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Translating Research to Practice on Individual and Collective Mathematics and Science Identity Formation: Pedagogical Recommendations for Teachers

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ABSTRACT

Recruiting students to science and mathematics fields continues to be a nationwide issue, resulting in a dearth of individuals to fill these present and future careers. Novel interventions, especially within the K-12 space, call for a move from content acquisition to the formation of individuals' identity that particularly fosters science and math interest and persistence. Identity research has evidenced results, yet greater communication is needed between the research and practitioner communities to realize the potential of cultivating collective science and mathematics identities in the classroom. In this paper, we bridge these spaces by describing the potential student affordances beyond individual identity formation to that of collective (classroom-level) identity formation considerations by K-12 teachers' within mathematics and science. Specifically, we explore how traditional K-12 classroom structures may reinforce stereotypes and hinder collective mathematics and science identity formation, whereas reform-oriented classroom structures that employ legitimate peripheral participation within a community of practice enable them. Last, we recommend pedagogical interventions to practitioners that promote collective student opportunities to co-construct skills specific to mathematics and science communities as a strategy to foster collective mathematics and science identities. Collective identity formation can provide K-12 classroom teachers pedagogical strategies for additional opportunities or enhanced experiences for students to co-construct and reinforce individual identities in math and science.

Keywords: *communities of practice; identity; mathematics education; science education; research to practice*

Introduction

The concepts and constructs related to identity have long held importance in learning; numerous research studies have sought to better understand the development of identity in fostering affinity to various groups (Gee, 2000; Taylor, 1989). Other studies have attempted to gain insight into identity's role in consequential generation of interest and persistence in educational endeavors (Billett & Somerville, 2004; Norton & Toohey, 2011). The examination into identity has been of recent importance to Science, Technology, Engineering, and Mathematics (STEM) education as STEM fields remain an urgent and present economic need (Kuenzi, 2008; National Academies of Sciences, Engineering, and Medicine, 2016), spurring high level policies like the America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science or COMPETES Act (Furman, 2013) and P-20 educational reforms to strengthen the American STEM pipeline (National Research Council, 2011). The majority of current STEM reforms are designed to advance students' knowledge within the STEM domains (Kelley & Knowles, 2016). Yet, the National Academy of Engineering (NAE) and the National Research Council (NRC) have called for research on strategies to cultivate STEM identity to improve the recruitment, retainment, and perseverance of students in STEM disciplines (2014). A STEM identity is defined as the ability to view oneself as a legitimate participant in at least one of the four STEM subjects and how the "individual [is] making personal meanings associated with their identity along with the cultural impact of social meanings on these various identities" (Hughes, Nzekwe, & Molyneaux, 2013, p.1980).

Cultivation of a STEM identity is thought to be important for K-12 students, specifically women and racial/ethnic minorities that are underrepresented groups within STEM, to engage in STEM subjects and careers (Carlone & Johnson, 2007; Espinosa, 2011; Johnson, Brown, Caroline, & Cuevas, 2011). For example, girls start to lose interest in science and mathematics in middle school (American Association of University Women [AAUW], 2010). A reduction of interest in identity within the K-12 grades is thought to increase the gender gap in STEM test scores, encourage fewer women to take advanced STEM courses, and lower overall female participation in STEM within college and later careers (AAUW 2010; Spielhagen 2008). The suggested gender dearth by the NAE and NRC in STEM identity research (2014) suggests further discourse is needed, given much of what has been published in this space has examined students as individual agents in the formation of a STEM identity.

The exploration of the locus of identity formation in mathematics and science education—from individuals to that of a collective mathematics or science identity— that is presented in this paper, is not based on new research. It instead, draws on prior work in social psychology by Rogoff (1990, 1995), Cole and Engeström (1993), and Wertsch (1993) to shift the focus "from an individualistic conception of agency towards a more social understanding of the individual" (Billett & Somerville, 2004, p. 310). Lave and Wenger (1991) brought attention to the central notion of identity formation for new learners within groups of people in a shared endeavor or profession, labeling this concept as a Community of Practice (CoP). They, along with other scholars, have demonstrated that both individual and group identity is inseparable from learning (Buysse, Sparkman, & Wesley, 2003). Subsequent sociological research has helped further shift the view of identity to social practice and discourses of members within multiple communities rather than pre-formed identities held by individuals, exclusive of group membership (Benwell & Stokoe, 2006). The work of mathematicians and scientists is built within CoPs via enculturation of novices, alongside experts, into the authentic practices of mathematics and science, respectively. This suggests science or math identity is developed through apprenticeship-based opportunities, where learners observe and participate in authentic research (Bell, Blair, Crawford, & Lederman, 2003; Lave and Wenger 1991; Sadler, Burgin, McKinney, & Ponjuan, 2010; Wenger 1998).

This paper will examine why collective identity is important to K-12 learning in mathematics and science, as well as identify classroom interventions, involving pedagogical shifts that may foster collective mathematics and science identity formations. The intent of paper is not to reconceptualize identity, argue aspects of individual or collective identity or identity's relationship to science or mathematics, nor is it to offer new empirical data to this extant body of knowledge. Rather, our intent is to bridge the gap between research that often resides at the large scale, among governmental entities and research institutions and practice that offers a guide to science and mathematics K-12 teacher practitioners who have interest in identity research and wish to lead in their classrooms by enhancing their curriculum and instruction with individual and collective (classroom-level) identity-fostering strategies. Since most American K-12 learning environments are typically structured with a teacher and students learning math and science together, it is logical to invite and discuss how K-12 teachers' classrooms may help foster collective mathematics and science identities for students. Moreover, the National Academies of Sciences, Engineering and Medicine (2015) has recommended that teachers should be involved in the use of research, where their engagement in research-based reform should be contextualized within their classroom practices. We address this call by first defining identity, both individual and collective, discuss its affordances in science and mathematics education, and then encourage teachers to engage in identity-based reform practices through tangible pedagogical strategies.

Identity and the K-12 Classroom

The research literature has long explored individual identity as a critical feature of the knowledge-building process or learning (Beatrice, 2010). We both acknowledge and appreciate the diversity of thought around the concept of identity. However, we employ the conceptual understanding of identity as viewed by situative scholars as shared interest (Wenger, 2011) and a sense of belonging and commitment (Handley, Sturdy, Fincham, & Clark, 2006) within a CoP. This stance permits viewing identity as it relates individually and collectively to a domain, like science and mathematics. Through this lens, we also perceive identity formation through Lave and Wenger's (1991) legitimate peripheral participation, where novices develop expertise through authentic learning opportunities via social engagement with experts. Legitimate peripheral participation affords an active means for learning, whereby knowledge is socially constructed within the normative practices of a CoP (Lave & Wenger, 1991).

Vygotsky's (1978) zone of proximal development (ZPD) offers a framework for how legitimate peripheral participation can be appropriately executed in the classroom, namely what a novice may progressively do within the CoP unaided by experts. Vygotsky outlines how students as novices experience crises at the junction between the zones of actual and proximal development, thereby requiring help from an expert, whether that is a more capable adult or peer, to resolve their intellectual or academic quandary. As students' progress from novices towards experts through the ZPD, the significance of individual achievements influence both learning and identity

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(Borthick, Jones, & Wakai, 2003). The progress within a CoP is a staple of constructivist learning environments (Beatrice, 2010). Therefore, this situative framework can visualize identity of both the individual and the collective, which may be useful to the current schema of K-12 schools where classrooms could function as CoPs for subject-area learning. Yet, despite decades of research, classroom instruction remains primarily didactic in nature, in which the culture and delivery of school science and mathematics directly impacts students entering these majors and careers (Aikenhead, 2006). In science, the nature of the curriculum itself has been termed inauthentic (Hodson, 1998), even downright dishonest (Aikenhead, 2006), not representing science as it is practiced among scientists (Stocklmayer, Rennie, & Gilbert, 2010). Mathematics curricula has failed to overcome similar challenges in illustrating and providing students the genuine CoP practices of mathematicians for decades (NRC, 1989, 2004, 2011). This asymmetry may stymie individual, much less collective, identity formation.

Classroom settings provide unique opportunities to develop multiple relationships between experts and novices. Enculturation into community-based practices may develop not only on an individual level, but also amongst and between group members. The evolving group participation, defined as "a group that derives from members' common interests, experiences and solidarity," is known as collective identity (Taylor & Whitter, 1992). Collaborative forces shape collective identity, which can be used as a cultural tool to bind members as they work together to accomplish shared goals of the community (Appiah, 2007). Collective identity formation is well described within multiple fields, like sports (Pelak, 2002), social movements (Choup, 2008; Fominaya, 2010) and politics (Greenhill, 2008; Wendt, 1994). However, research is needed on how collective identities are negotiated by students via their participation in a shared group within K-12 school settings. This identity plays a unique role in schools, through which students may write their internal narrative while they negotiate their roles within a CoP and accept the collective memories of others in the community (Appiah, 2014).

Accepting the view that individual identity is fluid (Gee, 2000) suggests classrooms may capitalize on this fluidity by fostering identities that strengthen the students' involvement in CoPs, helping them to negotiate multiple identities across academic disciplines over time. Encouraging identity formation in small groups can change individuals' attitudes and behavior through group interaction, making it a powerful pedagogical tool (Lewin, 1947; Thomas, McGarty, & Mavor, 2016). However, recent research by Idrus (2015) found "teachers were reluctant to relinquish their authority and power to students for various reasons which could be detrimental to the construction of shared identity" (p.28). This may stem from teachers' pedagogical practices shifting from a 'director' to that of a 'facilitator,' which is instrumental for CoPs to develop in classroom settings (Forbes & Skamp, 2014, 2016; Levitt, 2001). This suggests collective identity formation in classrooms deserves further exploration, particularly in disciplines like mathematics and sciences, where identity continues to play a key role in learning, persistence, and even the pursuit of advanced courses and long-term careers.

Collective Identity in Mathematics Classrooms

Mathematics is a subject that continues to receive unique attention in K-12 education, given its critical importance to the political and economic goals of global competitiveness (National Science Foundation [NSF], 2018). According to the National Science Board of Science & Engineering Statistics, high school students are woefully unprepared for college level mathematics and science coursework where underrepresented minority groups had lower benchmark scores. For example, benchmark scores reveal drastic differences between Hispanic and African-American students (27% and 13%, respectively) and their White and Asian-American peers (50% and70%, respectively) (NSF, 2018). Moreover, historically and presently, the community of mathematicians remains homogenous; evidenced by the low percentage of women and non-Asian minorities who pursue STEM degrees at US universities (NSF, 2018). Similar results from high school seniors who pass the National Senior Certificate examination in South Africa (Adler & Sfard, 2017) reveal that the pervasiveness of gender and racial/ethnic inequity among those who become eligible for entry into later tertiary STEM education and the workplace is not solely limited to the US culture. Factors such as parental socioeconomic status, language of instruction, and rural home environments draw further attention to the systematic disparity in educational outcomes faced by marginalized learners across cultures (Adler & Villay, 2017). Subgroup results from the Grade 9 Trends in Mathematics and Science Study (TIMSS) 2015 study support findings by Adler and Villay (2017), as well as reveal little change in mathematics achievement trends by gender (Mullis, Martin, Foy, & Hooper, 2016). These low numbers raise concerns among educators and mathematics professionals about the traditional classroom ethos that continues to prevail for subjects like mathematics (Kilpatrick, Swafford, & Findell, 2001). The societal consequences are evident. The NSF (2018)

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has indicated that reduced participation of underrepresented minorities facilitates a lack of diversity in the workplace. Other researchers have found that productivity and innovation in science and engineering spaces are negatively impacted (Hewlett, Marshall, & Sherbin, 2013; Ellison & Mullin, 2014).

An examination of school and classroom instruction structures reveal that students' experiences over time impact their views of mathematics and inform their mathematical identities. In traditional classroom structures, "children become socialized by school and society, they begin to view mathematics as a rigid system of externally dictated rules governed by standards of accuracy, speed and memory" (NRC, 1989, p. 43). Research from multiple developed countries revealed that elementary and secondary mathematics students share a poor, inaccurate view of the field (Picker & Berry, 2006; Rock & Shaw, 2000). Results from Rock and Shaw's (2000) Draw a Mathematician Test suggested that young children tended to think mathematicians did the same kind of mathematics they did in the classroom, with virtually all young children picturing mathematicians in classroom-like scenes. Picker and Berry (2006) found that middle-school students depicted similar images. Overall, younger children depicted mathematicians smiling. However, by middle school, these views changed. Approximately 23% of middle school respondents shared that "mathematicians did 'hard' and 'complicated' problems, as well as 'problems that no one else could solve'" (Rock & Shaw, 2000, p. 553). Similar negative trends in gender equity and knowledge about the field were evident as children aged. More than half of kindergarteners depicted more women than men, while second- through fourth-graders depicted an approximately equal number of women and men, often working collaboratively in real-world settings (Rock & Shaw, 2000). Yet, both male and female middle-school respondents depicted more males (93.8% and 61%, respectively) (Picker & Berry, 2006).

Both studies by Rock and Shaw (2000) as well as Picker and Berry (2006) concluded that students view mathematicians as doing hard work that no one wanted to do; they lacked a clear understanding of what mathematicians do in the real world. Picker and Berry found additional negative views of mathematics held by middle school students, such as a sense of power imbalance and mathematics as absolute knowledge held by authoritative adults. These recursive patterns reveal that the mathematics community comprised of teachers, other students and other outside influences is subtly shaping the shared identity of mathematics students are developing. These findings are particularly damaging for minority or underrepresented students, who lack experiences with authentic disciplinary practices; research suggests it is unlikely these novice learners will adopt the goals to be successful in defining themselves within the practice or embarking in the development of robust mathematical identities (Boaler, 2002; Nasir, 2002). Mathematics was viewed as a subject for those who have a certain innate ability and students often felt incompetent if they could not process the material with ease and speed, especially when teachers made it look effortless (Picker & Berry, 2006). This suggests that traditional classrooms, presented mathematics as a natural identity instead of as a CoP discussing the challenges that are naturally part of the thinking process. Additionally, teachers were largely unaware of students' stereotypical views and lack of knowledge about the field, as well as their own role in shaping and altering students' views; overall resulting in students lacking a sense of belonging to the group, relevancy to their lives, and encouragement to pursue mathematics fields (Picker & Berry, 2006). Later educational experiences may perpetuate these views. A recent poll of scholars across various disciplines at American universities revealed that academics in mathematics were the most extreme of the STEM fields in terms of emphasizing fixed, innate ability (Leslie, Cimpian, Meyer, & Freeland, 2015).

Mathematics remains a subject towards which students have strong feelings. Yet, the observed differences do not align with capability, but rather with learning practices (Boaler & Greeno, 2000). Most students receiving didactic instruction rejected mathematics overwhelmingly because the practices in which they participated were incompatible with developing situated mathematics identities (Boaler & Greeno, 2000), which are defined and based upon shared interest (Wenger, 2011) and belonging (Handley et al., 2006). Many of these students viewed traditional mathematics classrooms as requiring them to be passive recipients of knowledge, which they came to accept as part of the normative classroom behaviors. These same students, all of whom were successful mathematics students, perceived other subjects as requiring thought and creativity, affording them opportunities for expression and agency. However, opposite views of mathematics as a subject valuing connected understanding and opportunities to express thinking were held by students who received discussion-based mathematics instruction (Boaler & Greeno, 2000), which suggests that CoP classroom settings mediated the formation of these views. Their results suggest that abstract, decontextualized instruction is more alienating for girls and non-Westerners than boys and Western students. Even

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more concerning is that these findings by Boaler & Greeno (2000) substantiate concerns that systematic marginalization of select groups from a subject at which they show promise exists.

Collective Identity in Science Classrooms

The National Center for Science and Engineering Statistics found that the percentage of women who participate in science and engineering careers increased due to their roles into various health care industries (as nurses, dietitians, physician assistants, health technologists and technicians to name a few) but that their numbers in all science and engineering fields remains stagnant overall (NSF, 2018). Current data reveals that the majority of scientists and engineers in the United States are non-Hispanic Whites, followed by Asians and Asian-Americans (67%, 21%, respectively) (NSF, 2018). Hispanics, African-Americans, and American-Indian or Alaska Natives have low levels of participation (6%, 5%, and 0.2% respectively) compared to their U.S. residential population (NSF, 2018). A similar examination of the science and mathematics teacher workforce suggests most teachers are disproportionately White (Sleeter, La Vonne, & Kumashiro, 2014), despite lacking certification and years of teaching experience at schools that serve minority and high-poverty students (NSF, 2018). These statistics portray challenges science educators face to engage and sustain students from all backgrounds, which is has been credited to the science identity gap (Tan, Calabrese Barton, Kang, & O'Neill, 2013). Identity is a critical construct, omnipresent when students are partaking in science activities, regardless of it being intentionally incorporated into science instruction (Calabrese Barton, Kang, Tan, O'Neill & Brecklin, 2013). Tan et al. (2013) theorized that the science classroom can be an incubator for fostering and developing science identity. They argued that the science classroom can be viewed as a CoP in which students continuously co-construct their evolving identities as they engage in shared tasks with their classroom peers if the teacher creates classroom norms to develop and support emergent science identities (Tan et al., 2013). These authors dissected the experiences of young women and viewed classrooms that presented various narratives and histories of what it meant to be scientific, encouraged students to be curious, excited, and an active participant in learning and doing science. Numerous other scholars exploring identity have identified empirical connections between the critical importance of constructing a robust science identity (e.g. seeing oneself that can and does do science) to science interest and learning in all school age groups including young children (Archer, Dewitt, Osborne, Dillon, Willis, & Wong, 2010; Maltese & Tai, 2008), females (Brickhouse, Lowery, & Schultz, 2000; Fordham, 1996) and students of color (Nasir & Saxe, 2003). The literature has also established numerous connections between identity and STEM persistence for underrepresented groups through college and career (Brown, 2002; Carlone & Johnson, 2007; Espinosa, 2011; Johnson et al., 2011).

When considering identity, science education should be wary of the implications of an unfettered inclusion of value-based character education in which students evaluate the ethical issues science presents in society. This may introduce the misconception that scientists individually develop personal or opinion-based judgments on large bodies of knowledge as a whole, versus a careful and intentional group negotiation (e.g. reproducibility, peer review) that occurs within a CoP. This may also play a role in addressing the psychological and physical stereotypes of the typical scientist (Mead & Metraux, 1957). As Picker and Berry (2006) suggested for mathematics, the power imbalance that similarly exists in science classrooms needs to shift, so that students are presented with accurate images of mathematics and scientists that not only better conform to reality, but also more palatable for adoption within their own identities.

The future challenge for education is incorporating sustained ways of thinking about authentic problems and practices. Without such an intervention, individual and collective identities may be superficial and short-lived. New community members should be initiated into legitimate ways of thinking that mirror authentic practices within the field, meaning young children should be participating in developmentally appropriate and legitimate activities in classroom CoPs modeled from STEM-based CoPs. Therefore, the K-12 classroom setting holds incredible power in how to negotiate norms and practices, as well as how new knowledge is negotiated and legitimized by the community of its practitioners (Hodson, 2009). However, it is arguable that this element of instruction has serious consequences. Asymmetries between the classroom STEM-centered CoP and that of the actual STEM CoP will reinforce negative stereotypes of how science and mathematics are done by experts, reducing any shared interest or affinity (identity) to those CoPs. Until this is systemically remedied, educators and policymakers will continue to face challenges in sustaining the STEM pipeline, which include the social impacts that are derived from a skewed scientific worldview.

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Recommendations for Fostering Collective Identity in the K-12 Mathematics and Science Classrooms

Research indicates that in both mathematics and science, mindful educators can mitigate inequity and social stereotyping of classrooms. For example, Burton (1996) found that science teachers typically cued, prompted, and questioned boys more often than girls. In another study, known as the Computer Equity Expert Project, Sanders (1996) attempted to combat teachers' views regarding gender inequity. After teacher training, greater teacher awareness and perceptual changes around gender inequity occurred, as did subsequent differences within teachers' classroom practices. Some of the changes Sanders observed included providing girls with equal access to computers, incorporating explicit use of positive female role models during instruction, and calling on both genders equally during classroom discussions. Sanders proposed that larger, systematic changes would require greater training on the part of many more stakeholders within the school community. Reis (1998) similarly concluded that one reason some girls fail in mathematics is due to stereotypical perceptions they encounter in school and life, namely that they are simply not expected to succeed in mathematics and sciences. Teachers even attributed success differently for females; they viewed success as due to ability in males, while due to effort in females (Reis, 1998). Such research supports a widespread call for change in classroom structure through widespread initial and continuing professional development, so that all students develop a sense of belonging to the community and a more accurate collective view of mathematics and related disciplines.

More recent research reveals the related benefits of incorporating a growth mindset approach, or infusing concepts of goal setting and motivation to develop one's intellectual achievement over time (Blackwell, Trzesniewski, & Dweck, 2007). Teachers play a role in developing students' growth-oriented mindsets in schools through classroom-based interventions (Yeager & Dweck, 2012). In mathematics instruction, this manifests as helping students learn, understand, and appreciate mathematics concepts (Boaler, 2016; Paunesku, Yeager, Romero, & Walton, 2012). For example, one empirical study found mindset interventions positively changed classroom motivation and significantly reversed mathematics achievement declines for low-achieving middle school students within the same year, whereas their fellow classmates in the control group continued to decline academically (Blackwell et al., 2007). Dweck claimed that her research shows "that a fixed mindset contributes to this eroding sense of belonging, whereas a growth mindset protects women's belief that they are full and accepted members of the math community" (2008, p. 5), drawing a direct line between growth mindsets as a strategy to foster math-based CoPs and consequentially empirically linked concepts of identity and identity formation (Eckert, 2006; Goos & Bennison, 2008; Wenger, 1998, 2011).

Dweck (2008) describes that growth mindsets have affordances in also boosting science achievement and developing students' senses of science belonging. In addition, other instructional practices in contemporary classrooms have also successfully fostered science identity, and as an extension, collective identity. Hodson (2009) noted the use of case studies as "an effective way to bridge the 'gap' between the two cultures of arts and sciences…ensuring that future politicians and business leaders have some basic understanding of science, scientists, scientific practices and scientific developments" (p. 328). This aforementioned case study approach is defined as providing historical or current vignettes of scientists engaged in their CoP to address a specific societal problem or issue. Data, evidence, and observations, collected from experts in the field, guide students through the history of the individual cases. Hence, students vicariously participate in the successes and challenges that the scientist experiences to mimic the reality of scientific endeavor. Research suggests case studies for adolescent science learners be an "antidote to the excessive realism and determinism typical of many pupils…their image of the certainty of scientific knowledge is challenged…[and] the uncertainty of a scientific theory does not necessarily nullify its usefulness in making further progress possible" (Irwin, 2000, p.5). Additionally, Hodson acknowledged that this approach may be especially effective in even younger children as stories capture the social, cultural, and affective aspects of the discipline. Not only does this provide a rich and robust context for understanding complex scientific issues in situ, but also serves to stem issues in the "criticizing of scientists" that occurs when students resort to a "'villains and heroes' approach to scientific history" due to a lack of chronological appreciation that is derived by an understanding of science situated within time and history (Hodson, 2009, p. 329). Hodson further criticized that "scientists are portrayed as somehow free from human foibles, humor, or any interests other than their work" in which students may align their personal experiences or perceived shortcoming understanding content to that of authentic scientists and the scientific process (p.343), but by incorporating a strong contextual basis of scientific processes and inquiry, as well as leveraging original field notes, source materials and other primary

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resources (National Center for Case Study Teaching in Science, 2019), science educators can address such issues.

The introduction of scientific argumentation to the science classroom setting has been another successful strategy for promoting scientific literacy and inquiry and challenging students to make evidence-backed claims that withstand the community standard of peer scrutiny (Erduran & Jimenez-Aleixandre, 2007). Teachers serve as experts, who moderate and model this type of argumentation-based discussion for students, as these novices develop expertise through authentic and genuine community practices. Apprenticeship-based experiences, like argumentation, aid individual students in the adoption of a scientific identity (Polman & Miller, 2010). Moreover, teachers who cultivate classroom settings with robust peer interaction (e.g. whole- and small-group argumentation) may provide legitimate opportunities for collective peripheral participation by leveraging the authentic activity of the CoP of real scientists. Therefore, argumentation is a useful strategy as, "learning science involves both personal and social processes…On the social plane the process involves being introduced to the concepts, symbols, and conventions of the scientific community" (Driver, Asoko, Leach, Mortimer & Scott, 1994, p. 8). With opportunities for argumentation (a vetted and authentic science practice), students within a classroom CoP may foster a robust collective science identity. Developing teachers' mindsets to curate a classroom CoP requires sustained periods of time, as teachers' and students' views of science shift (Driver et al., 1994; Opfer & Pedder, 2011). Therefore, more research is needed on classroom-based scientific argumentation to fully understand its nuanced benefits for students.

Understanding the larger endeavor of scientific pursuit known as the Nature of Science (NOS), or the "values and assumptions inherent to the development of scientific knowledge" arguably affords students opportunities to develop a more accurate collective science identity (Lederman, 1992, p. 331). Numerous studies have sought to understand how teachers instruct students in the NOS (see Abd-El-Khalick & Lederman, 2000) and assess how students interpret the NOS (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). To aid teachers in NOS-grounded instruction, pedagogical recommendations by Lederman, Antink, and Bartos (2014) are to provide students opportunities to engage in scientific inquiry, so they may understand "scientific knowledge is tentative (subject to change), empirically-based (based on and/or derived from observations of the natural world), subjective, necessarily involves human inference, imagination, and creativity (involves the invention of explanations), and is socially and culturally embedded" (p. 287). Instruction grounded in the NOS has additional positive outcomes, through providing a more realistic picture of science CoP may help to remediate students' negative stereotypes of scientists and scientific endeavor (Bodzin & Gehringer, 2001; Lederman, Wade, & Bell, 1998). In sum, case studies and argumentation are two, of many, classroom-based strategies to aid students to engage in the practices of scientists as they occur within the scientific CoPs.

This leads to the most salient point, the most important aspect for a teacher to cultivate collective identify for his or her students is to foster a CoP through building a classroom community. As the teacher creates his or her own science community, characterized by shared discursive practices (Lemke, 1990), students are communally engaging in cultural apprenticeships within the classroom-based and content-centered CoP (Driver et al., 1994). Research indicates that the cultivation of a classroom community is the superstructure to effectively coordinate science students, materials, tasks and science concepts (Harris & Rooks, 2010). Hence, identity formation extends beyond the science classroom to mathematics and other related STEM fields, but the research suggests explicit instruction with level-appropriate scaffolds that are gradually removed to appropriate the cultural norms of a scientific CoP and rely upon a group consensus are critical factors.

Discussion

Given that learning and identity formation is an ever-evolving process, legitimate peripheral participation should exemplify the desired cultural practices. The emphasis should be on the value of verbal discourse as a process of learning a deeper sense of value of community and becoming part of the community for novices (Lave & Wenger, 1991). Also, this process should be sustained over time; as it requires incremental improvements for teachers and students to alter the current image of STEM professionals based on school instructions to one that more closely resembles their respective CoP. Recommended changes shared here have been utilized by many teachers for decades, but in-depth studies are needed to better understand and advocate for widespread change. First, the roles of teacher and learner require redefining, so that the environment is open and supportive of all students and the focus remains on the nature of inquiry (Reis, 1998). This notion is well established in the research field, yet can be challenging to replicate in the classroom. To this end, classroom teachers and their supporters continue

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to advocate for themselves to no longer be viewed as the sole authority figure, or simply a body of "objective" knowledge, but rather a distributer of intelligence centrally revolving around "relationships" and students learn through developing "a community of voices" that authority resides within the individuals and collectively within in the mathematics community (Burton, 1996, p. 142).

Children who perceive STEM skills as useful and necessary for future careers are more likely to enroll in optional and advanced, related courses (Hart & Walker, 1993; Picker & Berry, 2006) or select STEM careers for financial independence or empowerment (Stoet & Geary, 2018). This underscores the importance of this early and shared (STEM) interest Wenger (2011) ascribes to STEM identity formation. Students' attitudes towards various disciplines can be further improved when teachers show enjoyment and engage students through discovery lessons and use of concrete models, as well as show its utility in everyday life and application in future careers (Hart & Walker, 1993; Renga & Dalla, 1993). As teachers engage students in the content, they are actively fostering the sense of belonging Handley et al. (2006) ascribed to being important components of CoP-based collective identity. Furthermore, students who take advanced mathematics courses, in which they learn to work, think, and reason logically, are more productive later in their jobs (Rose & Betts, 2004). Teachers should also utilize explicit hands-on collaborative experimentation as is typical of the real world, avoid sex-stereotyped examples, not allow boys to dominate legitimate peripheral participation, furnish career information, provide more encouragement for girls and other less confident students, and use discourse-based instruction surrounding problem-solving practices that promote the creativity and depth of thinking that mirrors later working environments, so more students can develop realistic identities (Boaler & Greeno, 2000; Hart & Walker, 1993; Reis, 1998).

Students require more opportunities to struggle with appropriately difficult problems over time, as afforded through ZPD, to learn persistence and that problems require time, effort and even failure. When students were asked for reasons when they felt a sense of belonging in learning activities, they stated that they preferred curricular material with depth and relevance that came from real-world sources, differentiated level of challenge and pacing and having some choice in their development of own expertise (Hart & Walker, 1993). These same students also stated that motivating teachers were "supportive, caring, understanding, sharing mutual trust and respect, listening to and respecting diverse opinions, offering choices, explaining things, not telling all the answers, being fun, humorous and enthusiastic, sharing interests, holding high expectations, giving feedback, and being accessible" (Hart & Walker, 1993, p. 28). In addition to changes in instruction approaches, effort is needed so that assessments align with instruction. They should encompass a wide range of open-ended strategies with clear criteria, allow students to reflect on learning, recognize complexity and identify a range of problems (Gipps, 1996). Large-scale implementation of these various reform-oriented classroom components may help alter more students' perceptions of mathematics and science, and therefore, create more realistic and therefore facilitate the development of robust collective identities through developing shared interest through authentic activity warranted for identity development (Wenger, 2011) of both domains.

Conclusion

The cultural goal of the CoP was essentially summarized by Gipps (1996) when she said,

> we need to talk of not a pedagogy, for girls and boys, but pedagogy being composed of a range of strategies (which include a range of materials and content, teaching styles, and classroom arrangements/rules) for different groups of pupils and for different subject areas. (p. 265)

This shift affords all learners an opportunity to reconstruct their approach to learning, and thus for practitioners, careful planning is essential for successful implementation of these changes. This includes consideration of students' interests, establishing obtainable goals and adjusting the difficult level of tasks to the background and cognitive developmental level of students, thereby simultaneously building confidence and motivation to learn and understand (Renga & Dalla, 1993). To accomplish this feat requires a critical component, which are research-based strategies for teachers, so they may provide legitimate opportunities for participation and proper scaffolding that is not only developmentally appropriate for content but also develops the mental acuity for their students. It should be noted that this process takes time and administrative support, especially given no one prescribed system of rules will fit all different groups of students or subjects every year. Yet, incremental alterations must be made by mathematics and science educators to benefit all members within the community and alter a shared view of a collective identity that reflects the authenticity of STEM disciplines.

We are still far from reaching these desired goals on a large scale, despite decades of research on how to implement practices valued by the mathematics

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and science communities. Only if all members feel a sense of belonging and become legitimate participants within the CoP can we ensure more students make an informed choice about inclusion or exclusion from the group regarding their future careers rather than solely based on access or denial to resources. Inclusion of more students benefits the entire community and aids in field advancement to achieve the mission of an inclusive and engaged STEM pipeline. Therefore, both researchers and practitioners hold mutual accountability to ensure that students' collective identities are forged in K-12 classrooms that are reflective of STEM's practices and reflect the learners' unique contributions to STEM. Such classrooms will lead to students feeling engaged in science and mathematics coursework, and empowered to pursue science and mathematics in school, college, and career.

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