergraduate students enrolled in introductory geoscience courses. In Proceedings of the Improving Undergraduate STEM Education Summit, Washington, DC, USA, 1–3 June 2022.
44. Fairchild, E.; Newman, H.; Sexton, J.; Pugh, K.; Riggs, E. 'Not to be stereotypical, but.'. Exclusive and inclusive gendered discourses about geology field experiences. *J. Gend. Stud.* **2022**, *31*, 492–504. [CrossRef]
45. Sexton, J.; Newman, H.; Bergstrom, C.; Pugh, K.; Riggs, E. Multisite investigation of sexist experiences encountered by undergraduate female geology students. *Int. J. Gend. Sci. Technol.* **2020**, *12*, 353–376.
46. Sexton, J.M.; Pugh, K.J.; Bergstrom, C.M.; Riggs, E.M. Reasons undergraduate students majored in geology across six universities: The importance of gender and department. *J. Geosci. Educ.* **2018**, *66*, 319–336. [CrossRef]
47. Merriam, S.B.; Tisdell, E.J. *Qualitative Research: A Guide to Design and Implementation*; Jossey-Bass: San Francisco, CA, USA, 2016.
48. The Carnegie Classification of Institutions of Higher Education. About Carnegie Classification. Available online: https://carnegieclassifications.acenet.edu/ (accessed on 30 May 2022).
49. Miles, M.B.; Huberman, M.; Saldana, J. *Qualitative Data Analysis: A Methods Sourcebook*, 4th ed.; Sage Publications Inc.: Los Angeles, CA, USA, 2020.
50. MacQueen, K.M.; McLellan-Lemal, E.; Bartholow, K.; Milstein, B. Team based codebook development: Structure, process, and agreement. In *Handbook for Team-Based Qualitative Research*; Guest, G., MacQueen, K.M., Eds.; Altamira Press: Lanham, MD, USA, 2008.
51. Bernard, R.E.; Cooperdock, E.H.G. No progress on diversity in 40 years. *Nat. Geosci.* **2018**, *11*, 292–295. [CrossRef]
52. Caviola, S.; Toffalini, E.; Giofrè, D.; Ruiz, J.M.; Szűcs, D.; Mammarella, I.C. Math performance and academic anxiety forms, from sociodemographic to cognitive aspects: A meta-analysis on 906,311 participants. *Educ. Psychol. Rev.* **2021**, *34*, 363–399. [CrossRef]
53. Núñez-Peña, M.I.; Suárez-Pellicioni, M.; Bono, R. Effects of math anxiety on student success in higher education. *Int. J. Educ. Res.* **2013**, *58*, 36–43. [CrossRef]
54. Ahmed, W. Developmental trajectories of math anxiety during adolescence: Associations with STEM career choice. *J. Adolesc.* **2018**, *67*, 158–166. [CrossRef]