



Professional Growth and Identity Development of STEM Teacher Educators in a Community of Practice

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Abstract

Quality STEM teacher education is predicated on teacher educators who are well-equipped to design learning experiences, provide feedback, guide the development of teachers across their career span, and conduct rigorous research to advance education theory and praxis. While numerous models and approaches to professional development for teachers exist, few parallels can be drawn between the professional development of teachers and teacher educators (Loughran, 2014). To support the multi-faceted identity (trans)formation of STEM teacher educators, self-directed learning opportunities can help bridge knowledge and practice, enhance productive collaboration, and support efforts to negotiate multiple and conflicting agendas (Goodwin & Kosnik, 2013). The purpose of this empirical study was to explore the identity (trans)formation of teacher educators participating in a long-term interdisciplinary STEM-based Community of Practice (CoP; Wenger, 1998), which began in 2012. An analysis of our experiences through the figured worlds lens informs how a CoP can impact curricular approaches and teacher PD, imploring members to move through their comfort zones into innovative spaces. We conclude with suggestions for our STEM teacher educator colleagues who seek opportunities to challenge their own positions and best support preservice and in-service STEM teachers in a way that allows them to model for their students the value of community.

Keywords Community of Practice · Mathematics education · Professional development · Science education · Teacher education

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Introduction

Teacher educators (TEs) encounter personal and professional (trans)formations as they take on unfamiliar roles, navigate new relationships, orient to the institutional context of academia, confront conflicts between multiple professional identities, and develop personal pedagogies for teacher education (Guilfoyle, 1995; Williams, Ritter, & Bullock, 2012). Teacher education has been described as an “under-researched, poorly understood, and ill-defined occupational group” (Murray 2016, p. 35). TEs design and implement formal education activities for future or current P-12 teachers, which may include teaching subject-specific or pedagogy (methods) courses, guiding reflection, providing support during field work or student teaching experiences, or otherwise contributing to the professional development (PD) of future and current teachers. For those at research-intensive universities, and increasingly for TEs at colleges and universities where research has historically been less of a priority, conducting and disseminating rigorous research is an additional requirement. Furthermore, many TEs develop and maintain relationships with P-12 schools and teachers—either as part of a teacher education “partnership” or as sites for research. To complicate matters, expectations for TE within the realms of teaching, relationship-building, and research are often ambiguous (Dinkelman, 2011; Ellis, McNicholl, Blake, & McNally, 2014).

Despite the prevalence of teacher education in institutions of higher education for over a century (Evagorou, Dillon, Viiri, & Albe, 2015; Labaree, 2008), teacher education became widely recognized as a distinct profession merely two decades ago, “about the new millennium” (Kelchtermans, Smith, & Vanderlinde, 2018, p. 122). Although TE pathways into the profession are not well-researched, we can say assuredly that pathways vary among TEs in the USA and internationally, and each of these has unique impacts on PD needs (Loo, 2019). While some TEs have bachelor’s degrees (e.g. Namamba & Rao, 2017) or master’s degrees, many have further training as scholar practitioners or researchers with doctoral degrees. Most TEs are former classroom teachers, although recent years have seen an increase in TEs without any P-12 teaching experience (Mayer, Mitchell, Santoro, & White, 2011; Yuan, 2015). Regardless of their pathways into the profession, most TEs receive no formal preparation (MacPhail et al., 2019; Zeichner & Conklin, 2005). Advanced degree programs in education (i.e. PhDs), for example, typically emphasize research with little focus on explicitly preparing their graduates to engage in teaching (Abell et al., 2007; Barnes & Randall, 2012). Furthermore, discipline-based STEM TEs with PhDs in STEM fields, such as biology or mathematics, may have limited experience with social science research and will likely need to develop social science research skills (Jablon, 2002). Hence, TEs who enter the profession through these various pathways have distinct needs for support to develop pedagogical content knowledge (PCK) for teacher education (Abell et al., 2007) and to understand the systems and cultures of K-12 schools (Yuan, 2015), as well as those of higher education. Despite variations across international contexts or professional pathways into teacher education, there is a strong need for TE professional development (Akyeampong, 2017; Czerniawski, Guberman, & MacPhail, 2017; Hökkä, Vähä-santanen, & Mahlakaarto, 2017; MacPhail et al., 2019; Van der, Kools, Avissar, White, & Sakata, 2017; Vanassche et al., 2015).

The professional identity of TEs is multi-dimensional (Beijaard, Meijer, & Verloop, 2004; Swennen, Jones, & Volman, 2010), and we consider the dimensions of professional identity for STEM TEs to include five domains: (1) teacher educator, (2) STEM educator, (3)

STEM disciplinary expert, (4) STEM education researcher, and (5) teacher education researcher (Brownell & Tanner, 2012; Grier & Johnston, 2012). Izadinia (2014), in a review of international research on TE professional identity development, found that TEs' challenges in professional identity development arise from both lack of quality induction programs and tensions inherent in the role. There is a persistent need to understand how TEs' sub-identities (trans)form across and within domains, and the high-quality PD activities that might support this (Czerniawski et al., 2017; Flores, 2018; Swennen, et al. 2010).

The (trans)formation of STEM TE's identities in each of these dimensions is developed through complex social interactions (Dinkelman, 2011). Research on PD for TEs that might support identity (trans)formation remains highly fragmented (Cochran-Smith, 2003; Ping, Schellings, & Beijaard, 2018; Van Driel & Berry, 2012) and primarily centers on the shift of identity from that of a P-12 teacher to that of a TE (Van Driel and Berry, 2012; Dinkelman, 2011; Loughran, 2007; Murray & Male, 2005; Ping et al., 2018; Ritter, 2007; Wood & Borg, 2010). In this paper, we will describe multidimensional identity (trans)formation for STEM TEs within a participant-driven PD.

Professional Development for STEM Teacher Educators

The needs of STEM TEs are unique, and studies of disciplinary TE PD for this group are sparse (Even, 2008). All TEs, regardless of discipline, need continued PD over the entire span of their careers, specifically targeting their PCK for TE (i.e. knowledge of learners, curriculum, instruction, and assessment), and how to support the development of novice teachers' PCK (Abell, Rogers, Hanuscin, Lee, & Gagnon, 2009; Baser, Kopcha, & Ozden, 2016; Gess-Newsome, 2015) and classroom practices (Grossman, Hammerness, & McDonald, 2009). Findings from a systematic review show the majority of TE PD focuses on teaching aspects of the role, such as technology integration and the development or refinement of pedagogical skills (Phuong, Cole, & Zarestky, 2018). In addition to emerging identities as "teachers of teachers", many TEs' research-oriented identities are essential considerations as they seek academic promotion and tenure. Studies of the development of TEs as researchers tend to focus on the development of an inquiry-based attitude (Lunenberg & Hamilton, 2008; Murray & Male, 2005) for those acquiring a research orientation, as opposed to the negotiation of ontological and epistemological divides between disciplinary research and educational research. Thus, PD for STEM TEs should be inclusive of identity domains beyond teaching and should support the development of educational research approaches and methodologies that complement and extend disciplinary research expertise.

Higher education faculty, including TEs, are often on their own to design and implement their own PD (Berry, 2007; Koster, Dengerink, Korthagen, & Lunenberg, 2008; Ben-Peretz, Kleeman, Reichenberg, & Shimoni, 2010; Phuong et al., 2018; Van Lankveld, Schoonenboom, Volman, Croiset, & Beishuizen, 2017). Approaches to TE-driven PD include co-teaching (Weinberg, Sebald, Stevenson, & Wakefield, 2020) and self-study (Cochran-Smith, 2003; Zeichner, 2007). Self-study is a practitioner-oriented research approach that tends to focus on navigating professional identities during the transition from teacher to TE, navigating institutional contexts, or developing personal pedagogies for teacher education (Williams et al., 2012). As approaches to PD for TEs, both co-teaching and self-studies typically focus on shared problems of practice within "teaching" aspects of the role, rarely delving into the epistemological and ontological orientations or research-related behaviors, a need we address in this paper.

Theoretical Framework

The notion of identity can be a powerful analytic tool for understanding the interplay of theory and practice for educators (Gee, 2000). Professional identity, defined as “the various meanings attached to oneself by self and others” (Gecas & Burke, 1995, p. 42), is composed of interrelated attributes, beliefs, values, motives, and experiences (Ibarra, 1999). Identity transformation is considered a dialogical process of dynamic shifts across and within various sub-identities. The professional identity of STEM TEs is in the domains of teacher educator, STEM educator, STEM disciplinary expert, STEM education researcher, and teacher education researcher.

Figured Worlds

Identity is formed, or “figured,” within and through the “worlds” in which individuals engage (Urrieta, 2007). Informed by Vygotsky and Bakhtin’s sociocultural theories, Holland, Lachicotte, Skinner, & Cain, (1998) described figured worlds as a “socially and culturally constructed realm of interpretation” (p. 52). As cultural and historical contexts change, figured worlds are developed and shaped through the engagement of their participants and are defined by the social interaction of individuals who interact within them.

Figured worlds function as contexts of meaning, where identities develop and within which social encounters have significance. This identity development occurs through one’s own subjective experiences, personal histories, and interactions with others in the context of the figured world. Though figured worlds are shaped by their members, individuals’ positions matter. Figured worlds also acknowledge systems of power and privilege and recognize that individuals, relationships, practices, and actions are influenced by structures beyond those within the figured world (Urrieta, Martin, & Robinson, 2011). Because they are socially organized and reproduced, figured worlds are not static. They are dependent on members’ interactions and engagement with one another, and there is a shared understanding of the outcomes that are valued.

These characteristics make the figured worlds framework particularly well-suited for exploring the identity development of teacher educators in a Community of Practice (CoP). CoPs have been described as a type of figured world (Godwin & Potvin, 2017; Holland et al., 1998; Tan & Calabrese Barton, 2008) in terms of identity development because “ways of doing things, ways of talking, beliefs, values, power relations” (Lave & Wenger, 1991, p. 464) emerge through member interaction. Like CoPs, one can concurrently have membership in innumerable figured worlds that influence identity development in equally innumerable ways.

Community of Practice and Professional Identity Development

Lave and Wenger (1991) and Wenger (1998) characterized professional learning and identity development through the lens of social engagement in Communities of Practice (CoPs). We actively engage with the figured worlds around us, and carry experiences and understandings from one context to another; we use these understandings to interpret and make meaning across all contexts. CoPs position learning as a social activity; shared discourse and meaning making of norms and behaviors acculturate members into CoPs.

CoPs can occur formally or informally, and according to Wenger (1998), they are comprised of three elements: (1) mutual participation with negotiated meanings; (2) a joint endeavor that is based on mutual engagement; and (3) a shared set of resources to negotiate meaning (Wenger, 1998). Within a CoP, learning is an active process that emerges from a sense of community or belonging, and as learning progresses, individual participant identities transform and evolve over time (Lave, 1997).

Individuals play an agentic role in their identity development. Learning and identity development within a CoP are shaped by the participants as well as the context surrounding the CoP. An individual is likely to be simultaneously involved in multiple CoPs wherein the compositions, goals, and methods of CoPs differ—and the potential benefits of this are multiplicative, all shaping one's figured world. As learners notice the overlaps and tensions among understandings acquired in these various CoPs, they negotiate these to create new meaning and gain insights that would not be possible through participation in a single CoP. Rather than stark borders between groups, Wenger (1998) characterizes this “nexus of multimembership” (p. 158) as opportunities wherein new perspectives can emerge (Wenger & Snyder, 2000). Members of a CoP learn not only about themselves, but also the organizations or systems within which they are situated (Wenger, 1998).

This study represents an original and significant contribution to the development of a robust research-based body of knowledge around the multi-dimensional identity development of STEM teacher educators simultaneously engaged in teaching as well as rigorous theory-driven research. The purpose of this study was to (1) describe the authors' professional identity-based transitions across teaching and research domains of STEM TE identity and (2) analyze how these transitions were informed by our CoP.

Methods

To understand the identity (trans)formation that occurred as we engaged in our CoP, we conducted an interpretive phenomenological analysis (IPA; Smith & Shinebourne, 2012). This phenomenological approach (Giorgi, 1986) centralizes participants' lived experiences and own interpretations of those experiences, rather than an “objective” reality. Thus, this phenomenological approach allows us to acknowledge and draw from our past experiences as we describe our identity trans(formations) and how these frame and move through the present world. IPA is idiographic in nature, and we therefore begin by focusing on and describing significant professional identity transitions. Then, we explore direct experiences relative to the CoP over time for each participant to interpret how these transitions were informed or influenced by the CoP. Indeed, this interpretive approach allows researchers to capture “hidden” or implicit ideas and beliefs of the participants (Charmaz, 2005; Creswell, Shope, Plano Clark, & Green, 2006). Furthermore, interpretive qualitative studies recognize that participants have unique and sometimes convergent perspectives. As qualitative researchers we recognize the power we exert in our analyses when determining what words matter, whose voice should be heard or privileged, and why some data are more relevant than others (Mazzei & Jackson, 2008).

Context and Participants

Three TEs (the authors—referred to as AW, MB, and LSM) are the focus of this study. We are each cis-gendered women who identify as TE researchers, academics, and mothers. Our racial, ethnic, religious, family, socioeconomic, and other differences shape how we approach teacher education and how we engage in academia. Although our teaching and research backgrounds and socio-cultural contexts within which we work and live are different, our experiences of navigating academia as TE researchers overlapped and laid the groundwork for a successful CoP, which began in 2012. We recognize the significance of our ongoing CoP to support our evolving identities as STEM teacher educators. Although others have participated in the CoP at various points, we constitute the core group. A successful CoP is contingent upon “identification with the domain and enough mutual engagement to produce learning value,” and although “being a CoP does not depend on size,” it is important that small CoPs remain dynamic by regularly introducing and engaging with fresh and stimulating ideas (Wenger-Trayner & Wenger-Trayner, 2011). Although our CoP comprises only three core participants, it has accomplished this through dynamic and stimulating discussions, which draw from our shared and outside collaborations, as well as our independent work (e.g. teaching), trajectories, goals, and career stages. The current research grew out of 8 years of exchanges of ideas while navigating the worlds of STEM teacher education research and practice, and how our own professional identities have been impacted by the community we developed.

AW is currently an Assistant Professor at a large research-intensive university where she teaches science and mathematics courses to preservice teachers (PSTs), conducts PD with teachers around place-based pedagogies with an emphasis on social justice, and engages in school- and community-based research alongside graduate and undergraduate students. She is a white woman raised by college educated, working class parents. Unmarried at the time the CoP began, she has subsequently married and had two children. AW entered into teacher education by the most direct route of us all, transitioning from teacher to teacher educator after 8 years as a P-12 special education teacher specializing in mathematics and science. She received no training or orientation before working as a teacher educator, simultaneously as a graduate student, and research assistant (and later research scientist) on grant-funded K-12 interdisciplinary STEM teaching and learning projects. When the CoP began, she had been working in these multifaceted roles for nearly 6 years.

MB is currently a Professor at a large research-intensive university where she teaches biology content courses and is a TE researcher. She is an Asian American woman who is married and whose two children were school-aged when the CoP formed. She is a biologist and former P-12 science teacher who seeks social opportunities to learn discursively. As a Zoology PhD student, she conducted a dissertation on how biology majors (including PSTs) made meaning of evolution. Despite being taught by her biology mentors that hypothetico-deductive studies were the gold standard of scientific research, she valued the importance of ethnographic and critical studies because she grew up around several social science researchers. Nonetheless, the transition to qualitative TE researcher required self-study and support from informal mentors, as she learned more about different epistemologies and ontologies (Reimer, 1996; Smeyers, 2001). To learn how to study meaning making, she sought guidance

and looked for a peer community of like-minded educators and researchers at conferences, online, and across social science and humanities departments. Early in her TE career, MB started to collaborate with science teachers in classroom-based research, and they published and presented their findings together. When we formed our CoP, MB had just been hired in an education department, at the university where she is currently employed, to teach science methods and interdisciplinary methods courses, but she has since moved to the biology department.

LSM is currently the director of a university-level center at a research-intensive university, designed to support and collaborate on STEM research and education initiatives, including PD for preservice and in-service teachers. A married white woman, she had one young child at the time the CoP was formed and has since had two more children. She began her postgraduate career with the intent of becoming an atmospheric science faculty member and moved into education and social science research methodology when she realized the need to address the lack of diversity in the field of atmospheric science. As a master's student she was a graduate teaching assistant for atmospheric science courses, but had no formal P-12 teaching experience. LSM's ideas coming into education research were grounded in the similar post-positivist hypothetico-deductive gold standard of scientific research as MB's. As her research focused more on teacher education, she began to consider methods that might produce findings more relevant to teacher practice. Around the time the CoP was formed, she was working as a researcher and evaluator on a participatory action research project, and she sought collaboration and mentorship in these methods. It was through this project that she began to collaborate with AW, and was introduced to MB by her doctoral advisor.

Coming Together as a CoP

The CoP that is the focus of this study evolved over time and continues to change. Initially, we set modest goals as a writing support group. In our first year, we realized how our shared interests could be leveraged for formal collaborations, and how we could use the CoP as a place for professional growth. Through regular weekly or bi-weekly in-person and virtual meetings, we have undergone significant (trans)formations that are evidenced in our multi-dimensional identities as STEM TEs. While meeting frequency and major agenda items have changed throughout the 8 years, one consistent aspect of the CoP sessions is the allowance of unstructured time in which we share points of pride or tension, discuss professional challenges and opportunities, and explain how we are each navigating our personal and professional priorities. We realize and value our varied backgrounds, professional circumstances, and lived experiences, which enable us to bring diverse interpretations and insights into all aspects of our regular conversations.

As a CoP, we work within and across science, engineering, and mathematics to improve our respective teaching practices, collaborate to design and implement an ongoing PD and mentoring program for teachers, develop our own research identities, and support one another through career transitions. The boundaries of the CoP are impossible to draw. We are not tied by externally imposed forces (e.g. a university committee), shared professional roles or goals, nor are we part of the same department or even, in recent years, a single university. Instead, what constitutes the core uniting

features of this CoP is a commitment to enhancing STEM teacher education through teaching and research, respect for varied perspectives, and a conviction that collaboration and co-construction are an avenue for growth and development. Being a part of this CoP allowed us to draw on our respective figured worlds, catalyzing our CoP as we shared our ideas and challenged one another freely. We shared information about independent projects, or those outside the CoP about which we could advise one another. We discussed experiences, disruptions, and tensions as TE researchers. While our activities outside the CoP are inevitably consequential to our identity development, the CoP provided a consistent and explicit space for contemplation and growth—we processed our external experiences with the explicit aim of professional development. At some points, we have had common goals that brought us together (e.g. collaborative research projects), and at other points we have supported exploration of options and opportunities that had the potential to alter our individual trajectories away from close collaboration.

Data Sources

This study was naturalistic, and although we had not archived evidence of our collaborations with the intention of analysis, we have copious documentation that is representative of our professional identities, including approaches to teaching, research, and our professional pathways. We compiled five sources of data that allow us to better understand how our figured worlds were shaped, in part, by our interactions within the CoP: (i) meeting notes (referred to as “notes” in the findings) in the form of hand-written notebooks ($n = 7$) or electronically saved files ($n = 36$), each comprised of meeting notes for a finite period of time; (ii) peer-reviewed manuscripts ($n = 45$) and refereed conference presentations ($n = 63$) (“pub.”); (iii) teaching artifacts (“teaching;” i.e. course syllabi and professional development agenda; $n = 77$); (iv) grant proposals (“grant;” $n = 55$); and (v) iterations and final versions of professional documents (“prof. doc.;” i.e. annual review documents, job search statement, CVs; $n = 16$). We agreed that these data sources captured both informal and formal knowledge generation among members of our CoP, including dyads and the complete triad, and would provide evidence of identity transitions. All sources were organized for analysis by year, beginning with 2012, when the CoP began. Bibliographic information for the manuscripts and conference presentations referenced in the findings section can be found in the online supplemental materials.

Data Analysis

IPA is idiographic in nature, and therefore, we began our analysis by individually describing our significant professional transitions within the five STEM teacher educator identity domains (Fig. 1). Using thematic analysis (Braun & Clarke, 2006), we individually reviewed documents and identified major themes within each of the five STEM TE identity domains that captured our independent and collaborative interests and commitments. Each author individually looked for patterns and trends within their own data sources (e.g. teaching artifacts), meeting notes, as well as across those that represented collaborative work of the CoP. We had a preliminary discussion to resolve minor differences (e.g. we each used different terms related to interdisciplinarity) and clarify the meaning of codes, and then we each returned to our own data set to refine

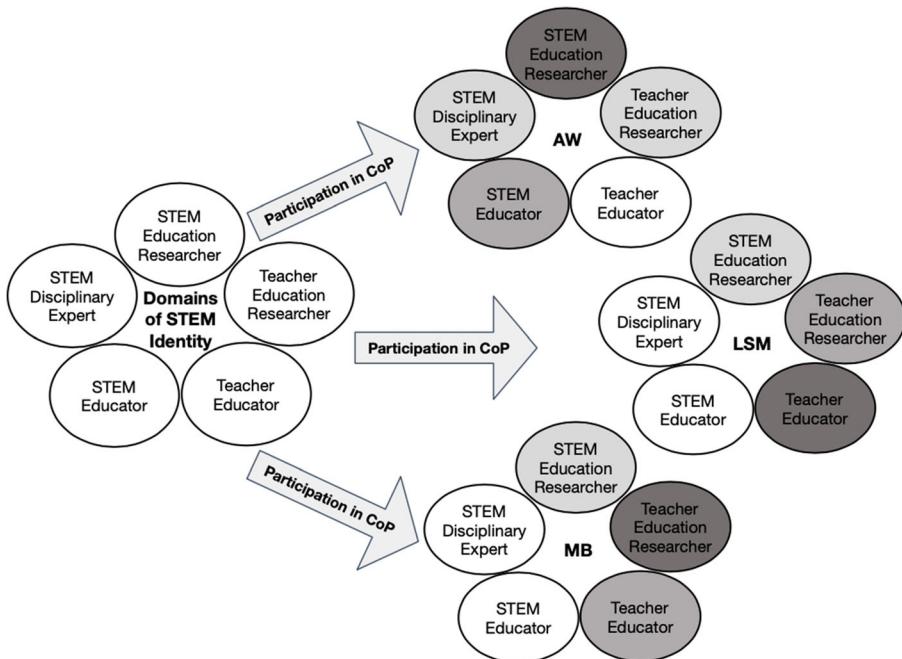


Fig. 1 The five domains of STEM TE Identity uniting us within the CoP. Strength of transformation within individual domains for each participant is represented by shading. Darker shading represents a greater transformation

coding as needed. By allowing each set of codes to be informed by our separate figured worlds, no one has imposed their interpretation on another. Next, we moved from the individual level to a group level of analysis within each of the identity domains. For each of the five identity domains, we identified a single theme that captured the CoP's influence on each identity domain. These themes are presented here, alongside an analysis of how these transitions were informed by our CoP.

Trustworthiness

We met weekly, using a virtual meeting platform, over several months during the preparation of this manuscript to establish trustworthiness during the interpretative phase (Creswell et al., 2006). In an effort to maintain methodological rigor, we participated in peer-debriefing, triangulation of data and analyses, and prolonged engagement with one another (Charmaz, 2005). We challenged one another on how to make meaning of evidence and arrived at consensus before agreeing to move on to the next stage of the study. Further, in the presentation of findings, we cite data sources that provide evidence for claims.

Results

In this study, we consider the (trans)formation of teacher educators involved in a CoP within five domains of STEM TE professional identity: (1) teacher educator, (2) STEM

educator, (3) STEM disciplinary expert, (4) STEM education researcher, and (5) teacher education researcher. For each of us, the extent of the (trans)formations varied across these five domains, a demonstration of the individualized effects participating in a CoP can have (Fig. 1). We describe overarching themes that represent significant professional identity (trans)formations, and explore how these were informed or influenced by the CoP. These themes, each aligned to a specific identity domain, include the following: (i) understanding educational systems and contexts; (ii) evolving epistemological orientations; (iii) shifting professional roles; (iv) disrupting the status quo; and (v) refining approaches to teaching and research.

Teacher Education Researcher: Understanding Educational Systems and Contexts

Significant identity (trans)formations within the domain of teacher education researcher centered on understanding educational systems and contexts. While we began with a shared belief that teacher education researchers must aim to have their work prove meaningful to both practitioners and policy makers, involvement in the CoP has transformed the ways in which we seek to accomplish this. To understand and potentially influence the local, regional, and national systems in which PSTs and current teachers are operating, each of us engages in local schools. The extent and nature of our efforts to understand educational systems and contexts outside of our obligatory teaching or mentoring commitments has shifted, particularly for LSM and AW.

Both in our individual and collaborative work, our commitment to understanding systems and contexts, and including stakeholders associated with them, has deepened over the years (e.g. grants, December 2013, March 2014, & August 2019). Early in our CoP, we exclusively positioned practicing teachers as study participants in our research—as a mechanism to impact student outcomes (meetings notes, November 2012; grant, 2012). MB, the senior TE in our CoP, urged LSM and AW to collaborate with schools attended by their children as potential sites for long-term research, as she had done when her children were young (e.g. pubs., 2011, 2014 & 2015). Through heightened engagement (e.g. volunteering, offering expertise), LSM and AW developed relationships with teachers at their children's respective schools, and began to see the potential of participatory work alongside teachers. This transformation of identities continues with deepened commitments to develop ongoing collaborative research and education partnerships with schools (grants, March 2015 & August 2019; notes, June 2020).

As we have come to better understand educational contexts and systems, we have incorporated this evolving orientation toward participatory approaches into our individually and collaboratively designed professional development (i.e. research interventions) for inservice and pre-service teachers (e.g. teaching, fall 2012, fall 2016, fall 2019, & spring 2019). Over time, we began to position teachers as experts during PD sessions to create co-learning opportunities for ourselves into our professional engagements with teachers. For example, LSM and AW co-designed a PD retreat for teachers and researchers across the USA in which we learned about the barriers and enabling factors to interdisciplinary STEM education and sought to understand the context within which teachers were teaching (teaching artifact, June 2016; pub., 2017). In another example, MB collaborated with other TEs and a local school district to acquire knowledge on how they might collaboratively address the district's ongoing STEM teacher shortage (grant, March 2019).

Further, for example, MB and LSM worked with a group of administrators and teachers at one school to evaluate their STEM programming and discovered that each stakeholder group (administrator, teacher, parent, and student) at the school defined “STEM” in different ways and had varied visions for STEM in their school (pub., 2014). Findings from this STEM definition study along with our individual experiences personally and professionally navigating through K-12 and university systems has informed numerous conversations around broadening participation in STEM—moving from discussions on recruitment into STEM (prof. doc., November 2014) to the impact of cultural systems that propagate inequities in STEM (teaching, fall 2018; prof. doc., January 2019; meeting notes, August 2019). Learning from each other’s experiences and the move toward a more collaborative approach with teachers and within schools has led to or informed the development of our teacher education research identities—shifting and (trans)forming toward more participatory teacher education research approaches, and research that explicitly bridges theory to practice for teachers.

STEM Education Researcher: Evolving Epistemological Orientations

Tensions centered on the concepts of STEM knowledge and knowledge production were central to identity (trans)formations for each of us. The tensions that arose from our various worldviews were not inherently problematic or troublesome within the CoP; rather, they moved us to consider various perspectives (notes, January 2014), ask one another questions to learn more (notes, November 2012), and re-examine our own epistemological orientations with heightened understanding of the worldviews of others (notes, April 2016). LSM’s and MB’s prior experience in post-positivist epistemological and methodological research paradigms was an asset for AW, as she was able to use their insights to navigate collaborations with disciplinary scientists and STEM teachers using an enhanced awareness of how they likely understood what “counts as” knowledge, and how it could be measured. Similarly, LSM experienced a disconnect between her post-positivistic lens, including what she considered “rigorous” knowledge production, and what was feasible when working with classroom teachers (notes, April 2012). Initially, LSM viewed teachers as research participants from whom she collected and analyzed quantitative data (grant, November 2012). AW and MB, with their experience as classroom teachers, challenged LSM’s research orientations and helped her reconcile the discrepancies that arose through conversations and collaborations around qualitative coding and data analysis (e.g. pub., 2014). CoP discussions also led AW to invite LSM to co-teach an action research course where she began to see teachers as researchers (teaching, fall 2016). Our discussions on the spectrum of participatory research (notes, May 2015) have led to LSM embracing participatory methods that include participants and co-researchers (pub., 2019). These same interactions helped MB identify her own ability to bridge different epistemic orientations by being “multi-lingual” in social and natural science methods as well as pedagogies and practices for effective science teaching (pubs., 2018 & 2018), and she now encourages mentees to engage in participatory research (grant, November 2017; pub., 2019).

Notes from several consecutive meetings include research questions that were drafted and rewritten amid ongoing discussions about what the comparison or control group would be, or if there even needed to be a comparison group (e.g. notes,

September, 2014; grant, November 2014). This orientation away from, and back toward, quasi-experimental designs is evidence of this tension around what constitutes valid knowledge production in educational research—from the more instrumental, with tight links to what is useful for those enacting change in schools, to conceptual research that is less tangibly connected to a specific application. An equally fundamental (trans)formation related to STEM educator identities and epistemic orientations can be seen in our evolving awareness of measurement tools, data collection strategies, and what types of outcome data were necessary in answering research questions (grant, March 2015; grant, August 2019). These have become decidedly more participatory, observational, or purely qualitative in nature (pubs. 2015, 2018, & 2020).

Disciplinary STEM Expert: Shifting Professional Roles

Over time, while we developed an identity as a community of STEM TEs, our individual identities and roles relative to the STEM disciplinary domains have shifted (Fig. 1). For each of us, the CoP was a respite from isolation we felt at various points on our professional trajectories. For example, when the CoP began, AW was in a teacher education department where the dominant culture associated TE professionalism with having an identity as a former teacher or school leader (notes, November 2014). As others have described teacher educators that identify in this way, their “attitudes to research are ambivalent or negative,” and they are disinterested in learning norms of higher education (e.g. Ducharme, 1993; Murray & Male, 2005, p. 127). While AW recognized opportunities for growth as a TE in this department, she identified as a TE researcher and was committed to becoming socialized into the culture of higher education by developing that professional identity (e.g. prof. doc., April 2015, November 2015, & December 2019). The CoP strengthened her resolve to achieve a tenure track position, and MB and LSM—each more enculturated into academia—encouraged AW to pursue a university position more aligned with her long-term goals. They offered advice on navigating the tenure-track job search process and hiring negotiations, and continue to provide insights into navigating the process toward tenure (prof. doc., December 2019).

Likewise, MB and LSM felt isolated from other disciplinary-based education researchers of whom there were few at their university (notes, November 2014). As with AW, both MB and LSM shared their CVs as they applied for other faculty and administrative positions. Drawing on collective knowledge, we supported one another as best as we could. For example, when LSM applied for positions, MB and AW gave feedback on her planned job talk to more effectively showcase LSM’s strengths (prof. doc., November 2013). In short, although we all identified our feelings of professional isolation, our CoP supported each person as they resolved these feelings. Although we all started in the same department, we are all in different departments or universities now that match our individual professional interests.

Teacher Educator: Disrupting the Status Quo

Concerned with reproducing status quo that perpetuate educational inequities in P-12 and university settings, each member of our CoP has a unique and evolving approach to disrupting non-inclusive policies, pedagogies, practices, and research approaches. Our distinct approaches to teacher education have (trans)formed, along with our TE

identities. We envision change that is achieved through a critical mass of educators who reflect upon and actively challenge systems and structures at all levels as they center the needs of their own students (notes, August 2018; teaching, fall 2018). We share what we learned about local, regional, and national contexts from our experiences in schools and classrooms to our PCK for TE by learning more about the prior knowledge of PSTs and teachers (Abell et al., 2009). Our individual and collective commitments to transformative science teaching through civic engagement have been strengthened by our CoP, where we have discussed using our formal TE roles to encourage preservice and in-service teachers to understand educational contexts and systems (e.g. notes, March 2015; grant, August 2019). This has allowed us to leverage these organizational systems for which we prepare teachers, so they can achieve agency to challenge the status quo once they are a part of them (pub., 2020).

Our commitment to disrupting the status quo is evident in both research and teaching. For example, LSM and MB, in a project with teachers, questioned the “STEM pipeline” analogy for the educational pathway for students into STEM fields that position STEM teachers *outside* of this pipeline rather than integral to an educational system that fosters comprehensive scientific literacy for an educated and engaged citizenry, as well as providing diverse and inclusive pathways into STEM professions (pub., 2014). Furthermore, AW and LSM (pubs., 2018, 2019, 2020) wrote about ways to engage STEM undergraduates in action-oriented pedagogies that have the potential to transform their perceptions of knowledge production. AW designs and teaches classes that specifically prompt action among PSTs around environmental justice concerns (pub., 2020; teaching, summer 2020), and has co-taught courses with elementary teachers. MB’s science pedagogy course (teaching, fall 2019) now includes new modules she created to help future teachers consider social justice issues in disciplinary contexts (e.g. teaching race in a genetics class, teaching about climate refugees in an environmental science class), and she recently designed a graduate course on inclusive pedagogy in the sciences (teaching, fall 2020).

Most importantly, our strong individual orientation toward STEM education as transformative is evidenced in the PD program co-developed by our CoP, where the overarching themes of all sessions promote authentic social justice while increasing STEM literacy (e.g. teaching, fall 2016 & spring 2019; grant, August 2019). This program emphasizes place-based STEM education, social justice, and active learning teaching practices (e.g. pub., 2019; grant, August 2019; teaching, fall 2017). Though the theme of the PD workshops was place-based education, we strived to frame this within the basic needs of PSTs and specific strategies for addressing inequities (meeting notes, April 2016 & August 2018). The student learning outcome goals centered on supporting novice teachers developing their competencies to both notice and support students who may feel minoritized or disenfranchised in public school settings (e.g. pub., 2019; teaching, spring 2019).

Our collaborations and discussions have continued to enhance our individual work. For example, most recently, MB has expanded her research working with two international non-governmental agencies to develop community and school-based partnerships. The goal is to increase environmental literacy in the Global South using place-based curricula that integrate locally important beliefs (pub., 2019). LSM has recently proposed the development of a regional community-based research center to promote university-community partnerships around

locally relevant science issues (notes, February 2019). AW is engaged in the development and implementation of a place-based curriculum to encourage student advocacy and activism around local environmental justice issues (teaching, spring 2020; pub., 2020).

STEM Educator: Refining Approaches to Research and Teaching

The different views represented among members of the CoP propelled us to consider our respective approaches to pedagogy and PCK for teaching STEM (Abell et al., 2009). Within our CoP, we engaged in reasoned arguments, not necessarily seeking consensus but to develop mutual understanding about the similarities and distinctions of various pedagogies (notes, May 2015 & June 2019). Our (trans)formations as STEM educators can be traced, in part, to our CoP and our commitment to sharing and problem-solving as we individually prepare for teaching, co-developing professional development or courses, and collaborating on STEM education writing projects such as grant proposals and manuscripts.

We have each moved toward more humanistic forms of teaching, especially those that challenge and aim to disrupt inequities (e.g. notes, March 2016; grant, 2019; pub., 2020; teaching, spring 2020). MB designed and is teaching a graduate course titled *Justice, Equity, Diversity, and Inclusion (JEDI) in Ecology* to help future ecology educators consider justice, equity, diversity, and inclusion issues (teaching, fall 2020; meeting notes, May 2020), and AW teaches a *Sustainability Science for Elementary Teachers* course to preservice teachers that foregrounds environmental justice issues and supports the development of action-oriented STEM pedagogies and practices (pub., 2020; teaching, fall 2019). Within our courses, there is a distinct trend away from didactic lectures with periodic engagement activities with students in community-based work, characterized by participant-driven agendas and co-constructed curricular changes made with students (e.g. teaching, spring 2013, fall 2016, & spring 2020).

Initially in our collaborative proposals, the emphasis was on promoting student interest and building engagement, which we assumed would lead to P-12 student motivation to study STEM (grant, December 2012). After some time, we began describing the importance of establishing relevance (e.g. through the integration of lessons on socioscientific issues) for students as a way to enhance conceptual understanding (grant, March 2015). Socioscientific issues are those for which there are no clear right or wrong answers, but for which multiple types of knowledge (e.g. natural science, social, and moral) are used to understand the complexity of the issue (Balgopal and Wallace, 2013). Ultimately, there was a decided shift toward the use of pedagogies that engage diverse students around topics of personal relevance that may promote feelings of civic engagement (pubs., 2013, 2017, & 2020). Although using context and place as starting points has long been advocated in STEM teacher education (Settlage & Southerland, 2007), we moved toward a focus on how to engage learners and value various types of knowledge (notes, February 2015 & June 2019). We shifted our respective teaching by positioning community knowledge and understanding as valuable, and where western and traditional (e.g. cultural funds of knowledge) are not seen as in opposition but are complementary (e.g. pub., 2017, 2018, & 2019).

Discussion and Implications

Independently and collectively, we used the CoP and figured worlds frameworks to analyze our data. Through this process, we explored the constellation of attributes, beliefs, values, motives, and experiences that form our identities to describe the evolution of our multifaceted professional identities as STEM TEs as we engaged in our CoP. In the same vein, we identified themes that captured how our respective emergent identities were shaped by our participation in a TE researcher CoP.

Although our results show how our identities evolved and emerged over time within the context of our CoP, our own TE PD was not formally guided by a specific model, such as those described by Kelchtermans et al. (2018). In this paper, we highlighted TE-driven professional development is common, primarily centers of the shift from that of P-12 teacher to TE, and rarely delves into the research orientations or research-related behaviors of TEs. To further efforts by other TEs to develop and sustain STEM TE research CoPs that can promote growth across STEM TE domains, we posit four necessary attributes: (1) identify points of intersection, (2) nurture existing and emergent identities, (3) adopt practices that support shared meaning making, and (4) make time for reflective and reflexive discussions.

The process of coming together as a CoP was iterative—we came together as a writing group because each of us had a STEM TE identity, read one another's writing, and then began collaborating and cowriting. The process of co-constructing became an integral part of our CoP. For example, even before the ability to co-write on web-based platforms, we projected documents from one computer onto a screen or huddled around a single large monitor so we could collaboratively make meaning and generate ideas. Because we drew on different knowledge and perspectives, which others in the CoP valued, we saw this as an added value of our collaborations. In the process, we were able to support one another through professional transitions and likely will continue to do so.

Identify Points of Intersection

Within a CoP, learning and meaning making comes from a sense of belonging, which is more likely to emerge after identifying points of intersection (Wenger, 1998). Unlike many TEs who struggle to find a research identity (Loughran, 2014), we each already identified as TE researchers. Like other TEs, though, we felt the need for connectedness and the need to be a part of a community (Hug & Moller, 2005; Williams & Ritter, 2010), which our CoP provides. Within our CoP we find a sense of solidarity because of shared feelings of isolation within our academic positions, shared personal commitments to family, and a shared drive to succeed professionally. Finding commonalities continues to inspire us to find professional points of intersection.

We realize, in retrospect, that the trust we had in one another, an emergent property of our team, allowed us to compliment others on their competencies, rather than to critique our own sense of shortcomings (Ilgen, Hollenbeck, Johnson, & Jundt, 2005; Simons & Peterson, 2000). We are a community of women who openly discuss personal and professional concerns regarding education and academia. Advocacy for one another has a meaningful impact on our professional and personal lives. Although we did not collect discourse dynamics data for analysis, we surmise that our single-

gender team engaged in engendered norms of communicating (e.g. acceptance of interruptions and verbal acknowledgements of other's contributions) that allowed us to more quickly build trust in our interactions with one another (Eckert & McConnell-Ginet, 2013). While this study is focused on our professional identities, our respective TE identities are a product of overlapping personal and professional identities (Hökkä et al., 2017). Having children helped our group become more flexible with deadlines and shifting workloads. Even as we co-wrote this paper, we faced the challenges of one member undergoing treatment for breast cancer, two members simultaneously supporting the remote learning of young children while continuing to work, and all of us responding to social and personal accommodations relating to the global COVID-19 pandemic. Yet, because we decided explicitly to integrate personal, social, and professional discourse, our CoP has stayed intact and productive.

Nurture Existing and Emergent Identities

The CoP helped each member to articulate her aspirations as goals. Professional learning and development occurred in a variety of situated contexts as we brought knowledge and understanding from other CoPs. Although the three of us experienced shifts to our epistemological orientations and approaches to teaching, these changes and development were somewhat stochastic, which can occur in long-term partnerships, particularly when participants are at various points in their career or identity development (John-Steiner, 2000). In discussing a shared vision, we acknowledge individual strengths, contributions, and abilities, coupled with new perspectives and qualities of successful teams (Ilgen et al., 2005; Kozlowski & Klein, 2000). Our transformations as TE researchers are ongoing. We continue to move closer to what we want to do: to affect change, to encourage others to understand who students are and what they can do, and to improve how future teachers are prepared to become agents of educational change. As our epistemic orientations, approaches to teaching, understanding of the systems and structures of educational systems have changed, so too have our commitments to our own professional paths and identities in STEM teacher education. All of us have moved into mentorship positions to help novice TE researchers as they work through balancing multiple identities (Hall & Burns, 2009). Not surprising for us, it was through the writing of this paper that we were able to see the value in explicit acknowledgement of each domain and how we can articulate this to our mentees.

Adopt Practices that Support Shared Meaning Making

Our CoP has been meeting regularly since 2012. Quality PD is ongoing and continuous (Guskey, 2002), and within our CoP, we have engaged in discussions around disciplinary content knowledge for teaching, knowledge about disciplinary science, as well as science methods curriculum, instruction, and assessment, and knowledge of teachers' understanding of science and science teaching—also described as PCK for teacher educators (Abell et al., 2009). While our individual identities were influenced throughout our CoP engagements, both through our own CoP and our boundary encounters with other figured worlds, our collective CoP identity developed most tangibly when we had a shared vision that we consciously allowed to evolve over time (John-Steiner, 2000). We navigated potential ontological and epistemological divides

between teacher educators and P-12 teachers. Ultimately within our CoP, teachers were framed in the same way we frame students (i.e. undergraduate, P-12)—as capable and agentic (Van Driel & Berry, 2012).

We recognized tensions during our discussions of STEM education, and when we did not address these differences, usually one of the members would challenge our group to articulate why we were not progressing. This process, though uncomfortable at times, required that we ultimately recognize the value of the CoP in the short and long terms and was grounded in our trust for one another (Preece, 2004). Furthermore, we found that a strong shared vision—our passion for TE, while improving the competencies of novice teachers—helped us refocus our efforts. For TE research-focused CoPs that have distributed leadership like ours, explicit efforts to identify shared visions and address tensions during collaborations are paramount, as this can strengthen their ability to understand and support teachers (MacBeath, 2005; Pearce & Ensley, 2004).

Make Time for Reflective and Reflexive Discussions

Although our CoP formed organically, we willingly navigated tensions while we identified our individual and collective objectives because we set time aside for such discussions (Paulus, Woodside, & Ziegler, 2010). This required all three of us to be not only flexible with our CoP but to recognize the value of professional humility—being open to engaging in self-reflection and critique (e.g. Tervalon & Murray-García, 1998). At each meeting we begin with negotiating our professional interests in general before we tackle more task-oriented action items. This allows us to regularly be cognizant of how we might generate new knowledge and push ourselves to be innovative (Wenger, 1998). In this way, we have allowed our individual and collective identities to be shaped by our CoP, in part, because our method of collaborating is so enmeshed with one another, it is not always clear to us when or where an idea originates. Because our PLC operated in a shared space and time, we could use the time to co-construct ideas to foster collective meaning-making, including, for example, how we should respond to reviewer comments (Bazerman, 1997; Myers, 1990). We are reflexive educators and researchers who confront discrepant ideas and approaches among ourselves, our figure worldviews, and across our regional educational systems. This requires us to challenge one another in respectful ways and to be good listeners. Our joint ventures have become more clarified as we aim to collaboratively address issues in STEM teacher education that we have recognized as problematic. As a result of this general approach to meetings, we believe we have become more innovative TE researchers.

Conclusion

Wenger (1998) identified three criteria necessary for a long-term functioning CoP. Our CoP met these criteria, and in addition, we identified additional attributes (i.e. identifying points of intersection, nurturing identities, sustained commitment, flexibility) that allowed our separate figured worlds to catalyze within the CoP as mutual trust in our joint enterprises (Hökkä et al., 2017). The figured worlds framework enabled us to explore how we socially constructed knowledge, developed our beliefs and

competencies, and subsequently identified the emergent aspects of our CoP that have allowed us to persist as we developed as TEs. We offer our experiences as an example of how the figured worlds lens can be used to understand how a CoP can impact curricular approaches and teacher PD, imploring members to push out of their comfort zones into new innovative spaces. Creating an environment that is supportive of growth, even when it held the potential to spatially and temporally separate us, as it eventually did, has allowed our TE researcher identities to grow and transform.

Our identities as teacher educators and researchers have evolved, allowing us to support STEM preservice and in-service teachers differently than we did almost a decade ago. We have experienced shifts in our epistemic orientations. Our understanding of the systems and structures of educational systems across the USA has evolved. We have acquired skills to enhance our pedagogical practice and have each experienced change in our roles relative to teacher education. While some shifts have been profound and others more subtle, they have collectively had a substantial influence on our identities. We attribute the value of our CoP to our professional lives to discussions about intersectional interests, our sustained commitment to collaboration, our recognition of our existing and emerging identities, and our willingness to be flexible. Although no two CoPs are identical, we encourage our TE researcher colleagues to engage in meaningful CoPs and take stock of how that community can help members transform professionally to push the agenda of STEM TE research in timely and meaningful ways that improve P-12 education.

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