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Science identity and metacognitive development in undergraduate mentor-teachers



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Abstract

Background: A growing part of the efforts to promote student engagement and success in undergraduate STEM are the family of Student Support and Outreach Programs (SSOPs), which task undergraduate students with providing support and mentoring to their peers and near-peers. Research has shown that these programs can provide a variety of benefits for the programs' recipients, including increased academic achievement, satisfaction, retention, and entry into STEM careers. This paper extends this line of inquiry to investigate how participation in these programs impacts the undergraduate STEM students that provide the mentoring (defined here as undergraduate mentor-teachers or UMTs). We use activity theory to explore the nature of metacognition and identity development in UMTs engaged in two programs at a public urban-serving university in the western USA: a STEM Learning Assistant program and a program to organize middle and high school STEM clubs. Constructs of metacognition and identity development are seen as critical outcomes of experiential STEM inreach and outreach programs.

Results: Written reflections were collected throughout implementation of two experiential STEM inreach and outreach programs. A thematic analysis of the reflections revealed UMTs using metacognitive strategies including *content reflection and reinforcement* and *goal setting* for themselves and the students they were supporting. Participants also showed metacognitive awareness of the *barriers and challenges* related to their role in the program. In addition to these metacognitive processes, the UMTs developed their science identities by attaching different meanings to their *role as a mentor* in their respective programs and setting *performance expectations* for their roles. Performance expectations were contingent on pedagogical skills and the amount and type of content knowledge needed to effectively address student needs. The ability to meet students' needs served to *validate* and verify UMTs' role in the program, and ultimately their own science identities.

Conclusion: Findings from this study suggest that metacognitive and identity developments are outcomes shaped not only by undergraduate students' experiences, but also by their perceptions of what it means to learn and teach STEM. Experiential STEM inreach and outreach programs with structured opportunities for guided and open reflections can contribute to building participants' metacognition and enhancing their science identities.

Keywords: Experiential, Inreach, Outreach, Metacognition, Identity

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Introduction

According to the President's Council of Advisors on Science and Technology, the USA workforce will employ an additional one million STEM (Science, Technology, Engineering, and Mathematics) professionals within this decade (PCAST (President's Council on Science and Technology), 2012). Roughly 42% of jobs in STEM fields require at least a bachelor's degree in STEM (Wang, Chan, Soffa, & Nachman, 2017), but recruitment and retention of STEM undergraduates remains a multifaceted challenge for most 4-year universities in the USA (American Association for the Advancement of Science, 2011, 2019). The National Science and Technology Council (Holdren, Marrett, & Suresh, 2013) and numerous other entities have identified that any solution to these challenges will hinge on systemic efforts to improve STEM education. Such improvements include classroom interventions, such as an increased implementation of active learning (American Association for the Advancement of Science, 2019), student support services, such as individual or group tutoring (Topping, 1998) or peer inreach programs (e.g., supplemental instruction, Learning Assistant programs), and rich K-12 STEM outreach opportunities. Of these, peer inreach and K-12 STEM outreach programs are increasingly recognized as crucial elements of the STEM pipeline to and through the undergraduate degree (Augustine et al., 2005; Chubin, Donaldson, Olds, & Fleming, 2008; Pierre & Christian, 2002).

This paper is focused on academic support and enrichment programs that task undergraduate students with providing academic support and mentoring to their peers and near-peers. In peer *inreach* programs, undergraduate students provide support and mentoring to undergraduate peers or near-peers at their home university. In K-12 *outreach* programs, undergraduate STEM students act as coaches and mentors that facilitate activities and explorations for K-12 students within their communities. We collectively refer to inreach and outreach programs as Student Support and Outreach Programs (SSOPs).

Both of these classes of SSOPs have been shown to be beneficial for the participants (i.e., having positive impacts on the students that *receive* the mentoring or coaching) (Aschbacher, Li, & Roth, 2010; Hayden, Ouyang, Scinski, Olszewski, & Bielefeldt, 2011; McGee-Brown, Martin, Monsaas, & Stompler, 2003; Otero, Finkelstein, McCray, & Pollock, 2006; Pollock & Finkelstein, 2013; Sahin, 2013; Talbot, Hartley, Marzetta, & Wee, 2015). However, there is a relative dearth of research on the experiences and benefits to the undergraduate students that *provide* the mentoring or coaching. This might be attributed to the assumption that mentors or coaches are intrinsically motivated to engage in these activities, e.g., this work validates and supports their interests in the subject. We define the undergraduate students that provide support to either

their peers or K-12 students within an SSOP as undergraduate mentor-teachers (UMTs). In this paper, we explore the experiences of a diverse sample of UMTs across two SSOPs in order to identify and compare potential benefits for UMTs within and across these programs.

Undergraduate mentor-teachers

The UMTs in this study were participants in one of two SSOPs at a mid-sized public urban-serving university in the western USA: The Learning Assistant (inreach) program or the Community STEM Clubs (outreach) program.

The learning assistant (LA) program is a nationwide peer inreach program in which undergraduates provide in-class support and mentorship for peers and near-peers in undergraduate STEM courses (Otero, 2006). Learning assistants (LAs) are undergraduate STEM students who have previously succeeded in the course that they support and have an interest in teaching or otherwise supporting the learning of their peers (Otero et al., 2006). LAs are trained to guide students through in-class activities and provide student-specific support (Talbot et al., 2015). At our institution, all first time LAs take a two-credit course through the School of Education where they learn about educational theories and effective, research-based pedagogies relevant to teaching and learning in undergraduate STEM (Table 1). See Thompson et al. (2020) for the course syllabus. LAs attend all class sessions for the courses they support and generally hold weekly office hours and/or study groups.

The Community STEM Clubs (CSC) Program is a K-12 outreach program in which undergraduate STEM students, designated CSC fellows, develop and facilitate in-school or afterschool STEM clubs or teams at a local middle or high school (Ferrara et al., 2018). Fellows work in interdisciplinary teams of two to three undergraduates and receive support from faculty mentors and the lead teachers in their host schools. Fellows also participate in a one-credit hour STEM Communication course focused on understanding and improving STEM communication in a changing global society (Table 1). See [supplementary information](#) and Table S1 for the course syllabus. The course is intended to dually support the design and refinement of effective outreach activities and to nurture the fellows' growth in communicating STEM to diverse audiences of all ages. The course is led by faculty from the CSC program team and considers multiple modes of communication, including popular science writing, videos, podcasts, museum displays, and children's toys.

Both the LA and CSC programs at this university were supported by multi-year grants funded by U.S. National Science Foundation (NSF) and have since been institutionalized through a variety of ways, albeit in different forms. For example, STEM outreach programs with K-

Table 1 Learning assistant pedagogy and STEM clubs communication course information

	LA pedagogy course	CSC STEMmunication course
Credit hours	2	1
Department offering course	School of education and human development	Interdisciplinary studies (arts and sciences)
Instructors	Faculty and/or PhD students	Faculty
Topics	Questioning, listening, assessment, metacognition, activity development	Written and visual science communication, audio and video communication, communicating in informal settings, social media
Major assignments	Development of active learning assignment for students, reflection on implementation of activity, reflection on the overall LA experience	Creation of table-top and long-form outreach activities, implementation of designed activities

12 schools exists at smaller scales, and the STEM Communication course has been offered to students outside the scope of the NSF grant. We have a prior publication (Ferrara et al., 2018) that describes the impact of SSOPs on UMTs experiences, but it did not specifically explore areas of overlap and synthesis between science identity and metacognitive development. The UMTs in both LA and CSC SSOPs meet regularly with presiding faculty to reflect on and discuss the challenges and successes they encounter in their UMT roles. These meetings and group discussions within the LA and CSC training courses provide multiple opportunities for UMTs to reflect on their experiences within each SSOP. These reflections are a natural and rich source for gaining understanding of what it is like to be a UMT and how being a UMT is valuable for the STEM undergraduate experience and can also promote metacognitive growth. This body of research presents the first step towards understanding the experiences and potential benefits STEM UMTs gain from participating as a mentor to either their peers or younger students within SSOPs. By focusing on UMTs engaged in both inreach (LAs) and outreach (CSC fellows), we are able to analyze a wide variety of experiences from a diverse population of participants.

In this paper, we are interested in two constructs that may better inform and explain the experiences of STEM UMTs: science identity, which is broadly how the UMTs view themselves as scientists, engineers and other STEM professionals, and metacognition, which is broadly how the UMTs think about their own thinking, problem solving and general cognition. Accordingly, our research question is the following: what metacognitive and identity development processes are evident in undergraduate students’ efforts to facilitate SSOPs?

There is strong evidence that UMTs self-reported increases in STEM content knowledge and interest in STEM career choices may be linked to their metacognitive growth and development of a strong science identity (Carpenter, 2015; Nelson et al., 2017). And although the UMTs in this study are typically seen as already successful students, it is worth looking into the potential benefits they may experience as mentor-teachers in order to more fully understand the processes that aid in their individual

and continued success in college, STEM retention, and matriculation. In our study, the population of UMTs engaged in the SSOPs under consideration is more diverse than the population of STEM majors as a whole. This aligns with research that indicates that students from underrepresented populations are often overrepresented in outreach efforts (Thiry, Laursen, & Liston, 2007). This phenomenon adds additional value to understanding the experiences of UMTs, as these programs have the potential to serve as conduits for equity within undergraduate STEM, and therefore the STEM workforce.

Framing the study

The LAs and CSC fellows in this study are part of separate (though similar) communities, which results in complex systems and interactions. What is needed is a framework which can help explain the experiences of LAs and fellows in relation to identity and metacognition across different socio-cultural landscapes. For this, we rely on the metatheoretical framework of Cultural Historical Activity Theory or CHAT (Engeström, 1987, 2001). In this paper, we use the term “STEM” when discussing the SSOPs, as one of our programs involves technology and engineering, and both of the programs involve science and math. We use the term “science” when discussing the construct of identity, because our framing of identity is based specifically on the literature around *science* identity.

Theoretical framing: cultural historical activity theory

The larger STEM community in which the SSOPs in our study operate are historically and culturally bound by discipline and structure, which influence (if not determine) how many of the interactions take place. CHAT helps us make this explicit. More importantly, it causes us to focus on the tensions and interactions between parts of a complex *activity system* (see Fig. 1).

In this system, the subject > object > outcome space could be interpreted from a purely cognitive perspective in the sense that the subject (a UMT) receives some treatment or exposure (engagement in the LA or CSC program), after which we characterize or measure the object of interest (development of science identity and metacognition) in some

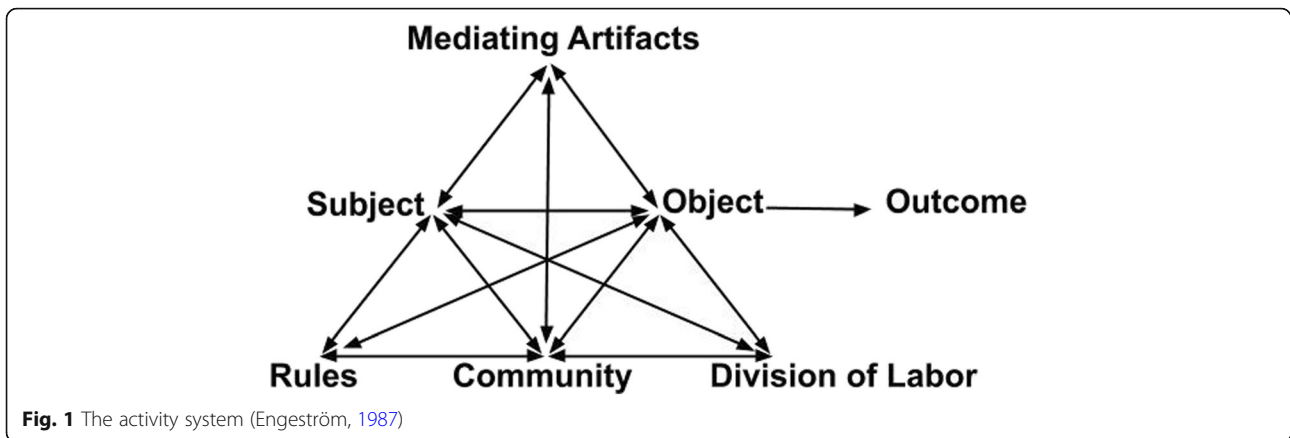


Fig. 1 The activity system (Engeström, 1987)

measurable way (the outcome). However, in a complex environment such as those in which our UMTs work, these cognitive processes are mediated by many other factors (shown as the vertices in Fig. 1). In the activity system, these factors include mediating artifacts (e.g., texts, modes of representation, manipulatives, etc.), rules, and norms of behavior (e.g., taking notes, listening, engaging in discourse), division of labor (e.g., how community members interact, how they learn), and community (e.g., the actors themselves). To the activity theorist, the primary reason to take this systems approach is to shift the focus to the interactions between these factors, and how those interactions change as the system is perturbed. All of these interactions are historically and culturally bound by the nature of the discipline in which the UMTs are working (e.g., biology) and by the structures in place surrounding and defining their community (e.g., higher education progress towards degree, “traditional” schooling).

Unlike much of the research conducted on similar SSOPs that focus solely on the knowledge or skills gained (the object) for the students within these communities, this study instead focuses on what specific members of complex activity systems (the UMTs) do and gain from their participation as mentors. We posit that this growth comes through enacting and shaping the rules, engaging in the community, shaping the division of labor, and designing and working around the mediating artifacts in our activity system.

From an activity system point of view, UMTs have specific and unique roles that impact the communities and the systems in which they exist. For this study, we were interested in how these unique roles and positions of the UMTs impacted the outcomes UMTs experience. By looking at an activity system from the UMTs’ perspectives, we were able to hone in on specific outcomes, science identity and metacognitive development, that are shaped by their perceived roles and participation in these systems.

Science identity

Identities are developed and shaped by different experiences influencing how we perceive and relate to the world around us. Identity theory states that our identities are filled with meaning based on how we perceive our roles as an individual and within the larger cultural groups we are part of within society (Burke & Stets, 2009). An individual person holds multiple identities, and each identity is attributed a specific set of meanings. Science identity is one identity that science students may hold to varying degrees depending on the situation. Carlone and Johnson (2007) developed a model with three components that contribute to a strong science identity: performance, recognition, and competence. Within this model, a person will identify as a scientist if they act, think, and explore like a scientist (i.e., use scientific vocabulary, tools, and think about the world from a scientific standpoint). Additionally, they are regarded as a “science-person” that “demonstrates meaningful knowledge and understanding of science content” (Carlone & Johnson, 2007, p. 1190). Thus, science identity operates as a feedback loop between a person acting, thinking, and exploring like a scientist, and then others understanding that meaning and reinforcing that identity back to the original person (Carlone & Johnson, 2007; Stets, Brenner, Burke, & Serpe, 2017). Science students with a strong science identity have been shown to have a higher interest in science, go on to pursue scientific careers or graduate degrees, and act in ways that others also perceive them as scientists outside of school (Merolla & Serpe, 2013; Stets et al., 2017).

A unique aspect of our study is that it questions the assumption that mentors or coaches intrinsically hold a science identity that is consistently verified and reinforced as a result of engagement in SSOPs. While this may be the case, it is important to understand if and how this happens in complex systems. Engaging in science activities in post-secondary education has a direct influence not only on retention in STEM careers, but

also the science identities of undergraduate students (Merolla & Serpe, 2013; Stets et al., 2017). Aspects of science identity, including positive associations with and intent to persist in STEM, have been shown in undergraduate students participating in STEM enrichment programs (Merolla & Serpe, 2013). In these and similar programs, students provided with opportunities for research, mentorship from faculty, and a supportive peer network of STEM-minded individuals maintained a commitment to their science identities over time (Carlone & Johnson, 2007; Hunter, Laursen, & Seymour, 2007; Lee, 2002).

Metacognition

Metacognition, often described as “second-order” cognition, thinking about thinking, or reflections upon one’s actions has been shown to play a crucial role in successful learning. Activities such as planning how to approach a given learning task, monitoring comprehension, and evaluating progress toward the completion of a task are metacognitive in nature, and contribute to successful problem-solving in STEM learning contexts (Schoenfeld, 1987). Flavell (1979) defined two key aspects of metacognition: metacognitive knowledge and metacognitive regulation. Metacognitive knowledge refers to any acquired or stored knowledge a person has regarding how they learn and process new information. Metacognitive regulation refers to how an individual reflects on and assesses their learning, knowledge, or comprehension. This assessment may be a fleeting moment or a lengthy internal reflection and is subjective to the individual regarding cognitive elements such as content, goals, or strategies (Flavell, 1979). Reflection is especially important when connecting new information with knowledge previously attained, which aids in the individual’s learning process. Flavell explains:

Metacognitive [reflections] are especially likely to occur in situations that stimulate a lot of careful, highly conscious thinking: in a job or school task that expressly demands that kind of thinking; in novel roles or situations, where every major step you take requires planning beforehand and evaluation afterwards; where decisions and actions are at once weighty and risky...Such situations provide many opportunities for thoughts and feelings about your own thinking to arise. (Flavell, 1979, p. 908)

Thus, metacognitive reflection is theorized to be a major part of one’s learning process, as the learner contemplates their level of comprehension of both new and old content in order to complete tasks and goals.

In our framing, metacognition is positioned as an important construct that student mentors use and

experience when mentoring. Metacognitive knowledge and reflection have been shown to be critical in the transfer of knowledge or learning (Pintrich, 2002). Accordingly, reflecting upon and understanding one’s own comprehension of content, strategies for problem solving, and cognitive processes are crucial in a teaching or mentoring role. The student mentors in the present study are positioned to teach complex scientific skills and content to the students they mentor. As such, these student mentors often think about how they themselves understand these concepts and skills in order to turn around and explain these concepts and skills to students.

Despite the plethora of research conducted on metacognition and science identity, the characterization of metacognition and science identity development in experiential inreach and outreach contexts is largely understudied. This study explores the nature of these processes as expressed through written reflections by students participating in STEM inreach and outreach programs.

Methods

This study explores the metacognitive and identity development processes of 20 undergraduate students engaged as UMTs in two experiential STEM SSOPs at a mid-sized public urban-serving university in the western USA. UMTs were part of either the learning assistant program or the Community STEM Clubs program. Both SSOPs are part of National Science Foundation funded studies that examine the impacts of different STEM SSOPs on undergraduate students’ content knowledge, metacognition, problem solving, communication, and pedagogical skills (Ferrara et al., 2018; Talbot et al., 2015). These two programs were not intentionally designed together. Rather, they represent complementary efforts to improve undergraduate learning in STEM disciplines on the same campus, thereby providing a unique opportunity to study program impacts on a broader scale.

Each SSOP is set in the context of a STEM-based program where undergraduate students are tasked with preparing and teaching STEM content to audiences in middle and high school or college. At the start of these programs, all undergraduate students were enrolled in a STEM program of study and recruited by faculty based on their expressed interest and consistent involvement in STEM. Table 2 shows the demographics, majors, and program participation of all 20 UMT participants in this study. Anonymity is maintained with pseudonyms for all students, adults, and schools.

Data collection

UMT reflections from their respective SSOP training courses were used as data sources for this study. Data collection for the LA program consisted of 14 reflections

Table 2 Sample of SSOP participants

Undergraduate student	Program	Major	Gender	Race/ethnicity
Fellow1	CSC fellow	Mathematics	Female	Hispanic/Latino
Fellow2	CSC fellow	Mechanical engineering	Male	Asian American
Fellow3	CSC fellow	Biology	Female	Hispanic/Latino
Fellow4	CSC fellow	Mechanical engineering	Female	White/Caucasian
Fellow5	CSC fellow	Bioengineering	Female	White/Caucasian
Fellow6	CSC fellow	Biology	Female	White/Caucasian
Fellow7	CSC fellow	Mechanical engineering	Female	Black/African American
Fellow8	CSC fellow	Electrical engineering	Male	White/Caucasian
Fellow9	CSC fellow	Mathematics, Biology, English, Psychology	Male	White/Caucasian
Fellow10	CSC fellow	Psychology, Economics	Female	White/Caucasian
LA1	LA	Biology	Female	White/Caucasian
LA2	LA	Physics	Male	White/Caucasian
LA3	LA	Biology	Male	Black/African American
LA4	LA	Biology	Female	White/Caucasian
LA5	LA	Chemistry	female	White/Caucasian
LA6	LA	Biology	Female	Asian American
LA7	LA	Biology	Female	White/Caucasian
LA8	LA	Math	Male	White/Caucasian
LA9	LA	Chemistry	Female	Asian American
LA10	LA	Biology	Female	Asian American

completed over a 16-week semester. LAs were given 15 min at the end of class each week to complete a reflection, and received participation points for submitting a reflection each week. CSC fellows completed 11 reflections over two 16-week semesters. Reflections were submitted monthly for participation credit in the STEM Communication course.

The reflection prompts for both programs were specific to the goals of each program and course, but were open ended and allowed for the student to elaborate and expand beyond the prompt. For instance, the reflection prompts for the CSC program focused on summarizing their planning and activities and solicited Fellows' thinking about how their work impacted their thinking or practice surrounding their role in their program, their STEM content knowledge and communication skills, and their ideas of STEM as a discipline. The reflection prompts for the LAs focused on their experiences serving as an LA for a course in which they had previously completed, engaging with their peers and probing their thinking and mental models, and the practice of teaching. Reflection prompts in both programs were intentionally designed to elicit deep reflection on the SSOP experience, before moving to more open-ended responses. Following a sequence of deep to open-ended reflection allowed for LAs and CSC Fellows to first practice identifying, accessing, and

articulating their thought processes and feelings about specific events related to their experience.

Methods for data analysis

Written reflections from the 20 LAs and CSC fellows were first anonymized and then coded using methods of constant comparison (Creswell, 2003). The coding process was theory-driven, with the framework for metacognition arising from Schraw (1998) and the framework for identity arising from Burke and Stets (2009) and Carlone and Johnson (2007). Two researchers affiliated with the project first worked independently to identify pieces of data fitting within the constructs of metacognition and identity development in reflections from three LAs and three CSC fellows. The researchers discussed codes that emerged within metacognition and identity constructs and their general observations. The two researchers came to an agreement on codes within the metacognition and identity constructs and then applied these codes to all 20 cases in a second round of coding. After the two researchers coded all 20 cases independently in this second round of coding, they met together with a third researcher (who had not coded any of the data) to confer and come to consensus on their codes. In this way, a moderation and consensus process (rather than independently working researchers rating for reliability) was used to develop the final coding

scheme (Harry, Sturges, & Klingner, 2005; Saldaña, 2015). The final coding scheme was applied to the entire sample for thematic analysis of the metacognitive and identity development processes observed across all cases. In total, six themes were built out and refined by the multiple iterations of coding and reviewing the extant literature. See Table 4 in Appendix for the codes and how they map onto the six themes.

To validate codes and further support the six developed themes, a key-words-in-context (KWIC) analysis technique was employed (Fielding & Lee, 1998; Leech & Onwuegbuzie, 2007). Keywords from the reflections were identified based on the codes and themes, as well as terminology and discourse commonly used in metacognitive and identity constructs. MAXQDA text analysis software was used to perform separate lexical searches of all keywords related to metacognition and identity. Once a list of keywords in their surrounding context was generated, the final coding scheme was applied and accuracy of the researchers' interpretations was checked against the context of how each word was used. After reviewing and reaching an agreement on the themes, consideration was given to how each theme fits into the story of the metacognitive and identity development processes happening across LAs and CSC Fellows in both programs. These six themes are not meant to be mutually exclusive, as we recognize that the development of science identity and metacognition are deeply entwined.

Results

Through our analysis, we identified three themes of science identity development and three themes of

metacognitive development experienced by our sample of LAs and CSC fellows within their respective roles as UMTs in our activity system (Table 3).

Identity development

The STEM SSOP experiences in this study serve as the interdisciplinary medium through which identities are developed and expressed. Specifically, the UMTs' varied roles, along with division of labor, rules, and norms within the activity system, served to support the development of science identity. Three emergent themes indicate a developing science identity: (a) claiming a role and attaching meaning to it, (b) setting performance expectations, and (c) feeling validated. These themes speak to the UMTs' recognition of the specific roles they play within their STEM SSOP.

Identity operates as a function of agency and structure. By claiming roles in their SSOPs, LAs and CSC fellows are acting as agents in the development of their science identities. There was a wide range of roles claimed across both LAs and CSC Fellows. Each role claimed by an LA or CSC Fellow during their SSOP experience is attached to a set of meanings and standards for operating within the role. The meanings for any role are acquired in the interactions and reactions of others, internalized as part of the self, and manifest in actions taken by the UMT. In most cases, LAs and CSC fellows perceived themselves as a people who guide and share knowledge with others (i.e., students). The roles UMTs claim and the meanings attached to those roles dictate the expectations for their actions, or performance, in their role within the SSOP experience.

Table 3 Themes of science identity and metacognitive development in UMTs

Theme	Thematic definition
Science identity development	
Claiming a role and attaching meaning to it	LAs and CSC fellows developed different meanings for what they perceived to be their role in the program. An LA or fellow describes who they are in the program.
Setting performance expectations	LAs and CSC fellows developed a set of expectations for themselves and engaged in actions consistent with their perceived role in the program. An LA or fellow describes actions they view as important for who they are in the program
Feeling validated	LAs and CSC fellows developed legitimacy for their role in the program by seeking appraisal and validation from others. An LA or fellow describes feelings of competence or incompetence associated with who they are and what they do in the program.
Metacognitive development	
Content reinforcement/learning	LA or fellow re-evaluates their level of understanding of the content which they are teaching to mentees/students. Content may be completely new or revisiting for the first time in many years. LA or fellow reflects that re-evaluating their knowledge of this content has helped them relearn or deepen their understanding of this content.
Identifying and overcoming barriers and challenges	LAs and CSC fellows acknowledge a perceived lack of confidence in their own knowledge of content, ability to articulate an answer or explanation to students (communication) or ability to build relationships with the students they mentored.
Goal setting within the program	LAs and CSC fellows set goals for themselves often pertaining to developing their teaching strategies, motivating students to be more involved during mentoring sessions, and improving their own communication with mentees.

Theme 1: attaching meaning to the role of LA or fellow

LAs and CSC fellows claimed different roles at multiple points throughout their SSOP experiences. Defined broadly, a role describes a social position that an individual occupies in a group or culture. That position is in turn shaped by the division of labor within the activity system, which is related to other elements in the system, and the interactions between those elements. In this study, we define a role as the different positions UMTs perceive that they occupy during their SSOP experience. It is important to reiterate that because these roles are set in the context of a STEM experience, we classify them as roles related to a science identity. As the UMTs progressed through their SSOP experience, they positioned themselves in different capacities relative to others in the program. In most instances, the UMTs claimed roles describing relationships with their students. We coded for the roles the UMTs made explicit in their reflections, as well as instances we interpreted from implicit claiming of a role. From this process, we found evidence of LAs and CSC fellows claiming the roles of teacher, collaborator, mentor, guide, peer, expert, facilitator, leader, and student. These self-proclaimed roles indicate that these UMTs saw themselves as more experienced community members that were capable of transferring their STEM knowledge to others.

Perhaps the most telling aspect of the roles claimed by the LAs and CSC fellows are the words used to describe the role of teacher. Across the entire set of reflections, LAs and CSC fellows overwhelmingly used the word “student” as a descriptor for the individuals they were mentoring. We perceive “student” to be a counter-role of “teacher,” making this a dominant role claimed by all UMTs. For example, Fellow8 repeatedly referred to the students participating in the outreach program as his students: “More importantly, I see now what an effect that had on my ability to communicate with my students” (Fellow8). This Fellow also refers to these students as his tenth graders in a number of reflections: “Now, I ask myself “how would I teach this to my 10th graders”? (and yes, they are *MY* tenth graders); “My 10th graders are smart, but they haven’t had the classes I’ve had.” (Fellow8). By referring to these students as his students and his tenth graders, Fellow8 explicitly is taking on the role of their teacher or knowledge broker. Fellow6 also refers to the students participating in the outreach program as her students: “I helped my students make solar cars. They each had jobs: ‘OK, you’re building the chassis, you’re building an axle, you’re building the body’” (Fellow6). Similarly, LA3 said in a reflection about a review session held outside of class: “It was a time for me to really show my knowledge of the material and connect with my students.” (LA3). This indicates that although LA3 is technically a peer to the students

he is an LA for, he views them as his students, further showing how UMTs often claim this role of teacher within their peer mentoring roles.

LA3 also reveals his leadership capacities in the LA program by claiming roles as a leader or captain:

I see myself as a team leader, or captain, as an LA. I have previous experience on the material and can help guide my section in succeeding in the material. I just hope to accomplish being valuable to the students. I want them to feel that I am a valuable source. (LA3)

The analogy presented here signifies that LA3 views his role in the LA program as a guide for his students. His role is also grounded in his past experience in the course and knowledge of the course content, making him an expert resource. As a resource or knowledge brokers, the LAs and CSC fellows were confident in their knowledge of STEM as well as in their ability to transfer this knowledge to others. Seeing oneself as a more experienced community member and being able to demonstrate STEM content knowledge like this are key tenets of science identity development (Carlone & Johnson, 2007).

For some LAs and CSC Fellows, different roles were more prominent than others at different points in the programs. For Fellow3, being a CSC Fellow meant being a student, teacher, and mentor. She explains her experiences facilitating one activity with students: “During this experiment I knew what I was doing and talking about. I really felt more like a teacher/mentor during this meeting than a student learning along with the high school student” (Fellow3). Here, the role identities Fellow3 assumes during her outreach experience switches from student to teacher/mentor, and is indicative of the multiple roles and dynamic nature of science identity development in the programs. These multiple roles are also illustrative of the complex nature of the UMT activity system.

Theme 2: setting performance expectations

Identities are formed and shaped through practice. When practicing an identity, individuals set performance expectations for themselves in order to maintain self-efficacy while enacting a specific role, as well as identification and acceptance within a community. As LAs and CSC fellows engage in experiential STEM SSOPs, they describe a collection of actions, attitudes and approaches that align with the performance expectations attached to their role in the program, and also to their identity within the broader STEM community.

Each role claimed by the LAs and CSC fellows was attached to a corresponding performance expectation. These performance expectations illustrate the rules of

interaction within the UMT activity system. Identities are formed through practice, and performance is viewed here as a process contributing to the identity development of LAs and CSC fellows. In these instances, LAs and CSC fellows formed their own interpretations of what it means to be, or act, in a particular role in their respective SSOPs. For example, when asked what it means to be an LA, LA1 explains her role as a teacher: “I think that what it means to teach is something way more in depth and complex, though, because you have to know also how to teach to many different types of learners” (LA1). For LA1, being a teacher means understanding how learners learn and having the pedagogical skills to accommodate this learning. However, not all UMTs in our sample held the same performance expectations for themselves when enacting their role as mentors. A different set of performance expectations followed each role claimed by individual LAs and CSC Fellows. For LA2, being an LA means supporting the faculty instructor and being a subject matter expert. He interprets the role of an LA to be:

Support for the instructor, since she is unable to spend time with every student and cannot participate in her own class, we can provide our experience having succeeded in the class before along with guidance to build a solid understanding of the subjects that are discussed in class. (LA2)

LA2 is setting performance expectations for his identity by drawing from previous experiences and success taking the same course. He uses this prior knowledge to guide and provide individual assistance to students.

Science identity development requires the participation of others (Burke & Stets, 2009; Carlone & Johnson, 2007). Therefore, for those LAs and CSC fellows claiming the role of a teacher or mentor, performance expectations were set based on the needs of the students with whom they were working. And because the addition of UMTs to these learning environments constituted a shift in the way that learning happens, there is variation in the observed performance expectations. Similarly, for LAs and CSC fellows interpreting their role to be more experienced in STEM than the students they mentored, expectations were set for the amount and type of knowledge needed to perform their role in the program. In some cases, the UMTs acquired new STEM knowledge that went beyond the specific disciplinary knowledge necessary to support a particular class or develop a particular outreach activity. Further analysis of this theme revealed performance expectations related to UMTs’ views of STEM, including how STEM is learned and practiced. In one example, Fellow2 sets his performance expectations as a Fellow from his belief in the importance of collaboration in STEM.

Acting on behalf of these expectations, Fellow2 allows his students a room to work together and problem solve:

It’s important I believe that when you are working with STEM related material to collaborate and try and guide people towards the right direction. Not explicitly telling them answers to problems, but making sure they are on the right path can be a great help when trying to spread awareness of STEM. (Fellow2)

Conversely, Fellow1 emphasizes growth as an important aspect of learning in STEM. In her role as a fellow, she promotes creative thinking and working alone to solve a problem so that her students might feel personal success from creating their own solution:

I think a big part of STEM, one we may forget, is growth. If everyone was hovered around and wasn’t able to think alone or creatively then no one would be able to make mistakes and grow to where they feel like they have created something new. (Fellow1)

These differences in performance expectations (rules) related to claimed roles (division of labor) speak to the contradictions within the UMT activity system. This tension or contradiction exemplifies Engeström’s Fourth Principle of activity theory: “When an activity system adopts a new element from the outside (for example, a new technology or a new object), it often leads to an aggravated secondary contradiction where some old element (for example, the rules or the division of labor) collides with the new one” (Engeström, 2001, p. 137). However, regardless of the difference in the type of performance expectations, the act of setting performance expectations for a novel role is indicative of identity development.

Theme 3: feeling validated

Within the Carlone and Johnson (2007) model of science identity development, recognition (i.e., being recognized as a “science-person”) is a key aspect to reinforcing one’s science identity. LAs and CSC fellows often reflected on moments when they felt validated, or recognized, by the students they mentored. In these moments of validation, the UMTs reflected on instances when students saw them as STEM people that they can learn from as well as leaders within their science classrooms, which further legitimized their role(s) within the community of their respective programs. This occurred in a number of ways, from the students using techniques taught by the LAs or CSC Fellows, to students verbally explaining how the LA or fellow helped them learn STEM content or skills, or UMTs explicitly reflecting on a strengthened identity based on interactions with students. For example, LA3

explained: “I enjoy however the appreciation I feel some of the students have for me as an LA. I feel more and more as a group leader each passing week” (LA3). In this instance, LA3 is explaining his own internal validation of his leadership role and LA role within the science classroom stemming from student appreciation and feedback. This type of internal validation is a central part of strengthening one’s overall science identity (Carlone & Johnson, 2007).

In other instances, UMTs felt validated when students used the techniques the UMT had taught them and from meaningful interactions with students. LA1 reflected on an instance in class where she noticed that many students used what she had taught them on an assignment: “After they finished the questions, Dr. B had us collect them and look over them to see what their misconceptions were, and I noticed many of them took my suggestions and explanations to heart” (LA1). In this instance, LA1 feels validated in her role as a science person and as a broker of STEM knowledge, as she recognizes that many students implemented what she had taught them regarding the content on this assignment. LA2 reflected deeply on his interactions with students during his arranged office hours, and in particular describes several instances in which he felt like students that were coming to his office hours were learning significantly due to their interactions. For example, LA2 reflected on two students that came to his office hours to go over several problems from class: “This week I had two people come in [to office hours] and discuss the challenge problems with me which is fantastic! Both of them said that they got a lot out of going through the problems with me” (LA2). For LA2, this moment of validation legitimizes his role as an LA and as someone that is capable of explaining complex problems to students. Additionally, the tone of this reflection exudes excitement, showcasing that LA2 is eager to help students during his office hours and is excited when students come to his office hours for help. Similar to LA2, Fellow3 is excited to be a mentor and feels validated in her role: “I felt I was more in a position of power, which felt great, and I would be able to help students when they were confused” (Fellow3). This feeling of power validates Fellow3’s position as a fellow and also as a more-expert STEM person (relative to the high school students she was working with) capable of showcasing her knowledge and skills.

These examples demonstrate how validation and recognition act as reinforcements to the LA and CSC Fellows’ science identities, as they not only see themselves as STEM knowledge brokers, but others do as well. Additionally, LAs and fellows both reflected on moments of validation throughout their journals, indicating that these feelings of validation are similarly experienced by UMTs across the SSOPs of interest. As Stets et al.

(2017) explain, having a role or position within a STEM community validated by others within that community is crucial to strengthening a developing science identity.

Metacognitive development

Metacognitive development is a key element in the transfer of knowledge from more experienced persons to less experienced persons (Pintrich, 2002). LAs and CSC fellows are viewed as being more experienced with STEM content relative to the students they mentor, and as such they have a unique role in the activity system. In that role, they work to support the development of students’ knowledge and to transfer that knowledge, by interacting and working with students in the system. Thinking or reflecting on one’s own comprehension of content, challenges or shortcomings, and learning strategies used is a key exercise when preparing to transfer knowledge to another person (Flavell, 1979; Pintrich, 2002). The UMTs demonstrated several instances in which they thought about and reflected on metacognitive elements. Three themes emerged from our analysis regarding these metacognitive elements, as outlined in Table 3: (a) reflecting on content knowledge, (b) identifying barriers and challenges, and (c) goal setting within the program.

Theme 4: reflecting on content knowledge

LAs and CSC fellows reflected regularly on their level of comprehension and knowledge of content. Within these reflections, LAs and CSC fellows described instances in which they were both confident or not confident in their knowledge relating to a specific STEM content area, instances in which they felt like their experience as a mentor was helping reinforce content they had learned previously, and instances in which they were able to learn new content or strategies. Fellow2 describes his year in the CSC program as a mentor as one that allowed him to think about and reflect on his knowledge of STEM content and his strategies for teaching this content:

Working with younger students every week and trying to convey science topics in order to spread the ideas that revolve around STEM was a bit challenging at times, but I was able to gain a lot from it. It challenged me to try and relate complex topics and subjects to a more appropriate level for the students to be able to learn. This allowed me to learn a lot more about a topic as well as reinforce the foundation of my knowledge. (Fellow 2)

Through the process of reflecting on his experiences, Fellow2 was able to gain a deeper understanding of what knowledge he holds, his comprehension of this

knowledge, and how to think about that knowledge in a way that allowed him to deliver it to the students he was mentoring. Fellow2 also reflected on his knowledge earlier in the year when he worked with students on figuring out how to calculate the velocity of a car based on distance traveled over time:

The biggest highlights for me this past week was doing the car activity. It allowed me to discuss what I am best at, which was Physics. The students were able to understand what to do easily and I was able to help the students understand basic physics concepts. Additionally, it helped me understand better how motion works with various materials and surfaces. (Fellow2)

Fellow2 not only reflects on his level of content knowledge specifically that he feels like he is most competent in Physics, but also on how facilitating the activity on velocity reinforced and strengthened his own knowledge on the subject. In this case, the activity on velocity mediated Fellow2's engagement with the students and in the program, which supports his metacognitive development (refer to Fig. 1).

In addition to Fellow2, several other UMTs reflected on their comprehension of content and how their role as a UMT added to their STEM knowledge base. Fellow1, a pre-service teacher, said the following in one of her first reflections:

I think this would be a wonderful opportunity for me to interact with students as well as learn from them for my own future classroom. This is a great atmosphere to help me broaden my knowledge with mathematics and apply it to kids who not only enjoy STEM but want to do something more with it. (Fellow1)

Fellow1 immediately recognized that her experience as a mentor will help her not only to better understand mathematics concepts as she teaches K-12 students, but also how others learn in relation to how she learns.

LA3 reflected on how his role as a UMT was helping reinforce content he had previously learned: "I am also just enjoying just relearning all of this stuff again. I am taking the MCAT soon so it is nice reviewing this kind of material. I really feel that it is benefiting me exceptionally" (LA3). When, as an LA, he was placed into a role that required explaining several complex STEM concepts to other students, LA3 recognized that this was actually helping to deepen his understanding and comprehension of these topics. Metacognitive reflection also speaks to learning new content. LA1 described an instance in which she recognized that she had a shortcoming on a specific area

of content and how talking with another LA helped her to understand this topic:

Right before we went into class, we had our weekly meeting and we all did like a little crash course about DNA replication. [Another LA] really helped me actually understand it. All of the sudden, I felt like oh my goodness, I finally get it! I understand. There was a very specific moment where it all just clicked. I felt so proud, and I went into class all excited to help. (LA1)

We note that this also represents a feeling of validation for LA1 and is thereby also evidence of the development of her science identity. As LA1 fulfilled the claimed role in the system, and because her engagement was mediated by the content, the experience supports both her metacognitive and identity development.

Understanding and reflecting on learning strategies and comprehension of knowledge are important components of metacognitive development. Pintrich (2002) explains how this reflective practice is especially useful for teachers in any setting that must transfer knowledge and skills to a wide variety of learners. The UMTs show clear practice of this type of metacognitive reflection when thinking back to their interactions with students, which were shaped by their roles and mediated by the content and activities.

Theme 5: identifying barriers and challenges

The UMTs also reflected on barriers and challenges in their novel roles within the activity system. A barrier refers to something that hindered the UMT from carrying out or completing a task they perceived to be part of their role, while a challenge refers to something that they were able to implement, but not without practical or personal difficulty. In many cases, we conceptualize barriers and challenges as arising from tensions or contradictions between the elements of the activity system (for instance, between the division of labor and the rules/norms of the system). These contradictions arise when a new way of thinking or behaving is introduced into the system, and is a defining principle of the activity system. They are not merely "problems." Indeed, Engeström highlights "the central role of contradictions as sources of change and development" in activity systems (Engeström, 2001, p. 137).

Flavell (1979) describes how recognizing and reflecting on obstacles is a crucial component of metacognitive development. These examples showcase how the UMTs recognized various barriers and challenges they faced in their UMT roles as well as their reflective processes for thinking about how to overcome them. The UMTs' reflections illustrate the higher order thinking they were engaged in relating to their own metacognition,

particularly when trying to identify, monitor, plan for, and evaluate a barrier or challenge that they experienced.

Most of the barriers or challenges experienced by the UMTs were centered on familiarity with the content, pedagogy, and communication skills, or building relationships with the students. Each of these barriers can be mapped onto mediating artifacts, norms of interaction, community, and division of labor in our activity system (see Fig. 1). During their reflections of these barriers and challenges, both LAs and CSC fellows utilized metacognitive skills to identify, monitor, and evaluate areas of the program and their role that they were unfamiliar with or struggling in, and in some cases, how to overcome these barriers. For example, Fellow1, Fellow2, and LA1 all identified barriers related to their new roles as UMTs. First, Fellow1 identifies how there were aspects of STEM that she was unfamiliar with:

I didn't have TSA [Technology Student Association] at my high school, we had robotics, which I still didn't participate in. So for me learning and acquiring knowledge for TSA was and is still a big challenge for me to wrap my head around all of their categories and their rules. (Fellow1)

TSA was a new element and a new way of thinking for Fellow1. Recognizing this type of knowledge gap and reflecting on what knowledge is necessary to add to one's knowledge base in any subject is an important metacognitive exercise (Flavell, 1979). Fellow1 also describes an instance in which she recognized challenges within the CSC program associated with the students she was mentoring not being fully prepared:

Unfortunately students didn't have portfolios done so we didn't have any to check. I believe this was unsuccessful because we assumed the students would be more prepared than they were, which was not all. If I were to re-do this demo I would probably do my own portfolio and show them what a finished one looks like. That way students could see a finished one and have something to reference to. (Fellow1)

This perceived lack of preparedness for the context/system in which they were operating was a contradiction with what Fellow1 might have seen as normal classroom practice. Helping students prepare for a forthcoming technology competition was one aspect of Fellow1's role in the CSC program, so the under-preparedness students inhibited Fellow1 from feeling like she could adequately perform her role as a UMT. After some reflection, she realized she could overcome the lack of student preparation by having an exemplar portfolio prepared ahead of time.

Similarly to Fellow1, Fellow2 recognized a barrier he experienced in his role as a fellow related to the task of

communicating technical STEM knowledge to a younger audience:

Working with younger students every week and trying to convey science topics in order to spread the ideas that revolve around STEM was a bit challenging at times, but I was able to gain a lot from it. It challenged me to try and relate complex topics and subjects to a more appropriate level for the students to be able to learn. (Fellow2)

Fellow2 recognized that his role as a fellow inherently included a challenge of communicating complex STEM concepts to young students, but he was able to reflect on and identify this challenge and evaluate how he could work through it. Fellow2 also struggled with under preparedness, albeit related to planning for their outreach experiences:

One thing I did not realize is how hard it is to know what materials are needed. Since our schedule is pretty tentative, we are unsure in some regards in what we need to get. This is one obstacle I feel like we need to overcome so we do not scramble last minute for materials or change our lesson plans because we don't have the proper materials. (Fellow2)

Here, Fellow2 recognizes an "obstacle" arising from a tension within the division of labor within the team of Fellows and expresses his intention to overcome it. The tentativeness of the schedule is perhaps unique to this context and presents a contradiction to Fellow2 in terms of their own preparedness.

Communication of STEM content was also a barrier for LA1. In several reflections, LA1 reflected on the barrier of explaining complex STEM content to her peers and how this barrier actually impeded her ability to perform her role as an LA. LA1 explains early in the semester that she kept "getting tongue tied and not knowing where to start when explaining things to students" (LA1). However, this barrier was hard for her to overcome and affected her LA experience as she explains in a later reflection: "The past couple weeks have been a big struggle for me, because I've been really intimidated to go up to students and talk to them" (LA1). Metacognitively speaking, LA1 actively recognized and reflected on obstacles that obstructed her ability to perform her role as an LA, which are key components of metacognitive development within a novel role (Flavell, 1979). However, LA1, unlike Fellow2 and Fellow1, did not reflect on ways to overcome these barriers.

Theme 6: goal setting within the program

Both CSC fellows and LAs set firm goals for themselves in their roles. A goal refers to something they would like

to achieve, which can include both mastery goals (goals linked to a personal improvement or a personal best) and performance goals (goals directly linked to the desired outcome). Goal setting has long been considered a key component of metacognition and self-regulation (Pintrich, 2004; Weinstein, Husman, & Dierking, 2000).

As explained by Flavell (1979), novel roles (like being a UMT) expressly demand reflective thinking on progress towards goals. This type of thinking and reflection is part of one's metacognitive development as they take on new roles. The goals explicitly stated by the UMTs in this study were varied in nature. Some were short-term for the following week, while others were for the following semester or even further into the future. The UMTs set goals that were specifically aimed towards the students they mentored, their respective SSOPs as a whole, or more personal inward directed goals. Specifically, goals being set were either related to the planning and development of teaching and/or learning strategies (mediating artifacts), increasing student engagement (rules), or to improve communication (community and division of labor).

For example, LA2 sets himself broad personal goals for improved communication and teaching strategies for the near future: "My goal for the semester is better understand how other people learn so that I can become better at it myself and to get to do this again next semester for the physics department" (LA2). Similarly, through her initial experiences as an LA, LA1 reflects on general, yet attainable goals she would like to achieve while in her role:

There are two big things I want to improve. The first is my ability to interact with students, because I hold myself back a lot due to my shyness and lack of confidence sometimes. I think this week really helped with that. The next thing I want to change is to get a whiteboard next to my section in class. Many of the students totally loved when Maddie and Frank utilized it last class, so I think the students in my section would like it as well. I already emailed Dr. X asking about it so hopefully he has a way to get one or something similar. (LA1)

Fellow1 also included goals for the future experiences of K-12 students served by the CSC program:

I know that I will redo this demo next semester (Fall 16') and get the students more on the mathematics behind the catapult and help them apply that to their own projects but also keep them engaged like this last time. (Fellow1)

This example is much broader compared to the example from LA1, and it is pertaining to a specific task

(mediating artifact), whereas LA1's goals refer to her general interactions with students.

Although the types of goals set varied, goal setting was seen throughout the LA and CSC Fellows' reflections. This indicates that they were self-regulating and self-monitoring as they moved through these experiential program experiences. This also indicates that the UMTs were considering their own performances and striving to better themselves in their roles.

Discussion

The six themes presented in Table 3 and discussed above represent the experiences we have identified in our UMT sample related to their science identity and metacognitive development. These themes serve as evidence for the outcomes we have defined in our activity system, in which the UMTs are the main subject, but these are not the only potential outcomes in the system. One could conceptualize communication skills, appreciation of teaching, and other affective components as desired outcomes of the system. The participation of UMTs within this activity system, and the varied roles and division of labor that participation entails, has allowed these UMTs to reconceptualize and construct their own science identities and metacognitive functions. This reconceptualization is a key component of Activity Theory (Engeström, 1987, 2001), as the UMTs used their position within this social activity system (as they interacted with students they mentored, other UMTs, and faculty) to re-think how they see themselves within the STEM community and how they understand and communicate complex STEM concepts. This reconceptualization is not only fueled by the social interactions that take place within the activity system, but also by the variety of participants and members of the activity system community.

One of the principles of Activity Theory is community, in which different members of the activity system take on different roles related to their point of view, interests, and skills (Engeström, 1987, 2001). As UMTs enter into already established activity systems (such as a classroom or afterschool program), they perturb the norms of those systems by taking on unique and novel roles and creating a new division of labor within the system. What we have seen through the UMT reflections in our sample is that perturbation and new division of labor (via taking on novel roles within the system) seemed to generate a reconceptualization and development of both science identity and metacognition that may not have occurred in this same manner if not for the original perturbation (i.e., the LA or Fellow entering into the classroom or after school activity system). In this sense, their participation in the system was itself a source of contradiction.

In terms of science identity development, the UMTs in our sample claimed and attached meaning to their roles as more-expert STEM knowledge bearers than the students they mentored. Roles were then validated by others within their classroom activity systems. These pieces of science identity development and strengthening may have not happened if not for the roles the UMTs took on within the larger activity systems they were participating. One facet of both the LA and CSC programs is that they are designed to empower UMTs to claim and explore their roles as content experts (in related but somewhat distinct ways). This contributes to the opportunities for identity development of the types we have observed here. This possibility aligns with the notion that identities are filled with meaning based on how a person perceives their role as an individual and within the larger cultural groups they are part of within society (Stets et al., 2017).

Stronger science identity has been linked to retention in STEM among undergraduates (Merolla & Serpe, 2013; Stets et al., 2017). Although UMTs in these programs have generally been successful in their coursework, stronger, and more developed science identities may impact their continued success in STEM and how they are perceived within the larger STEM community. In turn, this may severely influence how UMT roles evolve within the activity system and how UMTs positively impact the students they mentor (and as an extension, the effect of that impact on the mentored student).

In conjunction with science identity, metacognition development was also observed. Metacognition development included a deeper understanding of material upon reflection of content, barrier identification, and goal setting. These metacognitive functions are thought to be due to the novel roles UMTs take on within the activity system. Novel roles typically require extensive planning and reflection, which are metacognitive in nature (Flavell, 1979). As UMTs took on these new roles (and a new division of labor existed within the activity system), they were confronted with thinking about how they understood complex scientific concepts, what challenges and barriers they faced when it came to content, communication, and building relationships within the system, and what goals they had for themselves regarding their own preparation and interactions with students. As with the observed development of science identity, we presume that these metacognitive actions occurred because of UMTs' participation and novel roles within the activity system.

An area of overlap between science identity development and metacognition that warrants further consideration is science self-efficacy or a student's own perceptions if they are capable of doing and teaching

science to others (Stets et al., 2017). If a UMT believes they are capable of studying and doing science, through reflection of content knowledge or comprehension, this will become a core part of their science identity that they display outwards. Moreover, if a UMT believes that participating in science will lead to a positive outcome (i.e., feeling validated in their role as a "science-person" (Carlone & Johnson, 2007)), this will feed into their positive science self-efficacy, which will feed into a stronger science identity. The stronger the science identity (i.e., also stronger science self-efficacy), the more likely the UMT will display that identity outwards. However, if a UMT is not met with the reflected appraisal that Stets et al. (2017) describe, the likelihood that their science self-efficacy will diminish is high because their participation as a scientist and as a mentor was not met with a positive experience nor positive feedback from their external environment (i.e., community within the activity system).

Limitations

One limitation of this study is that the data was collected independently by the CSC and LA programs. In the future, a common set of prompts may be deployed to better understand shared and distinct impacts across a larger family of SSOPs. Also, this study considered only two SSOPs, which may limit the ability to make inferences about SSOPs writ large. On our campus, examples of other SSOPs include undergraduate teaching assistants in Chemistry, supplemental instruction leaders across several disciplines, and peer mentors in the peer advocate leaders program. It is possible that a study of these programs in concert with the CSC and LA programs would lead to new or different insights.

Conclusions

This paper represents the first steps in examining common and distinct outcomes of SSOPs on UMTs via an examination of the experiences of undergraduate learning assistants and outreach fellows. Across both programs, UMTs demonstrated evidence of strengthened metacognition and science identity, both of which are important components of success in STEM as defined by our activity system framing. An understanding of these and other potential outcomes may have implications for undergraduate STEM education. For example, this work could help develop a model of how these types of programs could be built, adopted, or adapted. Additionally, this work contributes to the growing literature that indicates participation in SSOPs may be a potentially transformative part of the undergraduate experience that could reinforce and enrich students' experiences in other STEM learning environments.

Appendix

Table 4 Themes, codes, and exemplars

Theme	Codes	Exemplars from reflections
Science identity development		
Claiming a role and attaching meaning to it	Teacher	<i>During this experiment I knew what I was doing and talking about. I really felt more like a teacher/mentor during this meeting than a student learning along with the GMHS students. (Fellow3)</i>
	Collaborator Mentor Guide Peer Expert Facilitator Leader Student	<i>I see myself as a team leader, or captain as an LA. That I have previous experience on the material and can help guide my section in succeeding in the material. (LA3)</i> <i>LAs I think are support for the instructor, since she is unable to spend time with every student and cannot participate in her own class we can provide our experience having succeeded in the class before along with guidance to build a solid understanding of the subjects that are discussed in class. (LA2)</i>
Setting performance expectations	Be knowledgeable in STEM content	<i>There were still the group of students who did not pay attention and were busy doing off topic stuff, but it's our job to ensure that everyone in the classroom is engaged and gains an interest about STEM. (Fellow2)</i>
	Get students interested in STEM	<i>I just hope to accomplish being valuable to the students. I want them to feel that I am a valuable source. That they see me as resource the way they see the office hours of Dr. K and SI tutors. (LA3)</i>
	Expose students to new concepts and experiences	<i>It's our job to expose them to something new things that they haven't experimented with yet. (Fellow1)</i>
	Engage students with material	<i>As a facilitator I focused on trying to get the students to understand the importance of each element in cellular respiration and focus on how these elements connect together. (LA3)</i>
Feeling validated	Be a valuable resource	
	Help students understand content	
	Promote creative thinking	
	Encourage failure and building perseverance	
	Positive appraisals	<i>I think that the thirst for knowledge resides in many of the students we engage with and it's fun to see them seeking answers to questions that we may not even know, but are able to find out for them. (Fellow2)</i>
	Students are curious and want to know more	<i>After they finished the questions, Dr. K had us collect them and look over them to see what their misconceptions were, and I noticed many of them took my suggestions and explanations to heart. (LA1)</i>
	Grades improve	<i>I felt I was more in a position of power, which felt great, and I would be able to help students when they were confused. (Fellow3)</i>
Misconceptions are remediated	<i>I felt like a total failure when I had to take a good 10 minutes to look over the book before helping the student who came to my office hours. (LA1)</i>	
Advice is taken		
Confusion is eliminated		
Students are engaged in the material		
Students are having fun		
Attending office hours		
Students asking for help		
Metacognitive development		
Content reinforcement/ learning	Self-evaluation of content knowledge	<i>I am also just enjoying just relearning all of this stuff again. I am taking the MCAT soon so it is nice reviewing this kinds of material. I really feel that it is benefiting me exceptionally. (LA3)</i>
	Re-learning old content	<i>Right before we went into class, we had our weekly meeting and we all did like a little crash course about DNA replication. [Another LA] really helped me actually understand it. All of the sudden, I felt like oh my goodness, I finally get it! I understand. There was a very specific moment where it all just clicked. I felt so proud, and I went into class all excited to help. (LA1)</i>
	Reflecting on learning strategies	<i>I think this would be a wonderful opportunity for me to interact with students as well as learn from them for my own future classroom. This is a great atmosphere to help me broaden my knowledge with mathematics and apply it to kids who not only enjoy STEM but want to do something more with it (Fellow1)</i>
Learning content in a new way		
Identifying and overcoming barriers and challenges	Learning content in a new way	
	Subject-specific content (Science	<i>Learning and acquiring knowledge for TSA was and is still a big challenge for me to wrap my head around all of their categories and their rules. From the demo aspect we have worked with some very new things that I had to learn and add to my repertoire when it came to STEM, such as google sketchup. I hadn't worked with anything CAD related so for me this was a very big challenge. (Fellow1)</i>
	Technology	
	Math	
	Engineering)	
	Pedagogy and communication skills	<i>Working with younger students every week and trying to convey science topics in order to spread the ideas that revolve around STEM was a bit challenging at times, but I was able to gain a lot from it. It challenged me to try and relate complex topics and subjects to a more appropriate level for the students to be able to learn. (Fellow2)</i>
	Explaining complex concepts	
Demonstrations		
Engagement	<i>I was a stranger in this new class room and was challenged to learn about all these new</i>	

Table 4 Themes, codes, and exemplars (*Continued*)

Theme	Codes	Exemplars from reflections
	Building relationships	<i>faces and what was the best way was to approach them. (Fellow2)</i>
	Collaboration	<i>Planning demos was something that I had never had to do before and having to collaborate with two other students was even more of a challenge. (Fellow1)</i>
Goal setting within the program	Asking questions	<i>Planning demos was something that I had never had to do before and having to collaborate with two other students was even more of a challenge. (Fellow1)</i>
	Initiating conversations with students	
	Develop learning and teaching strategies	<i>One thing I noticed was that many students left out the time they needed to complete everything. This is very applicable to all ages of life as we often forget about how massive a project can be and underestimate the amount of time we have to complete things. (Fellow2)</i>
	Planning and preparation	
	Monitoring time	
	Increase student engagement	<i>As I learn more about this approach to learning, I can see that I will need to engage the student at a deeper level, one where we need to approach the foundations of their learning style. (LA2)</i>
	Target learning styles	
	Improve communication	
	More interaction with students	<i>I know that I will redo this demo next semester and get the students more on the mathematics behind the catapult and help them apply that to their own projects but also keep them engaged like this last time. (Fellow1)</i>
	Utilize communication tools	<i>There are two big things I want to improve. The first is my ability to interact with students, because I hold myself back a lot due to my shyness and lack of confidence sometimes. I think this week really helped with that. The next thing I want to change is to get a whiteboard next to my section in class. (LA1)</i> <i>The first semester had taught me how to communicate with students so we could do better demos for the next semester (spring 16) and how to determine if the demos we were doing effective in getting them engaged in STEM. (Fellow1)</i>

Supplementary information

Supplementary information accompanies this paper at <https://doi.org/10.1186/s40594-020-00231-6>.

Additional file 1.

Abbreviations

CSC: Community STEM Clubs (Program); LA: Learning assistant; SSOP: Student Support and Outreach Program; STEM: Science, Technology, Engineering and Mathematics; TSA: Technology Student Association; UMT: Undergraduate mentor-teacher

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Authors' contributions

HH, RT, and MR wrote and edited the submitted manuscript. HM and AT collected and coded all of the reflections used for this analysis. HM and AT conducted the thematic analysis. BW assisted with coding and thematic analysis. All authors offered comments, suggestions, and edits for the submitted manuscript. The author(s) read and approved the final manuscript.

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Availability of data and materials

Please contact the author for data requests.

Ethics approval and consent to participate

The participants were all adults who volunteered for the program. The participating institutions/colleges currently do have and approved IRB protocols 14-0028 and 14-0077 with the Colorado Multiple Institutional Review Board.

Competing interests

The authors declare that they have no competing interests.

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