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Establishing an Explanatory Model for Mathematics Identity

Jennifer D. Cribbs
School of Teacher Education, Western Kentucky University

Zahra Hazari
Department of Teaching & Learning, Department of Physics, and the STEM Transformation Institute, Florida International University

Gerhard Sonnert and Philip M. Sadler
Harvard-Smithsonian Center for Astrophysics, Harvard University

This article empirically tests a previously developed theoretical framework for mathematics identity based on students' beliefs. The study employs data from more than 9,000 college calculus students across the United States to build a robust structural equation model. While it is generally thought that students' beliefs about their own competence in mathematics directly impact their identity as a "math person," findings indicate that students' self-perceptions related to competence and performance have an *indirect* effect on their mathematics identity, primarily by association with students' interest and external recognition in mathematics. Thus, the model indicates that students' competence and performance beliefs are not sufficient for their mathematics identity development, and it highlights the roles of interest and recognition.

In the study of child development, the investigation of identity formation has long been a cornerstone. From Erickson's foundational work on identity formation in the 1950s and 1960s (psychosocial theory of identity) to Marcia's operationalization of Erickson's work (delineating between *exploration* and *commitment*) and Crocetti, Rubini, and Meeus's extension of this work with their three-dimensional model (adding *reconsideration of commitment*), research in the area of identity has continued to expand and be applied in a variety of contexts (Crocetti, Rubini, & Meeus, 2008; Erickson, 1950, 1968; Marcia, 1966). In a more recent trend, researchers have increasingly applied identity concepts, particularly content-specific identity, to education and have investigated the ramifications of young persons' identities in educational settings, such as schools and universities. While there are different avenues through which research has approached the topic of identity in education, this study focuses on identity as a lens for understanding student persistence in mathematics. Exploring the motivational aspects of identity allows for students' engagement or disengagement with content to be explored (Schachter & Rich, 2011). As shown in Boaler and Greeno's (2000) work, students' experiences with mathematics have the potential to influence their perceptions and future pursuit of mathematics. The purpose of this study is to better understand how students' self-perceptions of their *interest*, *competence*, *performance*, and *recognition* in mathematics are related to their mathematics identity development. Our focus on these constructs is driven by prior work in mathematics and science education. In the next sections we highlight the importance of studying mathematics identity, discuss prior identity work and the constructs that may

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Correspondence concerning this article should be addressed to Jennifer D. Cribbs, School of Teacher Education, Western Kentucky University, Bowling Green, KY 42101. Electronic mail may be sent to jennifer.cribbs@wku.edu

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be important for mathematics identity development, and describe the particular framework we employed as well as the prior work from which it was drawn.

The Importance of Mathematics Identity

In a technologically advancing world, there is an increasing need for students to enter the fields of science, technology, engineering, and mathematics (STEM). An insufficient number of students entering these fields is a concern for many countries. According to the European Commission (2012), the number of STEM professionals is too small to meet the demand, anticipating a 9% overall employment growth for physical, mathematical, and engineering science professionals between 2010 and 2020. These shortages can be seen in Austria, Belgium, Germany, Hungary, Ireland, Italy, Sweden, and the United Kingdom (European Commission, 2012). There is also concern about the continued competitiveness of the United States in a dynamically changing global market that will be increasingly driven by science and technology. Compared to China and the European Union, the United States awards the smallest percentage of first university science and engineering degrees—10% compared to 23% and 19%, respectively (National Science Board, 2012).

The role that mathematics plays in students' futures is particularly important for students intending to enter STEM careers, especially because mathematics has been cited as a gatekeeper to students successfully negotiating the STEM path. Students' experiences with mathematics influence their continued pursuit of mathematics-related fields. For example, Chen (2009) found that students who take advanced mathematics classes in high school are more likely to pursue a STEM career. Undergraduate students' mathematics performance not only predicts their choosing to major in a STEM field but also predicts their earning a degree in STEM (Crisp, Nora, & Taggart, 2009). Additionally, STEM interest, as reported by students in Grades 8, 10, and 12, is an important predictor of students earning a degree in STEM (Maltese & Tai, 2011). Summarizing their research findings, Maltese and Tai (2011) stated that "focusing attention on increasing student interest in science and mathematics and demonstrating to students the utility of these subjects in their current and future roles may pay greater dividends in building the STEM workforce than focusing on student proficiency" (p. 900). Other research also supports the connection between attitudinal constructs, such as students' motivation and beliefs, and students' career choices (Lent et al., 2008; Simpkins & Davis-Kean, 2005; Simpkins, Davis-Kean, & Eccles, 2006).

In light of the research emphasizing the impact that students' self-perceptions have on their participation in mathematics, it is important to establish a theoretical framework that could provide a better understanding of how students' self-perceptions are influencing their long-term goals related to mathematics. This study intends to establish such an explanatory framework through the lens of mathematics identity, which we conceptualized as how students see themselves in relation to mathematics based on their perceptions and navigation of everyday experiences with mathematics (Enyedy, Goldberg, & Welsh, 2006). To motivate our work, we review the prior literature on mathematics identity and situate our work as answering several calls for more rigorous research in the area, particularly because mathematics identity is posited as an important explanatory link for learning and persistence in mathematics.

Identity Research

The construct of identity affords researchers the opportunity to explore the association between students' self-perceptions and their persistence in mathematics. Specifically, mathematics identity research can contribute to our understanding of mathematics classroom environments, the broader context of mathematics education, and what it means to be a mathematics learner (Lester, 2007). This, along with Gee's (2001) contention that identity can be used as an analytic lens for research in education, provides a strong rationale for deepening the examination of identity in relation to mathematics. In this context, Sfard and Prusak (2005) stated that the application of identity could be "the missing link" between learning and its sociocultural context. In addition to conceptualizing ways that identity can be viewed, Gee theorized identity as being complex with individuals having multiple identities, such as an identity related to an individual's ethnicity developed through affinity with the practices of a certain group (A-Identity) or an individual personality trait developed through discourse and interaction with others (D-Identity). Although the concept of mathematics identity—a D-Identity for many students in Gee's scheme—promises to aid in better understanding students' experiences and persistence in mathematics, Cobb (2004) stated that mathematics identity is still underdeveloped as an explanatory construct. He elaborated by noting that a "central issue for mathematics educators concerns the process by which students' emerging identities in the mathematics classroom might, over time, involve changes in their more enduring sense of who they are and who they want to become" (p. 336). Research on the construct of identity in relation to mathematics has begun to develop an explanatory framework (Holland & Lave, 2001; Sfard & Prusak, 2005), but these research efforts have been mostly confined to a moment-to-moment approach, as opposed to a global view for examining student identity—what Cobb referred to as the "enduring sense of who they are" (p. 336). Prior research also explored mathematics identity through a narrative approach. For example, Sfard and Prusak (2005) expand the definition of identity—previously defined by Gee as "being recognized as a certain 'kind of person'" (p. 99), and by Holland and Lave (2001) as an individual's narration of his or herself—by considering the "idea of identifying as communicational practice" (p. 44). Cobb and Hodge (2011) further delineate identity by detailing three constructs that relate to student identity in mathematics classrooms: normative identity—"as a doer of mathematics established in [students'] classrooms" (p. 187), core identity —"concerned with students' more enduring sense of who they are and who they want to become" (p. 189), and personal identity—"concerned with who students are becoming in particular mathematics classrooms" (p. 190). They describe how different research approaches are needed when exploring these identity constructs. For example, core identity, a construct drawn from Gee's work, could be examined (in addition to other approaches) through interviews and questionnaires that probe "students' long-term aspirations," because of its relative stability over time (Cobb & Hodge, 2011, p. 189). It is this core identity that we draw on in this article.

In particular, prior research has discussed specific factors related to students' self-perceptions toward mathematics, factors that might be viable building blocks for a mathematics identity framework. Interest is one of these factors because, similar to identity, it has been discussed as dependent on experiential context and has been linked to students' motivation and engagement with mathematics (Frenzel, Goetz, Pekrun, & Watt, 2010). Additionally, theoretical work posits important connections between interest and identity development and the role of interest development in informing educational settings (Hidi & Renninger, 2006; Renninger, 2009). A particular concern in mathematics education has been the decline in an individual's interest in mathematics from childhood to adulthood (Gottfried, Fleming, & Gottfried, 2001). This becomes even more troubling when considering that the decline in interest seems to be especially precipitous in later adolescence (Jacobs, Lanza, Osgood, Eccles, & Wigfield, 2002; Watt, 2004). This is relevant for students' persistence in and engagement with mathematics because interest has been associated with career choice (Su, Rounds, & Armstrong, 2009). The influence that interest has on students' future engagement with mathematics supports the inclusion of interest as an especially applicable factor to consider in a mathematics identity framework.

A second factor that has been discussed in the literature is recognition. The classic sociological concept of the "looking-glass self," developed by Cooley (1902), postulates that people form a sense of self by trying to figure out what other people think about them. Erickson's (1968) theory of psychosocial identity emphasizes the role that an adolescent's environment and relationships play in identity development. Roeser, Peck, and Nasir (2006) summarize this idea well in the following statement:

> Earlier orientations toward interpersonal trust are renegotiated in terms of new friends, romantic partners, cultural ideals, and social institutions in which you can have faith; earlier orientations toward personal autonomy are renegotiated in terms of self-images, activities, and ideologies to which youth can freely choose to commit. (p. 394)

Consistent with this general concept, research has found that how students perceived that their parents and teachers viewed them in relation to mathematics influenced students' academic competence and performance in mathematics (Bleeker & Jacobs, 2004; Bouchey & Harter, 2005; Eccles-Parsons, Adler, & Kaczala, 1982). Bouchey and Harter (2005) found that students' (ages 11–15) perceptions of teachers' beliefs and behavior were positively correlated with students' self-perceptions about their academic competence and grades. Considering how individuals might situate themselves in a community of practice, such as a mathematics community, how they perceive that others view them within that community is an important component of how they perceive themselves. As Wenger (1998) discussed, the trajectory of an individual in a community of practice is influenced by their identification with that community, and an individual's trajectory influences their participation within that community of practice.

A third factor of importance is students' competency beliefs and their beliefs about their ability to perform have been shown to influence the activities in which students participate (Bandura, 1997; Bussey & Bandura, 1999). A rich literature on self-efficacy beliefs has emphasized the effects of these beliefs on a wide range of students' attitudes and behaviors (Brown & Lent, 2006; Hackett & Betz, 1989; Pajares & Miller, 1994; Zimmerman & Kitsantas, 1997, 1999). For instance, undergraduate freshman students with high scores for self-perceived academic competence "are more persistent, more likely to adopt master and/or performance approach goals, less anxious, process the learning material at a deeper level, and achieve better study results" (Ferla, Valcke, & Schuyten, 2010, p. 530). In addition, Pajares and Graham (1999) found that sixth grade, middle school students' self-efficacy was the sole motivation variable that predicted students' performance, when also looking at anxiety, self-concept, and self-regulation. These results stress the importance of considering students' perceptions of their performance, because they, too, have been found to influence educational outcomes. This influence on educational outcomes suggests the need to include students' self-perceptions related to competency and performance in mathematics when constructing a mathematics identity framework. Such student self-perceptions have also been included in prior research investigating science and physics identity (Carlone & Johnson, 2007; Hazari, Sonnert, Sadler, & Shanahan, 2010).

Mathematics Identity Theoretical Framework

As mentioned earlier, it is important to consider identity because it has been connected to students' persistence and engagement (Boaler & Greeno, 2000; Hazari et al., 2010). A mathematics identity framework can help us understand how students might develop a sense of personal affiliation with mathematics as well as a sense of group membership within a mathematics community. In this way, students' socialization into a mathematics community (e.g., a mathematics class) can be explored and understood, including students' affiliation or alienation with this community, based on their perceptions. In this work, mathematics identity is related to an individual's self-perceptions with respect to mathematics. It is influenced by multiple internal constructs and is viewed, particularly for our population (college students), as being relatively stable over time in terms of an enduring sense of identification with mathematics. In particular, the inclusion of the three constructs (interest, recognition, and competence/performance) in this study provides a more comprehensive framework for investigating students' mathematics identity than considering only one of these constructs.

The mathematics identity framework used in this study draws from previous research in science and physics identity (Carlone & Johnson, 2007; Hazari et al., 2010). Carlone and Johnson (2007) conducted a qualitative study investigating identity development for women of color as they transitioned through undergraduate, graduate, and into science-related careers. That study used a framework of science identity that included the factors of recognition, competence, and performance. This research was further expanded through a quantitative study investigating students' physics identity, which surveyed college students enrolled in introductory English classes across the United States (Hazari et al., 2010). Because the study investigated students who may or may not have had science-related interests rather than studying scientists with pre-established science interests, the theoretical framework was expanded to include a fourth component—interest—in the concept of physics identity. To test the applicability of these factors discussed in previous identity research (recognition, competence, performance, and interest) to a mathematics identity framework, an exploratory factor analysis (EFA) was first conducted and reported in a prior study (Cass, Hazari, Cribbs, Sadler, & Sonnert, 2011). That analysis provided evidence that the factors of interest, recognition, and competence/performance together are viable for a mathematics identity framework. That factor analysis was performed with the same sample that is used for the current study, with four items relating to interest (18% cumulative variance explained), three relating to recognition (32% cumulative variance explained), and four relating to competence and performance (44% cumulative variance explained; Cass et al., 2011). These three factors and their hypothesized association with mathematics identity can be seen in Figure 1.

It is important to note that although these three factors are hypothesized to be integral to mathematics identity development, the precise association between these factors and mathematics identity is not clear. Competence is defined as students' beliefs about their ability to understand mathematics, and performance is defined as their beliefs about their

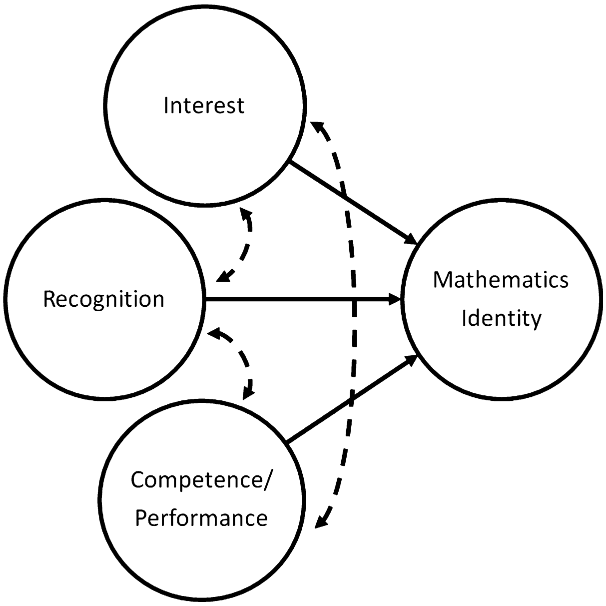

Figure 1. Hypothesized association between self-perceptions and mathematics identity.

ability to perform in mathematics. These two factors were found to be strongly correlated in our prior study; that is, they consistently loaded together in factor analyses (Cass et al., 2011) and, as a result, have been combined here into the competence/performance factor. Interest is the second factor considered in the framework and is defined as a student's desire or curiosity to think about and learn mathematics. Recognition, the third factor, is defined as how students perceive others to view them in relation to mathematics. It is by exploring the three factors of interest, recognition, and competence/performance together that students' emerging mathematics identity might be better understood. Thus, the research question guiding this study is: To what extent do our data confirm that the factors interest, recognition, and competence/performance are related to the construct of mathematics identity?

Method

This study is part of the Factors Influencing College Success in Mathematics (FICSMath) project, which is a national study that surveyed students enrolled in single-variable calculus classes at colleges and universities across the United States in the fall of 2009. Since calculus is a course taken by students in many different majors (e.g., in most STEM fields, and also in economics/business, science education, and by students planning on medical careers ["premed"]), we found a large degree of variability in this sample in terms of how the students saw themselves with respect to mathematics, including those who identified with mathematics and those who did not. The survey included 61 items about students' experiences in high school mathematics; their background, attitudes, and career goals; as well as performance in their college calculus classes.

Validity of the survey was established through a focus group with experts in science and mathematics education and pilot testing of the survey. The pilot study was conducted with 45 students at two separate institutions. Results helped revise the survey and supported its validity. A test–retest study was conducted to examine the stability (a form of reliability) of the survey. This entailed administering the survey to the same sample with a delay between administrations to determine if there were significant differences between the responses. The FICSMath survey was administered in the college calculus classes of four different universities at a 2-week interval, yielding 148 pairs of completed surveys. Results indicated an overall reliability coefficient of 0.71 for linear variables and 94% agreement for binary and categorical variables.

Drawing from a stratified random sample of colleges and universities across the United States, the national study obtained data from 10,437 students attending 336 college calculus courses at 134 institutions. Table 1 details the response rate for this study.

Of the respondents, 60% were male and 34% female, with 6% not reporting their gender. In terms of race and ethnicity, 70% identified as White, 4.6% as African American, 11.2% as Asian, 7.4% as Hispanic, 0.4% as American Indian/Alaskan Native, and 0.4% as Pacific Islander, with the remainder marking "Other" or not responding.

Structural equation modeling (SEM) was used to investigate the construct of mathematics identity. The first step in conducting SEM is to test the measurement model through a confirmatory factor analysis (CFA). EFA was previously conducted to analyze the association between the factors of interest, recognition, competence, and performance (Cass et al., 2011). That study confirmed the viability of the factors for a mathematics identity framework, also indicating that competence and performance should be combined as previously discussed. Because the viability of the three factors had been suggested in an EFA analysis, CFA was conducted in this study. Ten items from the FICSMath survey were used in the structural model as detailed in Table 2. There were originally 12 items

Table 1
Survey Response Rate

Response rate	Small	Medium	Large	Total
2-year institution				
Institutions contacted	15	97	49	161
Institutions returning surveys	10	38	25	73
Percent returning/contacted	66.7	39.2	51.0	45.3
4-year institution				
Institutions contacted	52	40	23	115
Institutions returning surveys	21	27	13	61
Percent returning/contacted	40.4	67.5	56.5	53.0

Table 2
Items From FICSMath Survey and Descriptive Statistics for Observed Variables

Latent variable	Indicator variable	Survey item	*N*	*M*	*SD*	Proportion agreement
Interest		*Do you agree or disagree with the following statements?*				
	Q44enjoy	I enjoy learning math.	10,019	—	—	0.80
	Q44interest	Math is interesting.	10,009	—	—	0.83
	Q44lookforward	I look forward to taking math.	9,725	—	—	0.59
Recognition		*Do the following people see you as a mathematics person?*				
	Q45mathpersonp	Parents/relatives/friends	9,850	0.63	0.29	—
	Q45mathpersont	Mathematics teacher	9,986	0.69	0.29	—
Competence/		*Do you agree or disagree with the following statements?*				
Performance	Q44understand	I understand the math I have studied.	9,698	—	—	0.87
	Q44nervous	Math makes me nervous.	9,972	—	—	0.59
	Q44persist	Setbacks do not discourage me.	9,922	—	—	0.56
	Q44exam	I can do well on math exams.	9,746	—	—	0.81
Scaling variable		*Do the following people see you as a mathematics person?*				
	Q45mathpersons	Yourself	10,009	0.64	0.31	—

Note. FICSMath = Factors Influencing College Success in Mathematics.

on the survey that related to the factors of interest, recognition, and competence/performance. Two items were dropped due to poor loading and fit. The first item, "Math is relevant to real life," was dropped during the EFA analysis, and the second item, "I wish I did not have to take math," was dropped during the CFA analysis.

All the indicator variables for interest are dichotomous variables (0 = *disagree*, 1 = *agree*) and include students' responses to the following FICSMath items: "I enjoy learning math" (Q44enjoy), "Math is interesting" (Q44interest), and "I look forward to taking math" (Q44lookforw). The indicator variables for competence/performance were also dichotomous variables (0 = *disagree*, 1 = *agree*) and include students' responses to the following FICSMath items: "I can do well on math exams" (Q44exam), "I understand the math I have studied" (Q44understand), "Math makes me nervous" (Q44nervous), and "Setbacks do not discourage me" (Q44persist). The final construct, recognition, was measured using Likert-scale variables (1 = *no, not at all*, 6 = *yes, very much*) that captured students' responses to the question: "Do the following people see you as a mathematics person?" on the prompts: "Parents/Relatives/Friends" (Q45mathpersonp) and "Mathematics teacher" (Q45mathpersont). Although it is ideal to have at least three indicator variables for each latent variable, it is acceptable to use two indicator variables for a latent variable if the following two conditions are met: (a) the errors for the two indicator variables are not correlated and (b) the errors of either of the two indicator variables are not correlated with the errors of another factor's indicator variables (Kline, 2010). These two conditions were met for the models presented in this study. In addition, Q45mathpersons, which is a Likert-scale variable (1 = *no, not at all*, 6 = *yes, very much*), is used as a scaling variable for mathematics identity. This FICSMath item corresponded to students' response to the questions: "Do the following see you as a mathematics person? (Yourself)." There is precedent for using this item as a way for conceptualizing how persons see themselves with relation to identity. For example, Hazari et al. (2010) used the same type of indicator to explore physics identity, and Carlone (2004) and Shanahan (2008) investigated what it meant for students to be a certain "type of person" or to "be a science person" to better understand their science identity development.

In addition to details concerning the FICSMath survey items used in this study, Table 2 displays general descriptive values for these items. It shows the sample size for each of the observed variables after missing values are removed. The mean and standard deviation are reported for the continuous variables, and the frequency (conveyed through proportions) is listed for the dichotomous variables. While most of the variables were dichotomous and did not need to be rescaled, the continuous variables, such as Q45mathpersont and Q45mathpersonp, were rescaled to have a range of 0 to 1. This was done so that all items were on the same scale and analysis could be more meaningfully interpreted. The variable Q44nervous was reverse coded.

Because several of the indicator variables in the measurement model were either dichotomous or categorical, polychoric and polyserial correlations were computed when appropriate (Kline, 2010). Guided by literature discussing appropriate fit indices and their criteria in SEM, the following fit indices will be reported in this study with recommended threshold levels noted in parentheses: (a) chi-square ($p > .05$), (b) goodness-of-fit index ($p > .90$), (c) adjusted goodness-of-fit index (AGFI; $p > .90$), (d) root mean square error of approximation (RMSEA; $p < .08$), (e) non-normed fit index ($p > .90$), (f) standardized root mean square residual ($p < .08$), and (g) expected cross-validation index (ECVI; Hu & Bentler, 1995; Schumacker & Lomax, 2010). The percentage of missing values for the items ranged from 4% to 7%. Furthermore, the analyses were rerun using imputed data sets to gauge potential bias due to data missingness. Fit indices were nearly identical and structural coefficients were similar when comparing the imputed data model and listwise deletion model. Therefore, listwise deletion was deemed appropriate for dealing with missing data and used for conciseness of reporting. The sample size after listwise deletion was N = 9,350 (10.4% missing) for the CFA analysis and N = 9,346 (10.5% missing) for the SEM analysis.

Results

Measurement Model

All analysis was done using R statistical software, version 2.13.0 (R Development Core Team, 2011). The SEM package in R was used for CFA and SEM analysis. This entailed using maximum likelihood estimation and bootstrapping as appropriate for the type of data used in this study (Fox, 2006). The results of the initial measurement model, along with corresponding fit indices, are included in Figure 2, which in essence represents a CFA.

When looking at fit indices, the chi-square is significant, but this is not unexpected because of the large sample size (Schumacker & Lomax, 2010). The other fit indices included in Table 3 provide a more accurate picture of the model fit. Two of the five fit indices were within the recommended level. It is recommended that the value for AGFI should be greater than 0.90, but the CFA model indicates that AGFI is 0.89, just missing the threshold. RMSEA is a measure of noncentrality. The fact that many of the variables used in this analysis are dichotomous is the likely cause of the elevated RMSEA. In addition, Table 3 includes the standardized factor loadings and item reliability (attained by squaring the standardized factor loading) for indicator variables as well as the construct reliability and average variance extracted from the latent variables.

Standardized factor loadings range from 0.47 to 0.99, which is greater than the 0.45 considered the minimum for inclusion in the model. Although the item reliability for Q44persist is low at 0.22, it is kept in the model because it is a significant pathway and improves the overall model fit. Item reliability (r^2) for all other variables ranged from 0.40 to 0.98. In addition, convergent validity and discriminant validity were calculated for the three factors in the CFA analysis, with all correlational values for each of the items in the three factors being 0.3 or greater. Furthermore, for each item, the correlation coefficients for all other factors are lower than the correlation coefficient for the factor in which it is included.

Structural Model

A structural model for mathematics identity was hypothesized and tested as shown in Figure 3. This model was tested using a correlation matrix as previously discussed and is included in Table S1 in the online Supporting Information.

It is important to note that the reference variable for mathematics identity, Q45mathpersons, was fixed in the model by setting the pathway to 1. The

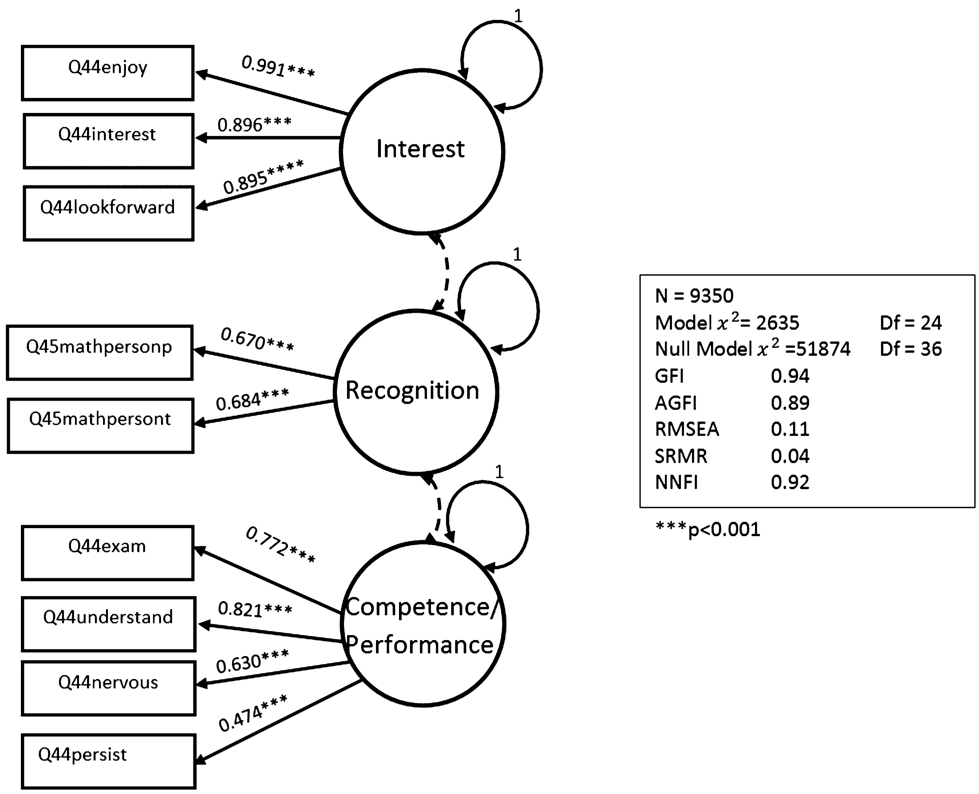

Figure 2. Confirmatory factor analysis results. GFI = goodness-of-fit index; AGFI = adjusted goodness-of-fit index; RMSEA = root mean square error of approximation; SRMR = standardized root mean square residual; NNFI = non-normed fit index.

Table 3
Confirmatory Factor Analysis Estimates and Fit Indices

Latent variable	Indicator variable	Standardized factor loading	*SE*	Item reliability (r^2)	Construct reliability	Average variance extracted
Interest	Q44enjoy	0.99***	0.007	0.98	0.95	0.86
	Q44interest	0.90***	0.010	0.80		
	Q44lookforward	0.89***	0.008	0.80		
Recognition	Q45mathpersont	0.68***	0.013	0.47	0.63	0.46
	Q45mathpersonp	0.67***	0.013	0.45		
Competence/ Performance	Q44exam	0.77***	0.012	0.60	0.77	0.47
	Q44understand	0.82***	0.013	0.67		
	Q44nervous	0.63***	0.011	0.40		
	Q44persist	0.47***	0.013	0.22		

***$p < .001$.

variable that is chosen as a reference variable is typically the best indicator variable for the latent variable. Prior research has also shown this type of question(e.g., "Do you see yourself math person") to be a highly appropriate way for conceptualizing students' identity (Hazari et al., 2010; Shanahan & Nieswandt, 2011). All pathways in Figure 3 were highly significant ($p < .001$), and fit indices were within recommended ranges, except for chi-square, which was significant. However, the goal in SEM is to achieve the best model fit without compromising the theory being represented. The mathematics identity framework suggests that the three factors are related, but the SEM allowed for the nature of

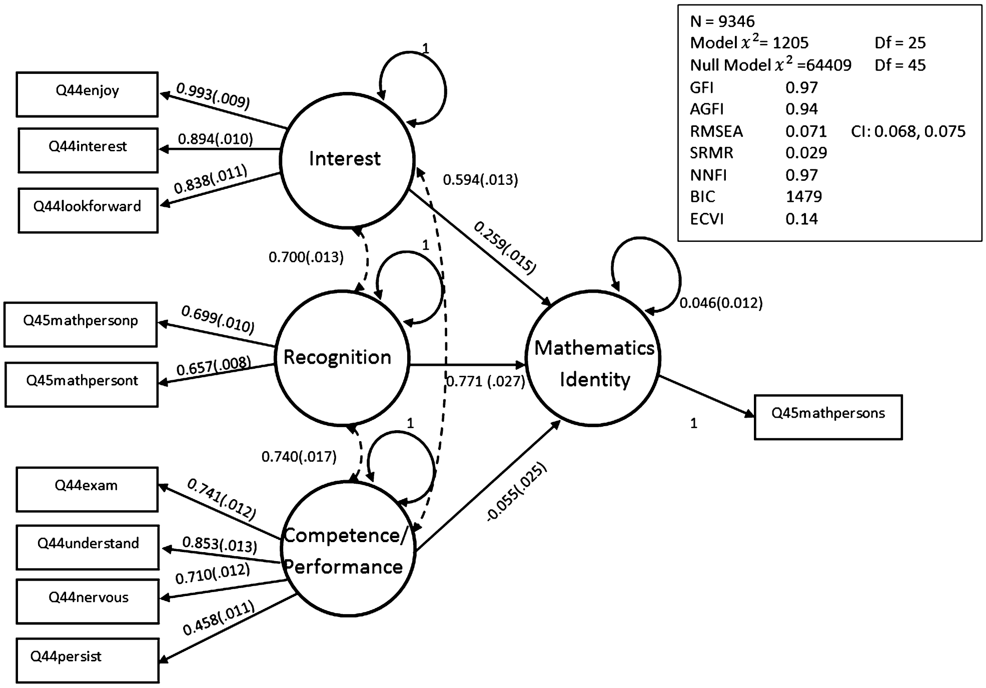

Figure 3. Initial structural equation modeling results. GFI = goodness-of-fit index; ADFI = adjusted goodness-of-fit index; RMSEA = root mean square error of approximation; SRMR = standardized root mean square residual; NNFI = non-normed fit index; BIC = Bayesian information criterion; ECVI = expected cross-validation index.

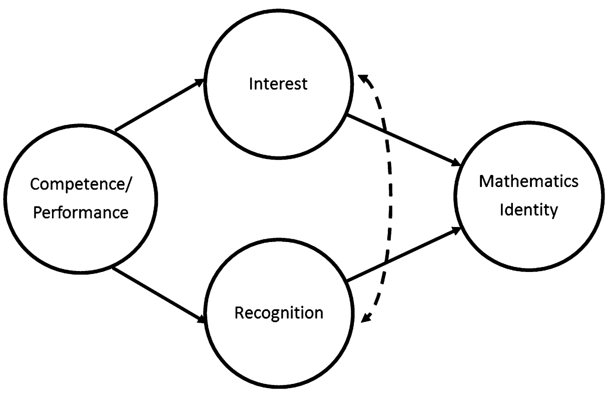

Figure 4. Modified structural model.

this association to be further explored. As always with this and other types of correlational studies, we need to caution that the word *effect* in the following exploration of the results cannot imply causality in a strict sense. The results in the initial model indicated there was a strong association between interest and competence/performance as well as recognition and competence/performance. Taking into account the strong covariance coefficient between the factors along with the weak effect, as seen through the structural coefficient, of competence/performance on mathematics identity, an alternative model was hypothesized and tested as shown in Figure 4.

Prior research related to social cognitive theory stresses the role that competency beliefs have in influencing an individual's self-efficacy and self-perceptions (Bandura, 1997; Bussey & Bandura, 1999). Furthermore, Wang (2013) found that mathematics achievement was not the strongest influence on high school students' intent to major in a STEM field. Students' exposure to mathematics and science as well as their attitudes and beliefs about mathematics were found to be important to students pursuing a STEM field of study (Wang, 2013). The existence of these connections highlighted the impact that students' experiences and self-perceptions related to their ability had on their interest and motivated testing an alternative model. It was therefore hypothesized that competency beliefs might precede and facilitate other perceptions that explain an individual's identity development, as indicated in the revised structural model in Figure 4. This alternative model tested an indirect effect of competence/performance on mathematics identity, mediated through interest and recognition. The resulting model can be seen in Figure 5 with the corresponding fit indices.

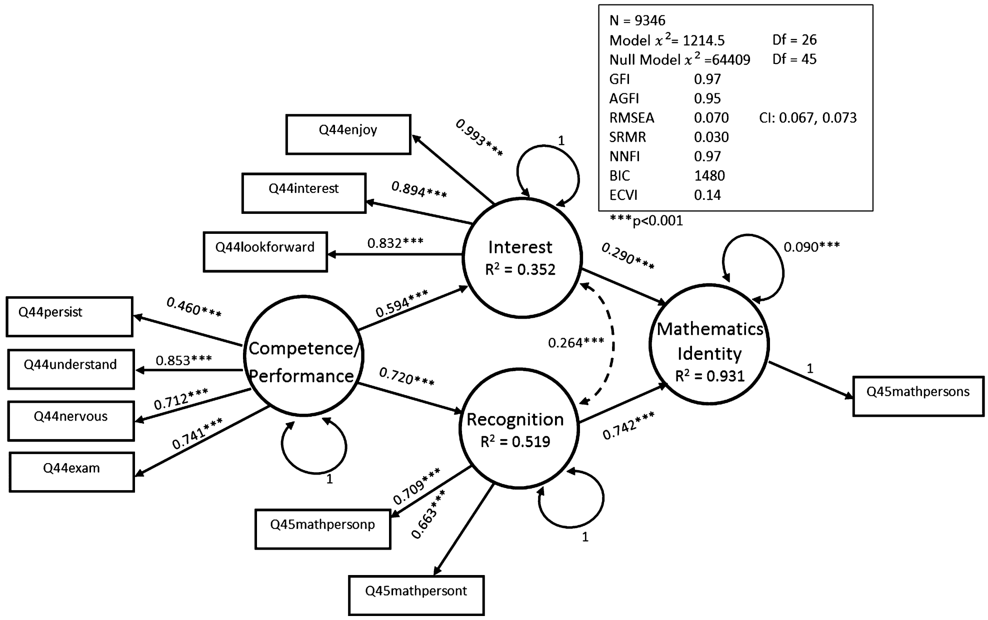

Figure 5. Results for Revised Model. GFI = goodness of fit index; AGFI = adjusted goodness of fit index; RMSEA = root mean square error of approximation; SRMR = standardized root mean square residual; NNFI = non-normed fit index; BIC = Bayesian information criterion; ECVI = expected cross-validation index; Df = degrees of freedom; CI = confidence interval.

The Bayesian information criterion (BIC) values (used to compare two models) were nearly equivalent for the initial and revised model. Therefore, other fit indices were evaluated to determine the best fit model. By looking at the fit indices between the initial and modified model, it can be seen that the modified model has a superior fit. With the exception of chi-square, all indices fall within recommended levels. It is also important to note that a direct pathway from competence/performance to mathematics identity was tested in this model, but was not included because it did not improve the fit indices (slightly increasing RMSEA value) and the pathway was not significant. In addition, the ECVI value for the model with the pathway was 0.135 and the ECVI value without the pathway was 0.136. Standard errors were calculated using the bootstrap method; these are generally larger than unadjusted standard errors since non-normal distribution is expected with dichotomous variables.

To make comparisons between the structural paths, standardized coefficients were calculated and reported in Table 4 along with unstandardized coefficients and adjusted standard errors.

The standardized structural coefficients are of particular interest in understanding the explanatory model for mathematics identity. The final model indicates that instead of competence/performance having a direct effect on mathematics identity, it has an indirect effect, mediated through recognition and interest. The direct effect of competence/performance on recognition, $\beta = 0.720$, is higher than the effect it has on interest, $\beta = 0.594$. In addition, the direct effect of recognition on mathematics identity, $\beta = 0.742$, is higher than the direct effect of interest on mathematics identity, $\beta = 0.290$. The total explained variance, reported as R^2 for endogenous variables in the software, is also higher for recognition, $R^2 = 0.519$, than it is for interest, $R^2 = 0.352$. Overall, the model explained 93% of the variance in relation to students' mathematics identity, $R^2 = 0.931$. This high value for R^2 indicates that a large proportion of the variance for mathematics identity is explained by the model displayed in Figure 5.

Discussion

The mathematics identity framework was strongly supported by the data, though not exactly as initially hypothesized. While the factors of interest and recognition had significant direct effects on mathematics identity, competence/performance had an indirect effect on mathematics identity, mediated through recognition and interest. The performance/competence effect was strongest on recognition, which indicates that the more strongly students believe in their ability to understand and do mathematics, the more likely they are to believe

Table 4
Structural Coefficients and Adjusted Standard Error

Parameter	Unstandardized	Adjusted standard error	Standardized
Structural coefficients			
Interest → Mathematics identity	0.22	0.01	0.29
Recognition → Mathematics identity	0.49	0.01	0.74
Competence/Performance → Interest	0.75	0.02	0.59
Competence/Performance → Recognition	1.04	0.03	0.72
Factor loadings			
Mathematics identity			
Q45mathpersons	1.00	—	0.95
Interest			
Q44enjoy	0.80	0.01	0.99
Q44interest	0.72	0.01	0.89
Q44lookforward	0.68	0.02	0.83
Recognition			
Q44mathpersonp	0.49	0.01	0.71
Q44mathpersont	0.46	0.01	0.66
Competence/performance			
Q44exam	0.74	0.01	0.74
Q44understand	0.85	0.01	0.85
Q44nervous	0.71	0.01	0.71
Q44persist	0.46	0.01	0.46
Measurement error variances			
Q45mathpersons	0.09	—	0.09
Q44enjoy	0.01	0.02	0.01
Q44interest	0.20	0.01	0.20
Q44lookforward	0.31	0.02	0.31
Q45mathpersonp	0.50	0.01	0.50
Q45mathpersont	0.56	0.01	0.56
Q44exam	0.45	0.01	0.45
Q44understand	0.27	0.02	0.27
Q44nervous	0.49	0.01	0.49
Q44persist	0.78	0.01	0.79
Factor variances			
Mathematics identity	0.06	0.01	0.07
Interest	1.00	—	0.65
Recognition	1.00	—	0.48
Competence/performance	1.00	—	1.00
Error covariance			
Q44enjoy ⟷ Q44lookforward	0.06	0.02	0.06
Q44interest ⟷ Q44lookforward	0.07	0.01	0.07
Q44lookforward ⟷ Q44nervous	0.10	0.01	0.10
Q44lookforward ⟷ Q44persist	0.12	0.01	0.12
Q44understand ⟷ Q44nervous	−0.15	0.01	−0.15
Factor covariance			
Interest ↔ Recognition	0.47	0.02	0.26

Note. All pathways, except the measurement error variance term for Q44enjoy, were statistically significant at $p < .001$.

that their parents, peers, relatives or teachers see them as a mathematics person. The effect of competence/performance on interest was also significant, which indicates that the more strongly students believe in their ability to understand and do mathematics, the more likely they are to be interested in mathematics. The role of the factor competence/performance is important, especially considering the positive direct effect that both recognition and interest have on mathematics identity. This is supported by self-efficacy theory, which has shown that competency beliefs influence students' related self-perceptions and the activities in which they participate (Bandura, 1997; Bussey & Bandura, 1999). If students develop a belief in their ability to do or understand mathematics, they are more likely to develop positive self-perceptions related to mathematics, specifically, self-perceptions related to interest and recognition. Note that in the initial model, when competence/performance was allowed a direct effect on mathematics identity, the structural coefficient was very small. This is important because it reveals that performance/competence self-perceptions are not sufficient to developing a mathematics identity—recognition and interest are paramount.

In support, the direct effect on mathematics identity was strongest for recognition, which indicates that the more strongly students believe that their parents, peers, relatives, or teachers see them as a mathematics person, the more likely they are to positively identify with mathematics. This result underscores how important it is for students to be recognized by others as a "mathematics person," not only in the classroom but also in their home and community. Social learning theories and research from this perspective support the idea that learning is a social process in which students negotiate meaning and are active participants (Boaler, 1998; Boaler & Greeno, 2000). The strong influence that being recognized as a "mathematics person" has on students' mathematics identity also indicates how much students value external acknowledgment. This finding is important to consider because students' perceptions then have the potential to influence their behavior and choices, such as the choice to take advanced mathematics courses or pursue a mathematics-related career, and thus may become self-fulfilling.

Interest also has a significantly positive effect on mathematics identity, indicating that students who have greater interest in mathematics self-identify more strongly with mathematics. The vital role that interest plays has been supported by previous research in mathematics (Köller, Baumert, & Schnabel, 2001; Krapp, 1999). In a study conducted with 602 students who were tested at the end of grades 7, 10, and 12, Köller et al. (2001) found that, while interest did not have a significant effect on achievement, it did predict students' choice of advanced mathematics courses. They also found that this correlation between student interest in mathematics and course taking was mediated through the instructional environment (Köller et al., 2001). That study supported the notion that students' experiences influence their interest related to mathematics and that students' interest in turn influences students' future choices. The Köller et al. (2001) study also provided evidence that teachers play an important role in encouraging student interest and future engagement in mathematics.

Limitations

One limitation in this study was that many of the variables used in the analysis were dichotomous. This study was constrained by the questions asked on the survey, which focused on other topics, that is, high school math experiences and performance, rather than mathematics identity. Although appropriate analysis methods were applied to account for this, these items still provided limited variability. There are also some issues with noncentrality that could not be completely overcome, even when using nonparametric methods of analysis. This was evident in the CFA fit indices, which had an RMSEA value that was greater than the recommended level. One final limitation is that, unlike most other studies, this work takes a reflexive macrolevel perspective on identity rather than a nonreflexive microlevel perspective (Lichtwarck-Aschoff, van Geert, Bosma, & Kunnen, 2008). Thus, we examine more stable aspects of mathematics identity that are a result of the aggregation of many experiences with mathematics rather than the fluctuations of mathematics identity that occur in the moment with new mathematics experiences. Future work will examine this framework from the perspective of the latter, because in-the-moment fluctuations are central to a deeper understanding of the process of mathematics identity development. Finally, it is important to keep in mind that this study is correlational, so causality is not certain.

Conclusion

As mathematics education has increasingly been framed as an issue of enabling all students, it is important to understand students' self-perceptions related to mathematics and how experiences are influencing mathematics identity development. The explanatory framework proposed in this study provides a way for educators and researchers to better understand and further explore students' persistence through focusing on their mathematics identity. As teachers, parents, schools, and community members look to provide opportunities for students to develop a sense of efficacy and motivation toward mathematics, they can help students develop a positive sense of affiliation with mathematics. These opportunities can occur both inside and outside of the classroom and include experiences where students are *recognized* in mathematics. This might include a focus on participatory methods in the classroom or the opportunity for a student to tutor peers inside or outside of the classroom. Research further exploring the connection between instructional practices and students' self-perceptions could provide more insight into how these practices influence students' mathematics identity. If educators want to find ways to provide students with the experiences and opportunities with mathematics that empower them and open doors for future engagement with mathematics, understanding students' mathematics identity development is essential.

The model for mathematics identity presented in this study adds to our current understanding of mathematics identity. Because identity research is complex, many avenues of further research need to be pursued. Exploration of these avenues might reveal ways in which educators and researchers can positively influence students' mathematics identity. Thus, it might be possible to fulfill the vision of equity, as discussed by the National Council of Teachers of Mathematics (NCTM; 2000), where all students are presented with worthwhile opportunities in mathematics. Perhaps then, we will finally be able to challenge the "pervasive societal belief in North America that only some students are capable of learning mathematics" (NCTM, 2000, p. 12).

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Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's website:

Table S1. Correlation Matrix Used for SEM Analysis.