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Unpacking Mathematics Identity: Exploring Undergraduate Students' Enduring Experiences

Descompactando a identidade matemática: explorando as experiências duradouras dos alunos de graduação

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Abstract

Changes in mathematics identity over time were examined as well as beliefs regarding the nature of mathematics identity and experiences with mathematics that might be related to mathematics identity development. Survey data from 131 college students were analyzed using a Wilcoxon Signed-Rank test to assess longitudinal changes in self-perceptions about mathematics identity. In addition, open-ended responses were analyzed using a phenomenological approach to examine experiences with and beliefs about mathematics. The results indicate that mathematics identity, as reported by students, is a stable measure over time. Several overarching themes emerged from the qualitative data to indicate that participants' reported formative experiences center around to performing in mathematics and teaching others or sharing mathematics. A majority of participants believe it is possible to become a "math person"; however, an underlying belief that mathematics is an innate ability is also evident.

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Resumo

Mudanças na identidade matemática ao longo do tempo foram examinadas, bem como crenças sobre a natureza da identidade matemática e experiências com matemática que podem estar relacionadas ao desenvolvimento da identidade matemática. Os dados da pesquisa de 131 estudantes universitários foram analisados usando um teste Wilcoxon Signed-Rank para avaliar as mudanças longitudinais nas autopercepções sobre a identidade matemática. Além disso, as respostas abertas foram analisadas usando uma abordagem fenomenológica para examinar experiências e crenças sobre matemática. Os resultados indicam que a identidade matemática, relatada pelos alunos, é uma medida estável ao longo do tempo. Vários temas abrangentes emergiram dos dados qualitativos para indicar que as experiências formativas relatadas pelos participantes giram em torno de atuar em matemática e ensinar outras pessoas ou compartilhar matemática. A maioria dos participantes acredita que é possível se tornar uma "pessoa da matemática"; no entanto, uma crença subjacente de que a matemática é uma habilidade inata também é evidente.

1. Introduction.

Individuals begin forming their self-perception with regards to mathematics when they are very young. These self-perceptions may begin to develop even before children embark on their formal education pathways. Self-perceptions are important because they often become an individual's reality. For example, research indicates that an individual's mathematics related self-perceptions strongly correlate with mathematics achievement (Bouchey & Harter, 2005; Huang, 2011; Skaalvik & Rankin, 1995; Sonnert et al., 2020a). Self-perceptions are also linked to motivation and persistence in mathematics, such as the number of mathematics courses taken (Simpkins & Eccles, 2006), completing a high school education (Fall & Roberts, 2012) and pursuing a STEM career (Cribbs et al., 2016). A great variety of experiences, both inside and outside the classroom, culminate in forming students' self-perceptions about, and ultimately their identity related to, mathematics. For example, an outside experience may be evident when students who are basketball players use professional player statistics (Nasir & de Royston, 2013), and an inside experience may be exemplified by the discourse occurring between two students in a 7th grade mathematics classroom (Bishop, 2012).

Whether for long-term application in a career or for everyday use, mathematics is an essential part of our technologically advancing society. The importance of students' self-perceptions about mathematics is apparent in the report *Adding it Up*, which lists a productive disposition toward mathematics as one of the five strands for mathematical proficiency (Kilpatrick et al., 2001). The National Council of Teachers of Mathematics (NCTM) further supports that stance, stating that mathematics teachers should "plan and implement units and lessons that promote positive dispositions toward the study of mathematics, including curiosity, self-confidence, flexibility, and perseverance" (2014, p. 114-115). One purpose of this study is to explore individuals' experiences with mathematics that contribute to their mathematics identity.

1.1 Societal factors and beliefs about mathematics: Factors that influence individuals' beliefs about what it means to be a "math person" are influenced not only by what occurs in the classroom, but also by what is observed in and reinforced by their culture. With regard to the current cultural view of mathematics in the United States, Boaler (2015) stated that “too often it is taught as a performance subject, the role of which, for many, is to separate students into those with the math gene and those without” (p. 93). Given the idea that there are people who can and those who cannot do mathematics, individuals are left to identify with one of these two groups, positioning themselves within—or outside of--the mathematics community, based on various experiences and input they receive about their ability. Stereotypes about what it means to be a “math person” is one factor that could dissuade individuals from participation in mathematics. Elementary-school children, for instance, were found to equate being in a mathematics or science field with being male (Steele, 2003). These stereotypes are observed with children as early as second grade (Cvencek et al., 2011). Even films can perpetuate societal stereotypes about what it means to be a female in mathematics-related fields, such as science and engineering (Steinke, 2005). Prior studies also point to parents’ and teachers’ beliefs about learning and identify the influence these beliefs have on students’ beliefs (Cimpian et al., 2007; Good et al., 2007; Mueller & Dweck, 1998). Furthermore, learning mathematics partly depends on a student’s broader cultural background (home and community experiences) (see Nasir et al., 2008). Cultural norms and beliefs about what it means to do mathematics and be a “math person” are integral to an individual’s mathematics identity development. However, as culture changes, so do these perspectives. Therefore, understanding how undergraduates currently view what it means to be a “math person” is important for better understanding how to counteract misconceptions and support equity in participation in the mathematics community, whether that be in a classroom, degree program, or career.

1.2 Societal factors and beliefs about mathematics: Mathematics identity is a construct that provides a lens for better understanding student choices related to mathematics. Researchers have explored mathematics identity in different settings, such as classroom interactions (Boaler & Greeno, 2000; Esmonde, 2012; Hima et al., 2019) and outside-the-classroom experiences (Nasir, 2002; Nasir & de Royston, 2013), and they have conceptualized mathematics identity in various ways. They have, for instance, focused on figured worlds (Holland & Lave, 2001), discourse (Sfard & Prusak, 2005), and social factors, such as race (Larnell, 2016; Martin, 2000, 2006). These different settings and ways of conceptualizing the construct are not mutually exclusive, but often overlap (Bishop, 2012), as seems inevitable when investigating a complex concept in what is often a messy and dynamic environment, such as the classroom. In addition to providing a way to understand how and why students position themselves in the classroom in certain ways, the concept of mathematics identity helps us better understand why students may or may not want to pursue mathematics (Boaler & Greeno, 2000; Cribbs et al., 2016).

This study adopts a macro-identity approach that aligns with the concept of core identity, as described by Cobb and Hodge (2011), who define it as students' “enduring sense of who they are and who they want to become” (p. 189). This macro-identity approach provides a picture of an individual’s lasting sense of identity that is more stable than identity viewed from a micro-identity approach (Lichtwarck-Aschoff et al., 2008). With the macro perspective in mind, we define mathematics identity as how students see themselves in relation to mathematics, based upon their perceptions and navigation of everyday experiences with mathematics (Enyedy et al., 2006).

In a prior study, an explanatory framework for mathematics identity was established, finding the construct to be comprised of two sub-factors, *Recognition* and *Interest*. That study also found the sub-factor of *Competence/Performance* to have an indirect effect on mathematics identity, mediated through *Recognition* and *Interest* (Cribbs et al., 2015).

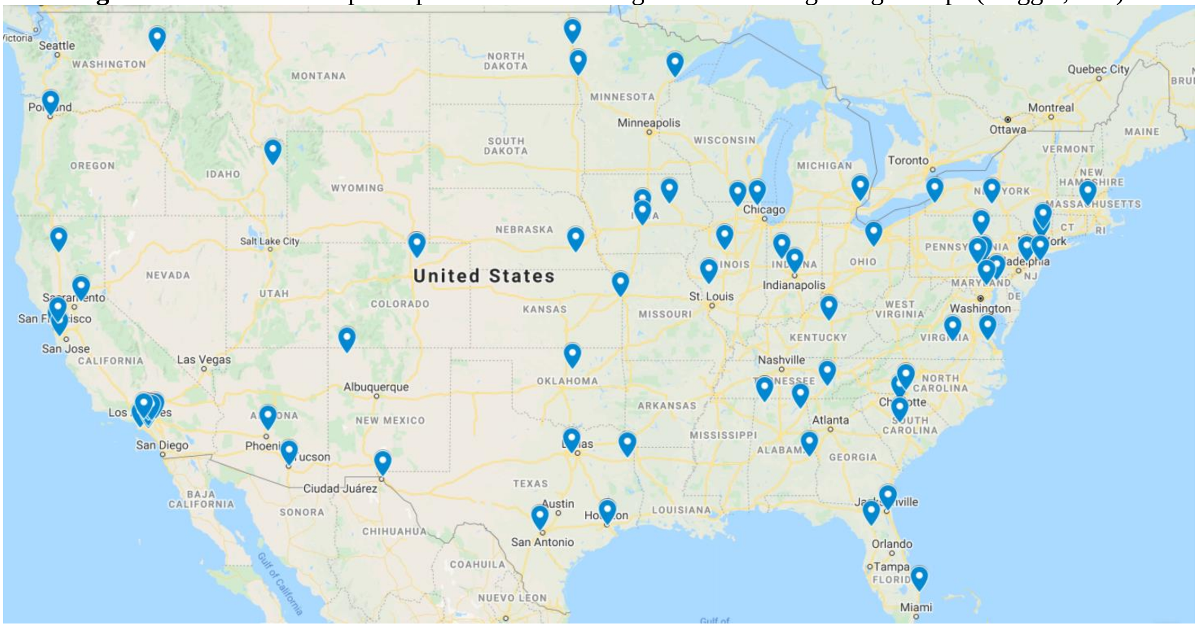
However, that study did not provide a description for the types of experiences that students equated with the sub-factors, which would be important for understanding the types of experiences that could promote or discourage further participation in mathematics. The sub-factor of *Recognition* is defined as how individuals perceive others view them in relation to mathematics. Prior work highlights the role of parents and teachers in influencing students' self-perceptions and achievement in mathematics (Gunderson et al., 2012). *Interest* is defined as an individuals' desire or curiosity to think and learn about mathematics, which is connected to students' motivation and engagement in mathematics (Frenzel et al., 2010; Silvia, 2006). Although *Competence* and *Performance* were not quantitatively distinguishable in the previous analysis (Cribbs et al., 2015), prior qualitative work discussed these sub-factors separately when exploring identity (Carlone & Johnson, 2007). For this reason, these sub-factors are considered separately in this study. *Competence* is defined as individuals' beliefs about their ability to understand mathematics. Prior research has linked competence to student goals (Ferla et al., 2010) and performance (Bouchey & Harter, 2005). Finally, *Performance* is defined as individuals' beliefs about their ability to perform in mathematics, related to students' motivation and actual performance in mathematics (Pajaras & Graham, 1999).

The following research questions guide this study: (1) Is mathematics identity, as defined by the framework adopted in this study, stable over three years of college experience? Assuming a stable identity can be confirmed, the follow-up research questions are: (2) What are individuals' beliefs about what it means to be a "math person"?, and (3) how do individuals describe their experiences with mathematics within the mathematics identity framework?

2. Methods.

2.1 Participants: This is a follow-up study drawing from a sample of students who had previously been surveyed in their entry-level college calculus classes about their high school experiences with mathematics. Quantitative and qualitative data were collected through a series of questions in an online questionnaire approximately three years later with a subset of the participants in the orginal survey study, yielding 131 responses. The purpose of this follow-up survey was to collect data about students' self-perceptions related to mathematics, students' current career choice, and details about students' mathematical experiences. Fifty-three percent of the responses identified themselves as female, 43% as male and 5% did not respond. Seventy-six percent of the participants identified themselves as White, 2% as Black, 7% as Asian, 1% as American Indian or Alaskan Native, 8% as other, and 5% as multi-racial. Nine percent of the respondents identified themselves as Hispanic. Based on where students orginally indicated they were attending college, 63% were at a 4-year institution (16% small, 35% medium, and 49% large) and 47% indicated they were at a 2-year institution (12% small, 43% medium, and 45% large; see Figure 1).

Figure 1: Distribution of participants based on college attended using Google Maps (Goggle, n.d.)



Source: Google Maps

2.2 Questionnaire: To address the first research question, one item on the questionnaire was intended to probe the stability of mathematics identity over time. This Likert-scale item asked participants to rate their level of agreement with the question, "Do you see yourself as a mathematics person" with choices ranging from 0 ("No, not at all") to 5 ("yes, very much"), which served as a proxy for mathematics identity. The same question was asked on the initial survey conducted three years prior to the online questionnaire.

To address the second research question, two open-ended items on the questionnaire probed the participants' beliefs about what it means to be a "mathematics person." They are:

1) Describe what it means to be a math person.
2) Can someone who is a non-math person become a math person?

Finally, five of the questions asked on the online questionnaire align with the mathematics identity framework (Cribbs et al., 2015) aimed at advancing our understanding of the types of experiences that made a lasting impression on the participants. These items specifically focused on the constructs of *Recognition*, *Interest*, *Competence*, and *Performance*. They are:

1) Describe a scenario where you have been recognized by your parent(s) as a math person. (Parent *Recognition*)
2) Describe a scenario where you have been recognized by your high school mathematics teacher(s) as a math person. (Math Teacher *Recognition*)
3) Describe ways you have enjoyed math. (*Interest*)

4) Describe how you know you "get" mathematics. (*Competence*)

5) Describe how you know you are performing well in mathematics. (*Performance*)

If participants did not have an experience to share, they responded with comments such as "I was not recognized," "Not applicable," or "Never."

2.3 Analysis: To address the first research question, a Wilcoxon Signed-Rank test was used because the data were non-normally distributed. We compared participants' responses to the following question "Do you see yourself as a mathematics person?" at two times three years apart to determine the general stability of college students' mathematics identity over time.

A phenomenological approach was used in analyzing data to address research question 2 and 3 because this study was trying to better understand the lived experiences of the participants with regard to mathematics (Moustakas, 1994). To ensure the trustworthiness of the data analysis, two researchers involved in the study analyzed a sample of ten to twenty responses individually for each survey question, highlighting significant statements – "sentences, or quotes that provide an understanding of how the participants experienced the phenomenon," interpreting the meaning of the statements, and developing potential themes (Creswell, 2008, p. 61). After initial themes were developed separately, the researchers met to discuss and establish consensus on emerging themes before separately coding the rest of the data set for each question. Finally, the researchers met again to come to agreement on all responses, based on the original set of themes that were developed. Results were quantified based on the frequency of significant statements for each theme, which aligns with the frequency of respondents that exhibit them. Additionally, the mean response to the question "Do you see yourself as a mathematics person", coded as MathID in the tables, is provided with each corresponding theme (for participants that included the theme – 1 in their response and for those who did not – 0) to better understand any correlation that might exist. A Wilcoxon Rank Sum test was performed to determine if differences existed between the means, but only for sample sizes (frequency) of 5 or greater for both groups. Further, a Kruskal-Wallis test was performed to determine if mean differences existed between response of "Yes", "No" and "Maybe" when asked if a "Can a 'non-math person' become a 'math person'".

3. Results.

3.1 Research question 1: A Wilcoxon Signed-Rank test was conducted to address the first research question--is students' global view of their mathematics identity stable over three years of college experience? Thirty-five percent of the participants responded the same way as the initial survey, 48% responded one point off from their initial response, 12% responded 2 points off from their initial response, 2 percent responded 3 points off from their initial response, and 2 percent responded 4 points off from their initial response. The non-significant p-value for the Wilcoxon Signed-Rank test indicates that participants' mathematics identity did not change over the three-year interval between data collection. A summary of responses, pre and post, and the results of the Wilcoxon Signed-Rank test are shown in Table 1.

Table 1: Summary of Responses and Wilcoxon Signed-Rank Test

		Summer 2012 Response						Total
		0	1	2	3	4	5	
Fall 2009	0	2 (2%)	2 (2%)	0	2 (2%)	1 (1%)	0	7

Response	1	0	0	2 (2%)	4 (3%)	0	1 (1%)	7
	2	1 (1%)	4 (3%)	2 (2%)	2 (2%)	2 (2%)	0	11
	3	0	1 (1%)	0	6 (5%)	11 (9%)	1 (1%)	19
	4	0	0	4 (3%)	10 (8%)	11 (9%)	14 (11%)	39
	5	0	1 (1%)	1 (1%)	3 (2%)	17 (13%)	24 (19%)	46
Total		3	8	9	27	42	40	129

	Mean (SD) Fall 2009	Mean (SD) Summer 2012	Test Statistic	p-value
Wilcoxon Signed-Rank Test	3.66 (1.45)	3.67 (1.27)	1774	p = .961

Note: SD = standard deviation

Source: the research

3.2 Research question 2: To better understand how individuals view what it means to be a “math person”, two items from the questionnaire were analyzed. Results for the first item, "describe what it means to be a 'math person,'" are shown in Table 2. The highest percentage of responses related to *interest* in mathematics at 19%. Example statements within this theme include “I’d say something that makes us math people is that we find excitement in using math to solve problems” and “Enjoys doing math for fun...” The second highest percentage of responses covered the theme *understanding* at 18%, with statements such as “Understands the language of math” and “Someone who can grasp how smaller elements work together to create a bigger picture.” The third theme was *achievement* (e.g., “Good with numbers,” “Capable of evaluating mathematical problems quickly and efficiently”), followed by the theme *characteristic or trait* (e.g., “Someone who has the ability to think logically,” “Be naturally good at math”) and *use or application* (e.g., “To be able to apply math,” “They use math to solve problems in their personal life, social life, and career”). These three themes represented 11% of the responses, respectively. All other themes represented less than 10% of significant statements present.

Means of mathematics identity were also reported for participants who mentioned the particular listed theme (MathID-1) and those who did not (MathID-0). Although no statistically significant differences were found for any of the themes, some trends could be noted. For example, a higher mean for mathematics identity was found for participants with a response that included the themes *interest*, *career in a mathematics field*, *value toward mathematics*, and *separate*. Conversely, a lower mean for mathematics identity was found for participants who included the themes *achievement* and *characteristic or trait*.

Table 2: Results for “What it means to be a ‘math person’”

Theme	Theme Description	Freq.	%	MathID(1) Mean(SE)	MathID(0) Mean(SE)	Wilcoxon p-value
Interest	Associates interest, enjoyment, or a desire for challenge with being a mathematics person.	70	19	3.83(.15)	3.47(.17)	.115
Understanding	Associates understanding, reflects cognition rather than a behavior related to an individual’s understanding or knowledge of mathematics, with being a mathematics person.	68	19	3.63(.16)	3.70(.16)	.752

Achievement	Associates performance, an action, in mathematics as being associated with being a mathematics person.	58	16	3.53(.18)	3.77(.14)	.423
Characteristic or trait	Associates being a mathematics person with personal characteristics, trait, or skill an individual is born with.	40	11	3.40(.24)	3.79(.12)	.267
Use or application	Associates use or application of mathematics with being a mathematics person.	39	11	3.85(.20)	3.59(.14)	.278
Comfortable with mathematics	Associates comfort or lack of comfort/anxiety with being a mathematics person.	20	6	3.80(.30)	3.64(.12)	.526
Career in mathematics field	Associates choice to enter a mathematics-related field or career with being a mathematics person.	17	5	4.18(.23)	3.59(.12)	.084
Participate in activities	Associates being a mathematics person with participation or desire to participate in mathematics activities.	13	4	3.69(.38)	3.66(.12)	NA
Share with or teach others	Associates teaching or sharing mathematics with others with being a mathematics person.	13	4	4.08(.21)	3.62(.12)	NA
Perseverance or effort	Associates a level of effort or lack of effort with being a mathematics person.	11	3	3.64(.47)	3.67(.12)	NA
Value toward mathematics	Associates importance of and appreciation for mathematics with being a mathematics person.	10	3	4.40(.22)	3.61(.12)	NA
Separate	Considers being a mathematics person as being separate from other types of people.	2	1	5.00(.11)	3.65(.00)	NA

Note: Wilcoxon Rank Sum test was not performed for sample sizes (frequency) less than 5 for both groups.

Source: the research

To better understand individuals' views about what enables a person to have a mathematics identity, two response to the question, “can someone who is a ‘non-math person’ become a ‘math person,’” was analyzed. Of the participants, 75% responded “yes,” 16% responded "no," and 9% responded "maybe." The mean response to the question “Do you see yourself as a ‘mathematics person’” for participants responding “yes” was 3.65, “maybe” was 2.92, and “no” was 4.05. A Kruskal-Wallis Test indicated there was not a significant difference between the responses and mean mathematics identity, $p = 0.074$.

Follow-up explanations that participants gave in support of their responses ("yes" or "no") are shown in Table 3. Differences in means for mathematics identity reported by participants who indicated “no” or “yes” were also assessed through a Wilcoxon Rank Sum Test. No statistically significant differences were found for the themes, though a marginal significance was found for *interest*, suggesting a higher mean for participants reporting “no.” The highest percentage of “yes” responses referred to *perseverance or effort* at 25%, and the highest percentage of “no” responses referred to a *characteristic or trait* at 35%. Another difference to be noted was evidence of divergent reporting related to effort, with 0% of “no” response for *perseverance or effort* and 0% of “yes” responses for *lack or ineffectiveness of* *effort*. Figure 2 provides a visual representation of how participants responded.

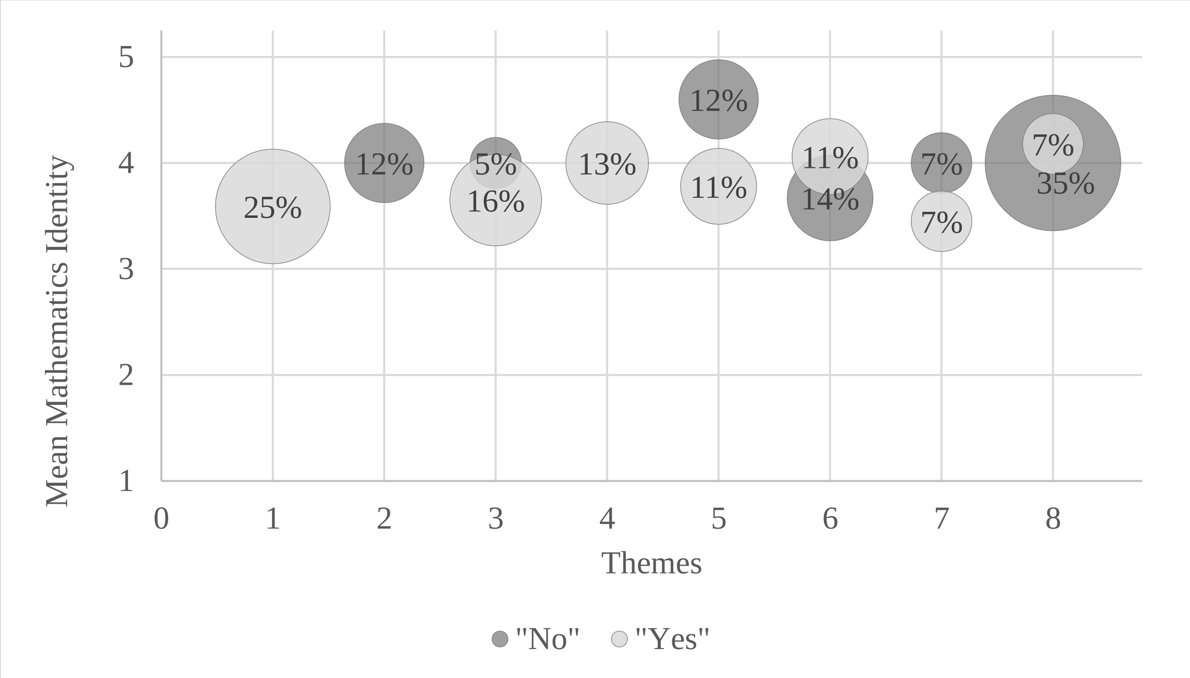
Table 3: Results for “No” and “Yes” responses to the question, “Can a ‘non-math person’ become a ‘math person’?”

Theme	Theme Description	% of “No”	% of “Yes”	MathID (“No”) Mean(SE)	MathID (“Yes”) Mean(SE)	Wilcoxon p-value
Perseverance or effort (T1)	Associates an individual working hard or persevering with mathematics, such as practicing a lot or studying, with being a mathematics person.	0	25	NA	3.59	NA
Lack or ineffectiveness of effort (T2)	Associates an individual not putting forward the effort or effort not being effective with being a mathematics person.	12	0	4.00	NA	NA
Way it is taught (T3)	Associates the way mathematics is taught or having a teacher/professor/ tutor that helps an individual understand or appreciate mathematics with being a mathematics person.	5	16	4.00	3.65	.431
Attitude or Confidence (T4)	Associates an individual’s state of mind and confidence about mathematics with being a mathematics person.	0	13	NA	4.00	NA
Interest (T5)	Associates an individual’s interest or enjoyment (or lack of) with mathematics with being a mathematics person.	12	11	4.60	3.78	.094
Understanding (T6)	Associates an individual’s understanding of mathematics with being a mathematics person.	14	11	3.67	4.06	.253
Choice (T7)	Associates an individual’s choice on whether or not to pursue/understand mathematics, for example an individual wanting to learn mathematics, with being a mathematics person.	7	7	4.00	3.45	.503
Characteristic or trait (T8)	Describes being a mathematics person as an innate ability, such as a way of thinking that someone is born with or a natural ability.	35	7	4.00	4.18	.719

Note: Themes with a subset of participants less than 7 were excluded from the results.

Source: the research

Figure 2: Mean mathematics identity for each theme and corresponding percentage of responses for “No” and “Yes” to the question, “Can a ‘non-math person’ become a ‘math person’?”



Source: the research

3.3 Research question 3: Results are grouped according to the mathematics identity framework (*Recognition*, *Interest*, *Competence* and *Performance*), with the findings for the two questionnaire items related to *Recognition* being summarized first. Themes evident in responses to the prompt "describe a scenario where you have been recognized by your parent(s) as a math person" are shown in Table 4, along with the corresponding theme description, frequency, and percentage of significant statements identified. The highest percentage of responses for parent recognition is related to *achievement* in mathematics at 27%. Examples of significant statements within this theme include “I got good grades in my math classes,” and “My mom has always said I’m good at math.” The second highest percentage of responses indicated a *lack of recognition* from parents at 16%. The third theme was *participate in activity with parent* (e.g., “My mom suggested that I apply to work at the Math Success Center…,” “They asked me to figure up the 15% tip when we eat out”), followed by the theme of *participate in activities* (e.g., “The fact that I’m doing an engineering major is mind boggling to them,” “I’ve done accounting work”). These two themes represented 15% and 14% of the responses, respectively. All other themes represented less than 10% of significant statements present. The themes with the highest mean for mathematics identity were *statement of confidence or pride*, *participate in activity with parent*, and *share with or teach others*. Not surprisingly, the theme with the lowest mean for mathematics identity was *lack of recognition*. Means were also reported for participants who mentioned a particular theme (MathID-1) and for those who did not (MathID-0). Several statistically significant differences were found, including participants reporting a higher mathematics identity with responses indicating that they “Participate in activity with parent” and that their parents made a "Statement of confidence or pride." It is also worth noting that participants indicating explicitly that they were not recognized by a parent reported a lower mean, even if this was not statistically different.

Table 4: Results for Parent Recognition

Parent						
Theme	**Theme Description**	**Freq.**	**%**	**MathID(1) Mean(SE)**	**MathID(0) Mean(SE)**	**Wilcoxon p-value**
Achievement	Recognized for accomplishments with mathematics such as "being good at math" and doing calculations.	50	27	3.60	3.72	.425
Lack of recognition	The individual was not recognized as a mathematics person.	29	16	3.21	3.80	.111
Participate in activity with parent	Recognition involved the individual participating with a parent in an activity such as a game or building project or parent challenging individual to participate in an activity such as taking math classes.	27	15	4.11	3.56	.050
Participate in activities	Recognized for participating in math-related activities such as taking mathematics classes, choosing or being in a mathematics-related career, or participating in a mathematics competition.	25	14	3.64	3.68	.935
Share with or teach others	Recognition involved helping others with mathematics such as through tutoring.	17	9	4.00	3.62	.438
Statement of confidence or pride	Recognized through stated confidence in individual's mathematics abilities or statements of pride.	13	7	4.31	3.60	.041

Note: Themes with a subset of participants less than 7 were excluded from the results.

Source: the research

Results for the item, "describe a scenario where you have been recognized by your mathematics high school teacher(s) as a math person," are shown in Table 5. These results were similar to those of parent recognition, with the three themes with the highest percentages being *achievement* in mathematics at 23% (e.g., "They see me excel in their classes", "My grades"), *lack of recognition* from teachers at 22%, and *promoting participation in activities* at 14% (e.g., "I was approved to move on to calculus by the calculus teacher herself", "My calculus math teacher said I would be a great math teacher"). The next highest percentage of significant statements was with the theme *exceptional* at 13% (e.g., "In my freshman year my teacher would post the top 10 students in her classes by their current grade and I was the first in her geometry classes", "…I was recognized as a more advanced mathematics student"). All other themes represented less than 10% of significant statements present. The themes with the highest mean for mathematics identity were *statement of confidence or pride*, *share with or teach others*, and *exceptional*. Again, the theme with the lowest mean for mathematics identity was *lack of recognition*. Means were also reported for participants who mentioned a particular theme (MathID-1) and for those who did not (MathID-0). A statistically significant difference

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was found, including participants reporting a lower mathematics identity with responses indicating a *lack of recognition*. A marginal significance was found for *statement of confidence or pride* with participant responses including this theme reporting a higher mathematics identity. A similar trend was also found with *achievement* and *share with or teach others*.

Table 5: Results for Teacher Recognition

Teacher						
Theme	**Theme Description**	**Freq.**	**%**	**MathID(1) Mean(SE)**	**MathID(0) Mean(SE)**	**Wilcoxon p-value**
Achievement	Recognized for accomplishments with mathematics such as "being good at math" and doing calculations quickly.	42	23	3.93	3.55	.145
Lack of Recognition	The individual was not recognized as a mathematics person.	39	22	3.10	3.94	.003
Promoting participation in activities	Recognition involved being encouraged to participate or participating in mathematics activities such as advanced mathematics classes.	26	14	3.77	3.65	.745
Exceptional	Recognized for ability or performance exceeded others.	23	13	4.00	3.60	.343
Share with or teach others	Recognition involved helping others with mathematics such as through tutoring.	14	8	4.14	3.62	.156
Statement of confidence or pride	Recognized through stated confidence in individuals mathematics abilities or statements of pride.	13	7	4.31	3.60	.062
Understanding	Recognized for ability to understand mathematics.	8	4	4.00	3.66	.513
Nomination or award	Recognition involved being nominated for or receiving a mathematics related award.	8	4	3.88	3.66	.975

Note: Themes with a subset of participants less than 7 were excluded from the results.

Source: the research

Findings for the sub-factor *Interest* are summarized next, shown in Table 6. The highest percentage of responses to the question, "Describe ways you have enjoyed math," related to individuals *use or application* of mathematics at 19%. Examples of significant statements within this theme include "I now use math for quantitative purposes in the laboratory setting on a daily bases (sic)" and "…I love when I can apply math to real life situations." The second highest percentage of responses related to *work with, share with, or teach others* (e.g., "I enjoy training new engineers at work on statistical analysis tools," "I also like teaching it. When I went to work everyday at the tutoring center there never was a day I did not wanna (sic) be there or not help someone") at 11%. This theme was tied for second with the *theme getting the right answer or understand mathematics* (e.g., "I love it when I get a math problem right," "I enjoyed math when I understood the material"), also at 11%. All other themes represented less than 10% of significant statements present. The themes with the highest mean for mathematics identity were *tricks with or mental mathematics*, *value toward* *mathematics*, and *enjoy learning*. The theme with the lowest mean for mathematics identity was *did not enjoy*. Means were also reported for participants who mentioned a particular theme (MathID-1) and for those who did not (MathID-0). Several statistically significant differences were found, with participants reporting *work with, share with, or teach others* and *value toward mathematics* having a higher mathematics identity than those whose responses did not include these themes. *Tricks with or mental mathematics* was also marginally significant with those whose responses included this theme having a higher mathematics identity than those with responses not including this theme. In addition, a statistical difference was found for *did not enjoy* with a lower mean for mathematics identity than those whose responses did not include this theme.

Table 6: Results for Interest

Theme	Theme Description	Freq.	%	MathID(1) Mean(SE)	MathID(0) Mean(SE)	Wilcoxon p-value
Use or application	Interest related to applying mathematics in other classes, work, or in other activities.	55	19	3.89	3.49	.133
Work with, share with, or teach others	Interest related to enjoying teaching, sharing or working with others in mathematics.	33	11	4.12	3.51	.016
Getting the right answer/ understanding	Equates understanding mathematics or getting the right answer with interest. Not the same as thinking there is always a right answer as described under the "Nature of math" theme.	31	11	3.42	3.76	.264
Challenge	Interest related to enjoying a challenge or working on difficult/complex problems or lacks challenge.	26	9	4.08	3.56	.140
Enjoy solving problems/ puzzles	Interest related to enjoying solving problems or doing puzzles.	26	9	3.83	3.60	.330
Participating activities	Interest related to prior experiences as seen through taking or wanting to take mathematics or participating in other mathematics activities, such as mathematics club or mathematics competition.	23	8	4.04	3.59	.110
Way it is taught	Interest involved the enjoyment of mathematics being taught by others in a certain way.	14	5	3.07	3.75	.142
Value toward mathematics	Interest related to seeing mathematics as valuable or important, such as being vital for success or the way the world works.	13	5	4.38	3.59	.033
Separate	Interest related to seeing self as separate because of mathematics ability.	13	5	3.62	3.68	.753
Did not enjoy	Does not enjoy mathematics.	11	4	2.27	3.81	.001

Tricks with or mental mathematics	Interest related to enjoying using mental mathematics, tricks or mathematics related games.	11	4	4.40	3.61	.051
Nature of mathematics	Interest related to the nature of mathematics such as being “black and white” or “being methodical” or there always being a right answer.	10	3	3.64	3.68	.475
Perseverance/effort	Interest related to seeing mathematics as struggling to overcome or equates with effort.	7	2	3.86	3.66	.927
Enjoy learning	Interest related to enjoying learning new things or learning mathematics.	7	2	4.14	3.64	.430

Note: Themes with a subset of participants less than 7 were excluded from the results.

Source: the research

For the sub-factor *Competence*, participants were asked to respond to the item, "describe what it means to 'get' or understand mathematics." As shown in Table 7, the most common theme related to *achievement* in mathematics at 20%. Examples of significant statements within this theme include “I am able to do problems” and “I receive good grades.” The second highest percentage of responses related to *understanding* mathematics at 19%. Examples of significant statements within this theme include “It just makes sense to me” and “I can see what needs to be done, how to do it, and know if my answer looks right.” *Apply to real life or other areas* (e.g., “Able to apply knowledge of mathematics to situations outside of the classroom,” “I can understand the science of it and apply it to areas such as physics and or engineering”) and *share with or teach others* (e.g., “I’ve been told that I can explain math very well to those who do not understand the topic,” “When you can tutor someone in a certain area of math”) in mathematics represented 13% and 11% of the responses, respectively. All other themes represented less than 10% of significant statements present. The themes with the highest mean for mathematics identity were *interest*, *multiple methods*, and *separate*. The theme with the lowest mean for mathematics identity was *does not seek guidance*. Means were also reported for participants who mentioned a particular theme (MathID-1) and for those who did not (MathID-0). Several statistically significant differences were found, with participants reporting *apply to real life or other areas*, *share with or teach others*, *interest*, and *mental math* having a higher mathematics identity than those whose responses did not include these themes. In addition, a statistical difference was found for *achievement* with a lower mean for mathematics identity than those whose responses did not include this theme.

Table 7: Results for Competence

Theme	Theme Description	Freq.	%	MathID(1) Mean(SE)	MathID(0) Mean(SE)	Wilcoxon p-value
Achievement	Competence involved being able to perform well such as doing well in classes or getting the right answer when solving problems.	59	20	3.36	3.91	.014
Understanding	Competence involved understanding mathematics concepts or underlying ideas.	57	19	3.84	3.51	.239
Apply to real life or other areas	Competence involved being able to apply mathematics such as	37	13	4.05	3.48	.043

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	relating to real-life concepts or relating to other courses.					
Share or teach others	Competence involved the ability to speak with others about mathematics (such as participation in mathematics conversations) or tutoring/teaching mathematics to others.	33	11	4.06	3.50	.039
Mathematics comes easy	Competence involved mathematics coming easily such as coming naturally or working problems quickly or with ease.	27	9	3.89	3.58	.338
Interest	Competence related to the enjoyment of or interest in mathematics.	12	4	4.42	3.57	.029
Perseverance or effort	Competence related to effort such as studying or practicing problems.	12	4	3.75	3.64	.938
Feeling of confidence or pride	Competence related to expressed feelings of confidence or pride in mathematics, feeling comfortable.	11	4	2.73	3.74	.070
Separate	Competence involved performing or understanding mathematics better than others.	10	3	4.20	3.60	.200
Does not seek guidance	Competence related to completing mathematics tasks without assistance such as not referring to notes.	10	3	2.70	3.73	.146
Multiple methods	Competence involved being able to solve mathematics in different ways or use multiple methods.	7	2	4.29	3.61	.195

Note: Themes with a subset of participants less than 7 were excluded from the results.

Source: the research

For the final sub-factor *Performance*, participants were asked to respond to the item, "describe what it means to perform well in mathematics." As shown in Table 8, the highest percentage of responses related to *achievement* in mathematics at 35%. Examples of significant statements within this theme include “I guess I think I’m doing well in math when I can crank through my homework and see I did all the problems right when I get it back” and “Have received mostly A’s and A-’s in my college math courses.” The second highest percentage of responses related to *understanding* mathematics at 19%. Examples of significant statements within this theme include “You know you are performing well when everything makes sense and you completely understand it” and “I understand the logic behind the answers.” *Share with or teach others* was the next highest percentage of significant statements at 13% (e.g., “I know I’m doing well in math if I understand and am about to help others understand as well,” “I am always a go-to person for my peers’ struggles with their math homework”). All other themes represented less than 10% of significant statements present. The themes with the highest mean for mathematics identity were *interest*, *multiple methods*, and *separate*. The theme with the lowest mean for mathematics identity was *perseverance or effort*. Means were also reported for participants who mentioned a particular theme (MathID-1) and for those who did not (MathID-0). Several statistically significant differences were found, with participants reporting *retaining content*, *positive reinforcement from teacher*, and *separate* having a higher mathematics identity than those whose responses did not include these themes.

Table 8: Results for Performance

Theme	Theme Description	Freq.	%	MathID(1) Mean(SE)	MathID(0) Mean(SE)	Wilcoxon p-value
Achievement	Performance related to doing well in classes or getting the right answer when solving problems.	107	35	3.66	3.70	.956
Understanding	Performance related to understanding mathematics.	43	14	3.47	3.77	.124
Share or teach others	Performance involved the ability to speak with others about mathematics (such as participation in mathematics conversations) or tutoring/teaching mathematics to others.	40	13	3.98	3.53	.103
Apply to real life/other areas	Performance involved being able to apply mathematics such as relating to real-life concepts or relating to other courses.	24	8	3.92	3.61	.374
Mathematics comes easy	Performance related to mathematics coming easily such as coming naturally or working problems with ease.	22	7	4.05	3.59	.114
Award or participation in activities	Performance related to receiving an award in mathematics (such as internship or for competition) or participation in mathematics activities (such as advanced classes).	13	4	4.15	3.61	.236
Interest	Performance involved an individual's enjoyment of mathematics (e.g., "Love it").	11	4	4.18	3.62	.228
Retaining content	Performance related to retaining mathematics content learned.	8	3	4.50	3.61	.042
Anxiety/Confidence	Performance related to either a lack of anxiety or feeling of anxiety about mathematics or a feeling of confidence about mathematics.	8	3	3.50	3.68	.825
Positive reinforcement from teacher	Performance related to a mathematics instructor making positive comments about an individual's ability in mathematics.	8	3	4.50	3.61	.048
Perseverance or effort	Performance related to effort or persevering such as practicing mathematics problems.	7	3	2.71	3.73	.079

Note: Themes with a subset of participants less than 7 were excluded from the results.

Source: the research

4. Discussion and Conclusions.

4.1 Research question 1: Our results have shown that mathematics identity, as defined in the theoretical framework used in this study, remains stable over three years of college experience. As Cobb and Hodge (2011) discussed through the construct of core identity, mathematics identity can provide a picture of students' "more enduring sense of who they are and who they want to become" (p. 189). This is particularly remarkable in light of the finding from the national college calculus study of the Mathematical Association of America that students' attitudes about mathematics become considerably more negative from the start to the end of their first college calculus course (Sadler & Sonnert, 2015). However, a large portion of the change found in the attitudinal measure used in that study related to confidence in math, which is closely related to an individual's competency and performance beliefs. Prior work (Cribbs et al., 2015) found that related self-perceptions had only a mediating effect on mathematics identity development for undergraduate students. Sadler and Sonnert's (2015) study provides an important glimpse indicating that attitudinal changes do occur over the college years, but they did not measure identity beliefs, which is a distinctly different measure. Results from this study support the idea that mathematics identity can be usefully conceptualized from a global or macro-level perspective, at least at the college level. Our finding of a great amount of stability in mathematics identity justifies a further exploration of the nature of this identity and of the associated mathematics-related experiences. This finding also highlights the importance of students' experiences prior to college, given the relative stability of mathematics identity for undergraduate students.

4.2 Research question 2: Our second research question examined participants' beliefs about what it means to be a "math person." The most common responses fell within the themes of interest, understanding, and achievement, which align with the framework for mathematics identity. A particularly disconcerting finding was the high frequency of statements belonging to the characteristic or trait theme. These responses align with the belief that being a "math person" is a trait that some individuals are born with, a not uncommon societal perspective in the United States. However, to the follow-up question provides evidence that that the belief that being a "math person" is a trait is not as prevalent among a majority of participants with 75% of the responses stating "yes" to the question "can a 'non-math' person become a 'math person.'" To highlight differences in the way that participants responded, results were broken up by the answers, yes, no, and maybe. In considering the "yes" responses, hard work or effort was mentioned most frequently, with statements indicating that perseverance plays an important role in mathematics. Despite the fact that these participants responded "yes" to the question, statements regarding a natural ability still came out in some responses; however, the number of these statements was relatively small. It may not be surprising that participants who stated "no" to the question more frequently supported their response with statements about people having an innate ability in mathematics. This might be due to the underlying influence that societal beliefs had on participants' perceptions of mathematics, as cultural representations provide a talent-based picture for what it means to be a mathematician and do mathematics (Epstein et al., 2010), and stereotypes about what it means to be a mathematics person persist (Steel, 2003). Participants might believe, on some level, that anyone can be a "math person", but also believe to some extent or at higher levels of mathematics, that innate ability is required (Leslie et al., 2015). However, a larger percentage of participants seem to reject the idea of a "math person"; instead, viewing identification with mathematics being malleable and associated with effort or specific experiences.

4.3 Research question 3: The participants' responses describing the types of experiences they had with mathematics provide insights into the sub-constructs of mathematics identity. With regard to *Recognition*, there was little difference between themes emerging for parents and teachers, with mathematics *achievement* accounting for approximately one-fourth of the statements in both cases. The theme for the second highest frequency for both sub-factors indicated that participants did not have experiences where their parent(s) or mathematics teacher(s) recognized them as a mathematics person, with a lack of mathematics teacher recognition being stated at a higher frequency than a lack of parent recognition. On the one hand, parents may be particularly inclined to show recognition to their own children. On the other hand, it could be that teachers did not recognize these participants in meaningful and memorable ways that contributed to their mathematics identity development. Lee and colleagues (2012) found that the quality of instruction students received in high school was significantly lower for mathematics and science classes than for English and social studies. These differences were particularly noticeable in mathematics courses, with lower scores for student participation, quality of student discussion, and personalism (how often the teacher talked with students about their "academic and personal lives and work"; p. 28). Perhaps this lack of personal connection and student voice in mathematics classrooms accounts for the lack of recognition being reported by participants in this study. It may be a cause for concern that a considerable group among the participants could not recall a single experience where they felt recognized, particularly when prior work indicates *Recognition* has a larger direct effect on mathematics identity than *Interest* (Cribbs et al., 2015). It is important to note a statistical difference in participants' mathematics identity, with those whose responses included the "Lack of recognition" theme having a lower mathematics identity than those not reporting this theme. Thus, similar to prior work, a lack of recognition does appear to correspond to a lower mathematics identity, particularly a lack of teacher recognition, which highlights the important role teachers play in students' mathematics identity development. Our findings also indicate that particular ways of being recognized may be correlated with a higher mathematics identity. Specifically, participating in mathematics-related activities with parents, such as games or projects, and affirming words from a parent or teacher. Additionally, sharing or teaching mathematics with others was an important experiences based on student responses, similar to findings from other research indicating students tutoring other students as a positive predictor for mathematics identity (Cribbs et al., 2020). These findings provide insight into particular experiences in a school or home setting that could promote positive mathematics identity development.

When considering the sub-factor *Interest*, the highest frequency of significant statements related to participants being able to apply mathematics, whether that be in other classes, activities, or work. Prior research has noted the impact teacher practice has on mathematics interest, such as the connection between student-centered instruction and interest (Lerkkanen et al., 2012). Additionally, Yazzie-Mintz (2006) found that high school students wanted to apply the learned content in ways that would engage them outside of teacher lectures, such as participating in discussions and debates, doing research projects, and role playing. It makes sense that, when content is more applicable and relevant for students, they are more inclined to be interested in it. Being able to share, teach, or work with others in mathematics had slightly more significant statements than getting the right answers or understanding mathematics. While being able to share mathematics with others hints at the need for social engagement in the context of mathematics, getting the right answers or understanding mathematics highlights the enjoyment participants derive from doing mathematics. Additionally, being about to share or teach others mathematics seems to be an integral part of mathematics identity development given the difference found for those whose responses included this theme and those whose responses did not. Given the connection between interest and students' career choice (Li et al., 2009) and the decline in mathematics interest for many students as they transition through K-12 (Musu-Gillette et al., 2015), better understanding the experiences that resonate with participants is beneficial.

The results for *Competence* and *Performance* are nearly identical, other than the theme *achievement* was—unsurprisingly--evident at a much higher frequency for *Performance* than for *Competence*. The similarity in experiences described by participants under both headings might account for the fact that these two sub-factors were found to be quantitatively indistinguishable in prior work (Cribbs et al., 2015). An interesting finding that set these two sub-factors apart from themes in the *Interest* and *Recognition* sub-factors was the theme that mathematics comes easy. The idea that mathematics is easy for people who are good at mathematics or that mathematics problems can be solved quickly is clearly seen in the K-12 setting, where speed is often assessed and valued at the elementary level. Despite the fact that this is a common practice, research provides evidence that it is actually detrimental, leading to student anxiety (Boaler, 2014). Boaler (2015, p.38) makes a case for this perception of mathematics having a negative effect on students, stating the following:

> Unfortunately, many classrooms focus on math facts in isolation, giving students the impression that math facts are the essence of mathematics, and even worse, that mastering the fast recall of math facts is what it means to be a strong mathematics student. Both of these ideas are wrong, and it is critical that we remove them from classrooms, as they play a key role in creating math-anxious and disaffected students.

Perhaps this idea of fast recall being associated with be a strong mathematics student is also linked to these participants' characterizing *Competence* and *Performance* as doing better than others in mathematics. Another interesting finding from the *Performance* sub-construct was with the themes *retaining content* and *positive reinforcement from teacher,* with students having a higher mathematics identity for responses including these themes than those that did not include the themes. These ideas seem align with developing a deep understanding of mathematics and having support from others (teachers in particular) as being valuable aspects of performing in mathematics, even if this finding was for a proportionally smaller group of participants than other themes such as *achievement* and *mathematics comes easy*.

Several overarching themes were evident across the sub-factors. The first was the theme achievement, which represented the highest percentage of significant statements for parent and teacher recognition as well as for the questions related to competence and performance. Whereas the fact that this theme represents a high percentage of statements for the question asking about performance makes obvious sense, the question related to competence with mathematics also had slightly more significant statements about performance than about understanding itself. It is clear that many of the experiences with mathematics that participants recall, both in a high school setting and at home, involve performing, such as getting good grades, performing well on standardized assessments, or being able to do calculations quickly. While the theme of perseverance and effort in mathematics was evident in the results, it represented a much smaller percentage of the statements. Do these findings reflect the continued pressure toward standardized testing and other performance goals, rather than mastery goals, in schools? While having high performance goals might be important for success in mathematics, high mastery goals in addition to high performance goals have been shown to be more adaptive in terms of motivation, affect, strategy use, and performance (Pintrich, 2000). Further, Blackwell and colleagues (2007) found a growth mindset predicted student achievement in mathematics in a longitudinal analysis. If our goal is to help students persist in mathematics long-term, it seems a focus on mastery rather than solely performance would be necessary.

Another overarching theme in the findings was sharing or teaching others. Whether it was mentioned in terms of being recognized for tutoring siblings, peers, and parents, or brought up as an expression of interest, competence, or performance in mathematics, this theme was repeated throughout the participants' responses. Other themes related to this idea were also evident, such as sharing mathematics through dialogue, and positive reinforcement from the teacher. This finding could connect to the socially constructed nature of identity development, discussed by Wenger (1998) for communities of practice and by Lave and Wenger (1991) for situated learning. Membership in the mathematics community is negotiated with other members (old-timers versus newcomers) and involves participating in ways that reinforce what it means to belong to that community. This process of negotiation occurs in classrooms every day where students are confronted with their own perceptions about what it means to be a mathematics person and other's perceptions about their identity as a mathematics person. Cobb and Hodge (2011) discuss this idea when describing normative identity, which relates to the socially constructed norms of what it means to participate in mathematics in a classroom. These findings highlight the types of experiences that students find significant and enduring to them and the types of experiences that contribute to students' mathematics identity development.

This study extends the mathematics identity framework by providing evidence of the construct being relatively stable for undergraduate students. In addition, this study provides insight into the concrete experiences with mathematics that lie at the heart of this identity. For example, regarding recognition by their parents, we now have a better understanding of what types of experiences participants might be reflecting on when responding. This study also highlights the types of experiences that participants consider important and that therefore have an enduring impact and contribute to the core of their mathematics identity. The study also highlights current societal beliefs about mathematics, because identity development is influenced by societal norms and expectations.

The small number of our participants meant low statistical power, which limited the number of statistically significant results. Future studies with a higher N may be able to confirm, at conventional p-levels, findings that we noted as trends. In addition, future work should explore how the experiences reported in this study play out in the classroom so that we could gain a better understanding of how teachers can support students' mathematics identity development.

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