Literature Review

PREPARED BY Jalisha Jenifer, PhD and Raúl Chávez, PhD

Introduction

The narrative around math acquisition is notably complex in the United States. While math education is generally described as being important and critical for economic success, it is also commonplace to de-identify with the subject, with many students and adults remarking that "I am not a math person" (Miller-Cotto & Lewis, 2020). These contrasting sentiments in the culture highlight the complicated world all students must navigate as they progress through K-12 education and develop their individual math identities.

How do students make sense of the diverse math narratives presented to them from various sources? What can be done to shift the negative math perceptions and identities that are especially commonplace amongst students from marginalized backgrounds? This review of the math identity development literature, its related mechanisms, and the relevant intervention research is meant to produce a better understanding of what can be done to shift students' math-related perceptions and identities and improve their post-secondary success and life outcomes.

The Identity Formation Process and the Role of Narratives

Identity formation and development have long been a topic of interest for psychological, sociological, and educational researchers alike (Syed et al., 2011). This process is traditionally viewed as being particularly salient during adolescence when cognitive development allows individuals to begin to construct a "theory of self" (Elkind, 1998; Marcia, 1980; Tanti et al., 2011). During the process of identity formation, individuals embrace characteristics, traits, social relationships, roles, and group memberships that define who they are or might become (Oyserman et al., 2012). Critically, identity formation provides individuals with a perspective through which

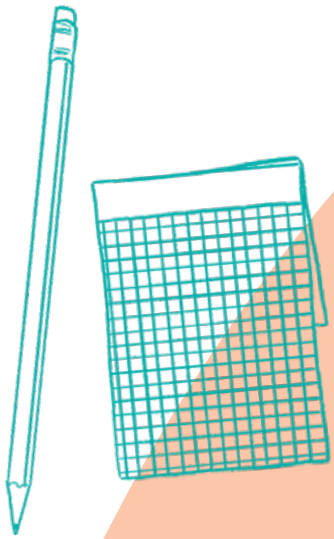
to make meaning of the world around them, determine which social groups they belong to, and determine whether certain behaviors are congruent with what it means to be a member of those groups (Miller-Cotto & Lewis, 2020).

Relatedly, identities are thought to be dynamically constructed, being influenced by features of individuals' immediate contexts, individuals within that context, and past experiences within the same semantic network (Oyserman & Destin, 2010). In this manner, central to identity is the concept of belonging. This dynamic construction includes influences from individuals' immediate social context, such as their family, teachers, and peers, as well as more external influences from the culture and social scripts that permeate society at large.

Given that identities encompass individuals' past, present, and future (Miller, 2002), narratives provide a natural source for understanding individuals' identity development trajectories. The narrative mode of thinking, at its foundation, represents the default mode of human thought (Engel et al., 2018), making narratives all the more salient. Furthermore, narratives play a crucial role in culture and human ways of remembering, reasoning, and behaving (Trzebinski et al., 2021). This includes narratives around math reasoning and, subsequently, individuals' formation of their math-specific identities (Bikner-Ahsbahs, 2003). As such, students' autobiographical accounts can advance the knowledge of their math learning experiences (Towers et al., 2016) and math identities. For example, narratives help explain how certain groups, such as Black male students, see themselves as inferior in their math abilities to other groups, such as Asian students (Nasir & Shah, 2011).

Social Stereotypes and the Development of a Math Identity

Math identities can be defined as the extent to which an individual feels empowered to engage with math, and can come from a combination of a student's perceptions of their performance ability and competence, recognition from others, and their interest in mathematics (Carlone & Johnson, 2007; Hazari et al., 2010; Siegel, 2021). The structures and cultures surrounding students, as well as the social scripts that emerge from those structures and cultures, play a key role in students' math identity development (Miller-Cotto & Lewis, 2020). Central to this relationship is the existence of pervasive cultural stereotypes regarding the nature of intelligence as well as stereotypes that posit the idea that particular racial, ethnic, gender, and socioeconomic groups are less likely to do well in math compared to others. For example, many individuals endorse the belief that success in math requires innate intelligence, a characteristic that is also stereotypically associated more with men than with women (Storage, Horne, Cimpian, & Leslie, 2016), with whites more than blacks (Steele, 2011), and with individuals from higher socioeconomic status backgrounds more than those from lower ones (Durante & Fiske, 2017).



Social Stereotypes and the Development of a Math Identity cont.

Stereotype is thus a mindset obstacle to developing a positive math identity. Stereotype threat disrupts math performance via a physiological stress response that directly impairs pre-frontal processing, as well as the ability to suppress negative thoughts and emotions (Schmader et al., 2008). The impairment of math performance reinforces the development of a weak or negative math identity. Empirical research has substantiated this theory. In an experiment conducted with black and white students, black students who studied rare words in a threatening environment performed worse than those who studied in a non-threatening environment, while white students remained unaffected (Jones Taylor & Walton, 2011). In another math experiment comparing men and women, the difference in gender math outcomes was removed when stereotype threat was lowered by describing to women before they took a test that the test did not produce gender differences (Spencer et al., 1999). Furthermore, the mindset of teachers is also important to the math identity formation of students. Research has shown that racial achievement gaps in courses taught by more fixed mindset faculty were twice as large as the achievement gaps in courses taught by more growth mindset faculty (Canning et al., 2019).

The existence of cultural stereotypes regarding intelligence has been shown to influence students' beliefs about the nature of their cognitive abilities, which collectively have been characterized as students' "lay theories" (Limeri et al., 2022). These lay theories include students' beliefs about whether intelligence is a fixed trait or if it is malleable and can be improved with effort (mindsets/theories of intelligence; Dweck, 1999; Dweck et al., 1995), beliefs about who (i.e. some people or everyone) has the potential to be excellent in a discipline (universality beliefs; Rattan, Good et al., 2012; Rattan, Savani, et al., 2012), and whether reaching excellence in a field requires raw intellectual talent (brilliance beliefs; Leslie et al., 2015; Meyer et al., 2015). The relation between cultural stereotypes and students' lay theories is particularly salient for the math identity development of students belonging to groups that have been historically stereotyped as lacking innate math ability. These students are more likely to view engagement with math as being antithetical to the stereotyped component of their identity, suggesting that the adoption of a positive math identity requires them to dissociate with the other, likely more salient, aspects of their background (Nasir & Shah, 2011).

Nonetheless, culture and identity are both context-specific, meaning that individuals hold many identities, and their environment informs which ones to make salient at a specific point in time. As such, context can produce different knowledge informing individuals' math identities, so that a child who feels at a math deficit in school can still feel positive about their math abilities at home with family members (Martin et al., 2010). Math itself is a cultural artifact, as it is a human activity (Secada, 1992). As human activities and contexts change in a day or over the lifespan, math identity narratives change (Andersson et al., 2015). Indeed, parent ethnographies reveal that math learning and participation can be conceptualized as a racial form of experience (Martin, 2007), which is itself changeable and

Social Stereotypes and the Development of a Math Identity cont.

context-specific. This explains why dominant norms and teaching based in white culture result in practices that contribute to cultural incongruities amongst students along racial and ethnic lines (Bonner, 2012). A review of the literature reveals that culturally responsive mathematics teaching can improve on the math learning experiences of students, as this approach lowers perceived stereotype threat and creates a safer learning context (Abdulrahim & Orosco, 2020; Aguirre & Zavala, 2012; Hernandez et al., 2013).

There is an absence of empirical research on culturally and language-diverse math learners (Abdulrahim & Orosco, 2020). And although English learners nationally score lower on math tests than English speakers, all students overall score less on word problems than numerical ones (Schleppegrell, 2007). This suggests that language is important to math competency for all math learners, but especially for those learning English. Furthermore, a literature review reveals that labels for English language learners can impede their math learning (Araujo et al, 2018), and, subsequently, their math identities. With support, however, English learners have the potential to thrive in math. However, achieving this requires additional training and support for their teachers. Developing positive cultural dispositions in teachers early in their careers can heighten their cultural awareness and retention rates in culturally and language-diverse schools (Williams et al., 2016). The teacher-student relationship and the learning environment the teacher creates are thus especially salient for culturally and language-diverse math learners' ability to overcome both language and stereotype barriers.

Key Socializers

Research also highlights a link between key socializers' math attitudes and associated behaviors, and children's math attitudes and achievement. These socializers include students' parents and teachers, whose math attitudes are theorized to influence their math-relevant behaviors, including their engagement of children in math achievement-related experiences (Pantoja & Levine, 2021).

One way in which socializers may impact students is by transmitting negative math attitudes to the children and students with whom they interact. For example, research finds that parents and teachers who experience mathematics anxiety, or tension and apprehension towards math, can transmit this anxiety to their students through experiences within the classroom and at home, including during homework help (Ramirez et al., 2018; Gunderson et al., 2012; DiStefano et al., 2020). Language is another powerful way that parents and teachers might inadvertently communicate beliefs about math to their children or students. For example, in many expressions of social comparison, one group–boys–is framed as the standard for the other (i.e., "girls are as good as boys at math"). These statements reflect beliefs about relative ability but can also perpetuate such beliefs (Chestnut et al., 2018).

Another behavior that can shape children's beliefs about their ability is unsolicited or intrusive aid (Chestnut et al., 2018). When an adult offers help to a child who has not asked for it, the child might infer that the adult has low expectations for them, leaving the child to feel incompetent. Relatedly, one study found that when parents hold strong math-gender stereotypes and associate math success with boys over girls, they are more likely to provide unsolicited help on math problems to girls (Bhanot & Jovanovic, 2005). Additionally, girls who received this unsolicited support were more likely to underestimate their math ability. These findings highlight the idea that even seemingly helpful behaviors regarding math can be influenced by implicit biases that can negatively impact students' math identity development.

Math Identity Interventions

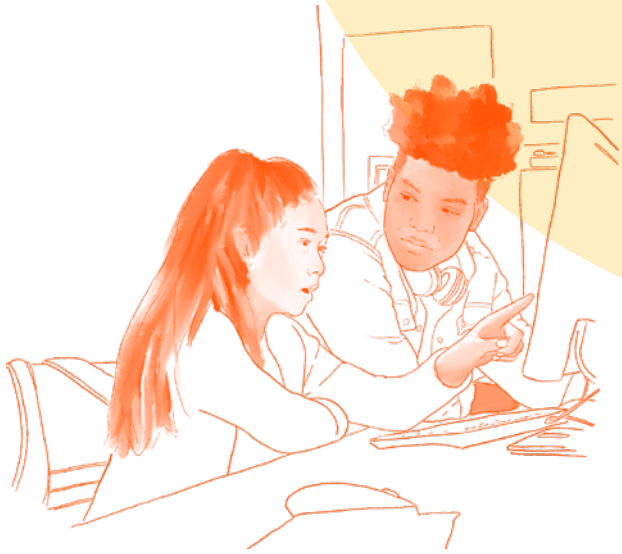
Interventions centered around the creation of safe math learning spaces have the potential to shift students' mindsets, their personal narratives regarding learning math, and, subsequently, their math identities (Yeager et al., 2013). Advancement Via Individual Determination (AVID) is a college preparation program for students with low-grade point averages but whose aptitude tests indicate they are capable of higher academic achievement. The program is centered on creating classroom communities with students' backgrounds, their interests, and their well-being in mind (Robinson, 2015).

Empirical research has found that after one year in AVID, students displayed mastery of goal-oriented thinking and growth mindsets when discussing difficult coursework (Danskey, 2017). This could be because, as other research has demonstrated, perceived teacher caring at the beginning of the school year increases academic motivation by the end of the school year, including for math (Umarji et al., 2021). The creation of safe learning environments makes the reduction of stereotype threat and its detrimental effects possible (Johns et al., 2005), which augments the potential for math identity change.

Social-psychological interventions targeting students' thoughts, feelings, and beliefs about school have been found to promote positive math attitudes, and subsequently support the development of positive math identities (Yeager & Walton, 2011). These interventions target various aspects of students' perceptions of the mathematics domain. For example, numerous studies have targeted students' mindsets by highlighting the malleability of intelligence through lessons on neuroscience and the science of learning (Aronson et al., 2002; Blackwell et al., 2007; Paunesku et al., 2015; Yeager et al., 2016).

These interventions have been shown to be effective in shifting students' mindsets toward the growth end of the spectrum (Hocker, 2017), which is associated with more persistence in problem-solving, reduced learning anxiety, and improved academic achievement (Dweck, 2016).

Additional considerations, however, are crucial when considering social-psychological interventions. Proponents of mindset-based interventions



caution individuals to be mindful and avoid promoting false growth mindsets: the misleading belief that you can do anything if you simply put in enough effort (Chestnut et al., 2018; Dweck, 2016b). Additionally, focusing solely on students' effort (e.g. "you must have worked really hard") runs the risk of being misinterpreted as suggesting that the student does not possess ability and must therefore compensate through effort (Amemiya et al., 2018; Chestnut et al., 2018). Careful thought should therefore be utilized in the design and implementation of interventions when attempting to help students develop positive math identities.

Other studies have intervened on students' purpose for learning, encouraging the development of self-transcendent learning goals that highlight the potential of learning to have some effect on or connection to the world beyond the self. These interventions have been shown to increase student self-regulation during learning, increasing their persistence in tedious or uninteresting tasks, and promoting STEM-related GPAs (Yeager et al., 2014; Paunesku et al., 2015). Additionally, research has found that targeting students' math self-concept, or their beliefs about the relationship between themselves and math, can be effective for promoting the development of positive math identities and increasing math achievement.

These interventions include explicit targeting of students' math self-concept by having students verbally express positive stereotypes regarding math that apply to the groups they belong to, as well as the implicit targeting of students' math

self-concept by having them engage in motor acts and listening to auditory cues that pair math with positive traits (Cvencek et al., 2020).

Several online programs have been designed as interventions to change the mindsets of students regarding learning, although the impact of these is mixed. Online programs have proven successful in creating stronger growth mindsets in girls in rural areas (Burnette et al., 2017), and across demographic groups (Nallapothula et al., 2020) amongst undergraduate students. They have also been successful in increasing academic control and interest, as well as skill and learning, in ninth-grade students, but not in seventh-grade students (Schmidt et al., 2017).

All of these factors foment the development of a positive math identity. Nonetheless, other research has found that the same online program did not produce a sustainable impact on mindset shift (Donohoe et al., 2012), nor did light-touch written interventions on the mindsets of low-income students (Gandhi et al., 2019). This suggests that mindset shifts require interventions that are both time and dose-intensive. For instance, an eight-week cognitive tutoring program was found to be successful in reducing math anxiety (Ramirez et al., 2018), giving it greater potential to shift math mindsets.

While many interventions encourage the development of positive math identities by targeting the students themselves, others have been effective by targeting key socializers in students' lives, such as parents. The home numeracy environment parents foster at home supports the development of math skills throughout childhood (Elliott & Bachman, 2017). Parental provision of structure for doing math has been found to positively impact the math grades of low-income middle school students (O'Sullivan et al., 2014).

Middle school students with the most supportive parents have also been found to be the most math achieved (Cai et al., 2016). This research demonstrates that the home environment is a salient one in the development of math identities. Related to this, parents' own math anxiety and beliefs regarding the importance of math have been found to be related to students' math activities and engagement at home (Elliott et al., 2019). As such, an intervention that brought students and parents together through the joint use of a math app was effective in reducing the link between parents' math anxiety and their positive attitudes about math for their children (Schaeffer et al., 2018). Another intervention found that providing parents with informational brochures and websites highlighting the usefulness of STEM courses increased the number of math and science courses their children took in high school (Harackiewicz, Rozek, Hulleman, & Hyde, 2012).

Naturally, teachers have also been found to play a critical role in increasing student math identities. Empathetic teaching skills can create a safe learning environment in the classroom, lowering the learning anxieties of students (Moldovan, 2019). This suggests that empathy teacher training could be an area for teacher-targeted interventions. Similarly, creating the space for students to reflect on and share their autobiographical learning accounts can change

Math Identity Interventions cont.

students' perceptions of themselves as learners and increase their confidence in learning math (Ellsworth & Buss, 2010). Parent-teacher home visits have been found to change students' mindsets and their implicit biases by improving parent-teacher partnerships that support student success (McKnight et al., 2017).

Interventions designed to promote growth-oriented mindsets have been found to work more effectively for students whose teachers themselves held more growth-oriented mindsets (Yeager et al., 2022). Furthermore, training teachers to embrace a standards-based grading mindset focused on how much students learn rather than whether or not something was learned has been shown to change students' self-regulation regarding their learning goals (Schimmer, 2014). These findings indicate that teachers are important context-setters, and the learning environments they foment can either support or hinder positive math identity development.

Conclusion

Math identity formation for students is a dynamic process that is influenced by key agents (parents and teachers) and numerous factors, such as context and social stereotypes. In addition to pervasive cultural stereotypes that influence students' lay theories regarding the nature of intelligence, key socializers such as students' parents and teachers can significantly impact how students view themselves in relation to math. Interventions that target the learning contexts of students as well as these influences have subsequently been found to be successful in promoting the development of positive math identities for students. However, special attention to language and the role of context have been highlighted as important aspects to consider during implementation.

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