Transformative Dialogues: Teaching and Learning Journal
Summer 2021, Volume 14, Issue 2
https://journals.kpu.ca/index.php/td/index

Learning Assistantships in College Mathematics: Value for Preservice Teacher Development

Kelly Gomez Johnson
University of Nebraska at Omaha

Paula Jakopovic
University of Nebraska at Omaha

Janice Rech
University of Nebraska at Omaha

Angie Hodge-Zickerman
Northern Arizona University

Abstract
Increasing the participation and achievement of students in Science, Technology, Engineering, and Mathematics (STEM) from early grades to college coursework continues to be at the forefront of educational transformations and research. Faculty members at Institutions of Higher Education (IHE) plan, implement, and investigate how program structures might aid in the development, retention, and overall success of undergraduate students in STEM. Active learning classrooms, especially in mathematics, are one way IHE are reforming student learning experiences, and these environments also provide a unique opportunity to engage undergraduate learning assistants with faculty to support near-peer students and deepen their own learning. Identifying aspects of undergraduate learning assistants' experiences that they find most valuable and interrogating how those are linked to their development can help IHE faculty better understand and plan for how to support undergraduate students in particular fields, such as STEM and STEM teaching. In particular, this paper examines scholarship participants serving as learning assistants in active learning college mathematics classrooms to see where and how they find value in their experience. Implications of this research can inform faculty and university programs on how they might prioritize and transform learning opportunities for students to impact their current and future development in STEM and beyond.

Keywords
mathematics; active learning; learning assistants; preservice teachers; STEM education; undergraduate student development

Introduction

Faculty at Institutions of Higher Education (IHE) across the United States are heavily invested in determining how programs can recruit, support, and retain undergraduate students in STEM fields, including STEM teaching pathways. For long-term retention and success, students need both strong core competencies in their field and also professional competencies (e.g., critical thinking skills, collaboration, communication) (Dolan, 2015). A particular area of consideration for IHE is how STEM undergraduate students can develop these competencies along with their professional identity to be competitive and prepared for a 21st century workforce (Davis et al., 2015; Hattie, 2009). Specifically with regards to this paper, STEM education programs seek to develop opportunities for preservice teachers to promote content and pedagogical training that prepares future STEM educators to be equally qualified and competitive.

Seminal work by Chickering & Reisser (1993) characterized undergraduate student development through the lens of cognitive and psychosocial theory. Undergraduate student learning therefore extends beyond classroom-derived content to include educating the whole self through rich learning experiences and interactions. Chickering and Reisser's (1993) model illustrates the fluid nature of students' psychosocial development along seven core areas that include Vector 1, developing competence (e.g., intellectual, interpersonal)—the focus of this study—and Vector 7, establishing identity. Intellectual competence refers to student reasoning and critical thinking. Interpersonal competence refers to the ability to communicate and work well with others. In terms of STEM identity development, recent research points to factors such as the development of content competence, the ability to showcase learning to others (performance), and recognition of competence and ability in STEM by others (e.g., Carlone & Johnson, 2007; Herrera et al., 2012). These points support the multi-faceted work of Chickering & Reisser indicating that competence, performance, and recognition are influenced by interacting with others and are aligned with an individual's various social and cultural identities (Herrera et al., 2012).

IHE can influence undergraduate student development in a variety of ways. Factors that influence individuals' vectors include institutional structures and programs. These influencing factors involve aspects such as active learning, collaboration, and mentoring (Chickering & Reisser, 1993). However, evaluating the value of student experiences and how they might support student development and learning is complex, especially when positioned outside of traditional classroom settings (Lave & Wenger, 1991). Situated learning theory (Lave & Wenger, 1991; Wenger, 1998) posits learning as an inherent component of participating in a group or organization. Framing value theoretically as a fluid and interconnected process helps IHE faculty more deeply understand the varied layers of student experiences in social and academic contexts (Wenger, 1998; Wenger et al., 2011). Wenger et al. (2011) and Wenger-Trayner & Wenger-Trayner (2014) assert that value can exist in a variety of types, including immediate (in the moment), potential (for the future), applied (tested implementation), realized (actualized implementation), and transformative (broader dissemination to others) (see Figure 1).

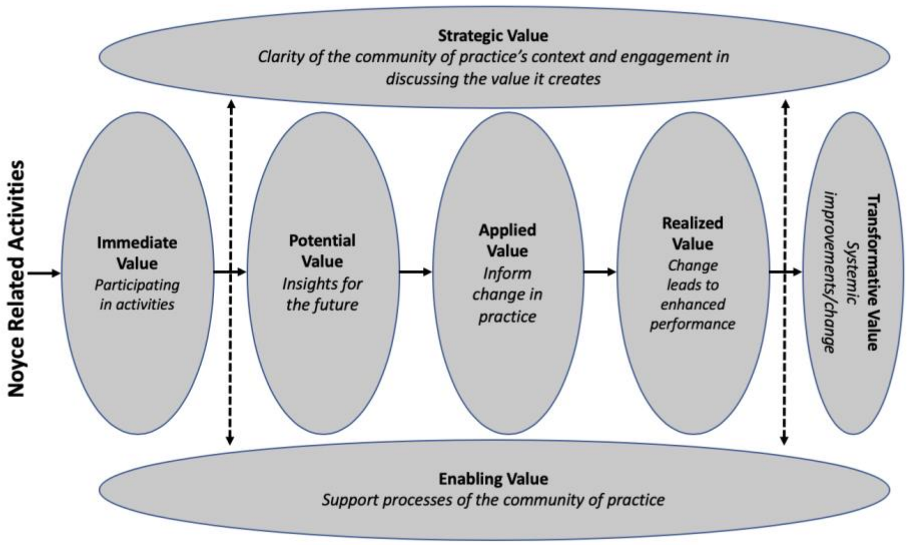

Figure 1. Seven Types of Value, adapted from Wenger-Trayner & Wenger-Trayner (2014) with permission.

Identifying aspects of learning experiences that students find value in and interrogating how those are linked to their development can help IHE faculty better understand and plan for how to support undergraduate students in particular fields, such as STEM and STEM teaching. The current study is part of a larger study at a large midwestern university that seeks to understand the value undergraduate students find participating in a STEM scholarship program. The students are recipients of a National Science Foundation (NSF) Robert Noyce Teacher Scholarship aimed at recruiting, training, and retaining high-quality mathematics teachers. This study examines a subset of Noyce students' perceived value serving as Learning Assistants (LA) in active learning-structured mathematics courses.

Active Learning

Active learning environments offer many benefits to students as they develop their competencies and identity in STEM and teaching. Active learning has become more prevalent in college coursework over the past two decades as a means to improve student learning outcomes, persistence, and retention (Freeman et al., 2014; Graham et al., 2013). Most recently, the definition of active learning has been viewed under the umbrella of inquiry-based mathematics instruction. Laursen and Rasmussen (2019) discuss the characteristics of such instruction in terms of Four Pillars:

- Students engage deeply with coherent and meaningful mathematical tasks
- Students collaboratively process mathematical ideas
- Instructors inquire into student thinking
- Instructors foster equity in their design and facilitation choices (Laursen & Rasmussen, 2019, p. 138).

Active learning practices around the Four Pillars have resulted in increased academic success, lower drop/fail/withdraw (D/F/W) rates compared with traditional lecture courses, and improved attitudes toward the subject (Bowen, 2000). Importantly, studies have revealed that active learning can help close the achievement gap between disadvantaged and non-disadvantaged students in STEM courses (Haak et al., 2011; Hrabowski & Henderson, 2017).

However, traditional, teacher-led instruction (TLI) is still the prevalent mode of teaching in college mathematics classrooms (Jaworski & Gellert, 2011; Laursen et al., 2019; Nolan, 2006, 2010). TLI often requires low-level cognitive demand and results in superficial understanding, short-term retention, and minimal stimulation (e.g., Thomas, 1998). Meta-analysis studies over the past decade show lower student achievement outcomes and negative long-term impacts from TLI (e.g., reduced grade-point average, increased student tuition costs) in comparison to more student-centered teaching methods like project-based and active learning (e.g., Chen & Yang, 2019, Freeman et al., 2014). With a focus on inquiry and equity, active learning environments establish students as partners in the learning process with the faculty/teachers rather than passive observers (Cook-Sather et al., 2016; Healey et al., 2014, 2016; Huber & Hutchings, 2005; Werder & Otis, 2010).

A Focus on Preservice Teachers

For undergraduate STEM students interested in teaching (preservice teachers), access to active learning courses can provide rich and reflective learning experiences necessary to translate to their teaching practice (Rieger et al., 2013). Preservice teachers often draw from their past learning experiences when planning their own instructional decisions (Cady et al., 2006). The instructional practices they experience prior to and during college can consciously or unconsciously perpetuate ineffective or dated practices. There are multiple domains of mathematical knowledge needed to become an effective mathematics teacher (Ball et al., 2008). For example, teachers require specialized content knowledge for teaching and knowledge about students and how they learn mathematics.

However, research on preservice teacher preparation shows that undergraduate students who experience active learning environments in mathematics often shift their understanding of what it means to teach and learn mathematics (Litster et al., 2020). In particular, preparing preservice teachers to implement student-centered, active learning environments of their own requires them to experience learning and reflecting in these environments through college coursework, field experiences, etc. (McDonnough & Matkins, 2010). This includes, but is not limited to, access to multiple mathematical representations, opportunities to struggle in a constructive way, and structures to engage in collaboration and communication with peers (National Council of Teachers of Mathematics [NCTM], 2014). Learning assistantships can offer a low-risk experience where they are “on the other side of the desk” as they consider teaching as a future career.

Learning Assistantship Benefits and Opportunities

Inviting students to work in an active learning classroom as a learning assistant (LA) ensures that they have access to noticing how other students approach problems along with the varied responsibilities of teachers in these types of environments (AMTE, 2017; Litster et al., 2020; Sherin, et al., 2011). Developing awareness of what active learning looks like and how it impacts student engagement and learning can shift LAs' understanding from unawareness to awareness and even exploration of such teaching practices (Hall, 1974; Tunks & Weller, 2009).

In a recent study, undergraduates consistently rated their experiences working as an LA as being beneficial in terms of increasing their ability to work with people as well as their understanding of how students behave (Weidert et al., 2012). LAs also improve their development of content understanding and identity (Close et al., 2016) and enhance their communication skills (Goff & Lahme, 2003). Engaging potential preservice teachers as LAs serves as a unique opportunity for colleges and university programs to provide early teaching experiences for students (Philipp et al., 2016). Since 2003, the LA program in the physics department at the University of Colorado-Boulder has increased the number of qualified secondary physics teachers threefold (Otero et al., 2010). Faculty within the department recruit preservice teachers as LAs in the introductory physics classes. LAs recruited to K-12 teaching have exhibited more reform-based practices than their peers (Gray et al., 2016). While increasing research is being done on the processes and outcomes of embedding learning assistantships into undergraduate and graduate programs (e.g., Vandergrift et al., 2020), data are sparse in examining mathematics-related learning assistantship experiences and their effects on undergraduate student development.

We seek to investigate what undergraduate STEM students value in their mathematics-focused scholarship program. Further, we explore the things students value related to their development as both students and future STEM professionals (e.g., math teachers). For the purpose of this study, we are not focusing on determining outcomes or direct links to the program, but interrogating student experiences as LAs to inform how, what, and where students find value.
We aim to inform and refine our own Noyce Scholarship program and share our preliminary findings with other programs supporting undergraduate STEM student development to improve STEM student success. Therefore, this study examines the questions *What aspects of learning assistantships in active learning mathematics classes do undergraduate STEM students find valuable?* and *How might these experiences benefit preservice mathematics teachers?*

Methodology

This study is part of a larger project investigating the immediate and potential value that participants experience as Learning Assistants (LAs) in an active learning mathematics class while enrolled in a Noyce Scholarship program at a large, urban university in the Midwest. Understanding how participants engage in experiences they find valuable (or not) requires the collection of rich, descriptive data (Yin, 2018) to uncover participant conceptions of value (Charmaz, 2008). Utilizing a qualitative research methodology affords the opportunity to understand "how people interpret their experiences, how they construct their worlds and what meaning they attribute to their experiences" (Merriam, 2009, p. 5).

Participants, Setting, and Context

Undergraduate STEM participants for the Noyce Internship and Scholarship program are recruited each semester of the 5-year grant-funded period. Scholarship applicants must meet the selection criteria: namely, being a junior or senior majoring in mathematics and in teacher education, with an overall GPA of 2.5 or higher. The goal of the Noyce Scholarship Program is to prepare highly qualified future teachers to serve in high-needs schools, defined as having 50 percent or more of the student body qualified to receive free/reduced lunch.

The Noyce leadership team is composed of faculty from both the Teacher Education and Mathematics Departments. The authors of this study are all members of the Noyce leadership and research team. Authors 1, 2, and 4 served solely as researchers and did not serve as faculty mentors during the data collection period. Author 3 was an LA faculty mentor at the time of the study.

Students at the university are recruited into the Noyce program at two different levels: Interns and Scholars. Interns are either freshmen or sophomores majoring in a STEM field who express a potential interest in teaching. Participating in an Internship allows students to "test the waters" as they consider teaching as a possible career path. Scholars are typically juniors or seniors, double majoring in mathematics and secondary teacher education, who commit to teaching in a high-needs school upon graduation. Both Interns and Scholars engage in a variety of activities including STEM outreach activities and active learning teaching experiences. These activities take place both at the university and in the local community and include working as LAs in university mathematics classrooms.

As part of the normal program expectations, participants complete weekly reflections on their activities. Participants agree at the onset of their Internship and Scholarship to the use of the reflections as data collection to inform the research side of the grant. All LA participants are part of the Noyce scholarship program, and as a program we have received IRB Exemption status due to program improvement research and evaluation structures. All data are aggregated and de-identified to protect the anonymity of subjects in the study. Where appropriate, pseudonyms are used in this report. Participants of this study (see Table 1) are a subset of 13 undergraduate Interns and Scholars who served as LAs in university mathematics classes during a three-semester time period.

Table 1
Learning Assistant Demographics Fall 2018 - Fall 2019

Semester Participants Engaged as LA	Noyce Intern	Noyce Scholar	Total LAs
Fall 2018	2	2	4
Spring 2019	1*	1	2*
Fall 2019	5	3*	8*

Note. Same participant engaged as an LA as an Intern in Spring 2019 then as a Scholar in Fall 2019, resulting in a total n = 13

LAs are undergraduate students who have successfully completed the course in which they provide support, and they generally have an interest in both the content area and helping others (Talbot et al., 2015). Due to their recent experience taking the same course, LAs provide "near peer" support for other undergraduate students experiencing similar struggles and/or experiences (Otero et al., 2010). The LA participants in this study were paired with four mathematics faculty members who utilize active learning techniques in their undergraduate mathematics courses (e.g., precalculus, calculus, introduction to proofs). We define active learning in alignment with the Four Pillars of Inquiry-Oriented learning in that 1) students engage in meaningful math tasks, 2) students engage collaboratively, 3) instructors are focused on student thinking, and 4) instructors intentionally promote access and equity (Laursen & Rasmussen, 2019). All LA participants were previously students in these active learning classes, and as such, positioned with experiences from the student perspective in engaging undergraduates in active learning. Their roles were primarily to encourage and support students through one-on-one or small group engagement in the course.

All LAs in this study were paired with a faculty mentor. Mentors are typically mathematics or teacher education faculty members closely tied with mathematics or other related STEM fields (e.g., computer science). Faculty mentors meet with their assigned Intern or Scholar weekly or bi-weekly to discuss these structure reflections, encourage extended reflections, and/or co-plan for collaborative projects (e.g., LA coordination). Research indicates that more structured and intentional opportunities for reflection need to be built into teacher preparation programs (Rieger et al., 2013). The grant leadership team provides faculty mentors with initial mentorship training, a mentorship handbook, access to a common learning-management group, and ongoing checkpoints throughout the semester.

Data Collection

The subset of reflections examined for this study include Fall 2018, Spring 2019, and Fall 2020 journals from LAs enrolled in the Noyce program. A total of 65 reflections from 13 Intern and Scholar LAs were extracted and examined for this study.

Prior to Fall 2019, the Noyce leadership team noticed that some Scholar and Intern reflections lacked depth or clarity in their descriptions of their activities and also their potential learning.
In Fall 2019, the Noyce leadership team re-evaluated and revised the prompts for the weekly journal reflections and end of semester reflection. Some reflections read more as a list of completed activities rather than a reflective narrative. Where initial prompts were more focused on the descriptive nature of what participants were doing, the new prompts promoted deeper reflection thinking about current and potential future implications of participants' experiences. A sample of prompts are below:

1. *Briefly* describe one or more of your activities this week
2. What was something you learned or gained from your activities this week that is valuable to you:
    a. as a CURRENT student? (Note: this could be related to school or your own personal life)
    b. in your future work as a teacher/mathematician?
3. What do you wish would/could have gone better? How could your peers or Noyce faculty help support you in the future?

The research team also conducted an annual focus group interview with Scholars. This focus group was voluntary, and no identifying information was gathered during data collection. The data were utilized to triangulate the findings from the written reflections. The questions in the focus group interviews examine the activities and experiences that Scholars have previous to and during their time in the Noyce program to determine the specific aspects of Noyce-related activities participants find most valuable. The focus group interviews included the following questions:

1. Prior to engaging in mentoring, teaching, and outreach projects as part of this research study, describe the types of activities you engaged in related to mathematics and/or teaching.
    a. How did these activities influence your thinking about teaching/mathematics?
    b. Which activities were most useful to you?
    c. Which were least useful to you?
    d. Did you learn anything new about teaching or mathematics through these activities?
2. Describe your experiences related to the Noyce program this year.
    a. How did these activities influence your thinking about teaching/mathematics?
    b. Which activities were most useful to you?
    c. Which were least useful to you?
3. What were some of the important ideas related to teaching and/or mathematics that you learned through these experiences?
4. In what ways has participating in Noyce experiences (mentoring, teaching opportunities, outreach) influenced your relationships with faculty? Peers? Others?
5. What do you most remember about the Noyce experiences you participated in this year? What stood out?
6. How would you describe the value of these Noyce experiences?
7. How would you describe the impact of these Noyce experiences on your future teaching?

Data Analysis

To answer our research questions, the research team utilized Wenger et al.'s Value Framework (2011) defining cycles of value creation—which flow from "immediate value" to "transformative value." The types of value created within participants' experiences as LAs are supported (or challenged) by contextual value factors that can be categorized as "strategic value" and "enabling value." This value framework served as a foundation from which the research team developed *a priori* parent codes for the five value types presented in the framework. The team used descriptive coding (Saldaña, 2016) to create sub-codes that focused on the topic of each coded passage (Miles, et al., 2014). After reading a representative sample of journal entries, the research team developed nested sub-codes (Gibbs, 2007; Miles et al., 2014) to interrogate whether participants perceived value related to teaching, mathematics, understanding how students learn, etc. For example, to ensure validity, the team identified seven immediate value and six potential value sub-codes to narrow down on the specific, unique experiences of participants.

Two members of the research team utilized the parent and sub-codes to create a codebook, which included specific, illustrative examples of each code and sub-code, to stabilize subsequent coding of data. To ensure reliability of results, the same two members of the research team coded all journal entries and the focus group interview data simultaneously, allowing the team to resolve any discrepancies real-time and consistently apply codes throughout the analysis process. This article focuses solely on the immediate and potential value codes from the journal entries and focus group conversation of LA participants. In the larger study of Noyce participants' value (Jakopovic & Gomez Johnson, 2021), the research team found that experiences were most often categorized as "immediate" or "potential" value, which the authors hypothesized was a result of participants' limited opportunities to enact what they have learned in their own teaching practice at this juncture in their undergraduate programs. The following sections present the initial results of this qualitative analysis examining the specific value identified by LA participants along with a discussion of potential implications for mathematics and teacher preparation programs.

Results

LA Immediate Value for Understanding Content

An examination of the reflections recorded by Scholars and Interns serving as LAs, revealed 43 instances where immediate value was reported. The research team anticipated that, since the participants served as learning assistants in college mathematics courses, they would self-report value in learning mathematics. However, only 5 of 43 instances coded for immediate value were excerpts where students reported finding the mathematics as the source of value. The research team hypothesized that this finding might result from the fact that each of the LA participants had taken numerous mathematics courses beyond the course they assisted in prior to taking on the role of learning assistant. As such, they may already feel competent with the mathematical concepts in the course. Although the majority of the immediate value-added instances were not tied to learning new mathematics specifically, participants reported a shared experience about how their content knowledge evolved as they engaged with near peers as LAs. For participants like Moriah, a novel idea came from her seeing familiar content from a new, more conceptual lens:

> I also continued to freshen up my Calculus skills through being a teacher's assistant in Calculus I. I finished the test 4 review packet and noticed how much easier this class is now that I have a chance to review it from a different perspective. I definitely have a deeper understanding of the subject because students always ask me questions and I constantly have to review the different subjects taught during class. (Intern Moriah, 2018)

For Moriah, her new interaction with the course, instructor and course material, free from the pressure of being graded, now allowed her to focus on understanding mathematics in ways that support teaching and assisting others (Healey et al., 2014). Moriah's preparation for student questions added a different layer of engagement with the mathematical content likely not previously accessed as a student. As an LA, knowing the answer is not necessarily the only goal. The ability to explain the process, create deeper connections, or prompt students' thinking related to the topic might be the larger goal. This connection to the process of planning and enacting active learning techniques using the four pillars affords LAs the opportunity to engage with content from the perspective of the mathematician and teacher, in order to better understand and support the learner.

In the following excerpt, Anadelia recognizes that while she served other students and worked with a mentor, she also gained other valuable skills such as developing her own content-area competence, interdependence and hands-on experiences (Chickering & Reisser, 1993).

> I worked with some of Dr. Wyn's students to help them understand the material they are going through in Calc 2. I also worked on homework that Dr. Wyn assigned me. Besides helping out others, I am also helping out myself. I am learning how to understand proofs and how to become a better mathematician. I am in the process on how to better explain myself. (Intern Anadelia, 2019)

These excerpts from the data support previous research in recognizing that undergraduate students like Anadelia find increased understanding of previous coursework and gains in their own ability to communicate content from participating in LA experiences (Talbot et al., 2015). Additionally, Adadelia identifies as a mathematician who is growing in her own knowledge and experience. Being an LA has been shown to increase undergraduate students' content and STEM identity (Close et al., 2016). The acknowledgement of increased competence through completing a learning assistantship alongside the reassurance that it is natural to continue growing in conceptual understanding and communication of previous mathematics are both indicators of growing undergraduate identity development as future STEM professionals (Chickering & Reisser, 1993).

LA Potential Value for Teaching & Working with Students

Beyond mathematics, the majority of the LA narratives of value-added experiences were linked to implications for their future. Of the coded 69 responses related to potential value, 29 of them referenced value through novel teaching activities and experiences. After further examination, 20 of the 29 responses referenced how a specific LA experience or learning had implications for their future teaching careers or opportunities. For example, participants elucidated the role and intricacies of questioning in teaching. As they worked to support students, they were confronted with opportunities where they needed to make in-the-moment decisions about the level of guidance they were going to provide. In the case of James, he shared his initial discomfort with his positionality in the classroom. As an LA, he shared how helping students to critically think about mathematics through questioning added to their depth of understanding and his understanding of what it means to support them as learners:

> At first, I was nervous about my role in the classroom, but I feel that as the classes went on, I began to feel more comfortable with my position.... Instead of just seeing if they got the right answer, I would ask students about how and what steps they used to solve the problem. One thing I have gained from this is that if you can get the students to discuss what steps they are taking, they are able to grasp the concept even more. They gain the ability to understand the process.... It will also help me in my future as an educator because I will be able to interact with students more effectively. I will be able to ask students the right questions that get them to think more critically about the topic and generate a better understanding of the material. (Scholar James, 2019)

James identified a key concept often missed by novice teachers, perhaps at both the university and K-12 levels. Rather than focus on the right answer, or "product," James recognized how instructional practices, like questioning and communication to promote critical thinking, can lead to student learning (AMTE, 2017). Another participant, Natalie, similarly shared, "I think I'm starting to get a little bit better at asking them questions to help them be able to figure out the proofs, or at least get them going in the right direction." Ultimately, the students were able to produce the desired product without directly being told by the teacher. Being an LA provided opportunities to implement research-based instructional practices, often prior to officially taking methods for teaching mathematics coursework, highlighting the importance of active learning structures and practices in involving students in their own learning for participants (Laursen & Rasmussen, 2019).

As a pillar of active learning classrooms, teachers must be able to inquire into their students' mathematical thinking (Laursen & Rasmussen, 2019). Instructional practices take time and practice to develop. While the aforementioned 20 of 29 responses related to potential value as a teaching idea that may be implemented in their own classrooms, another eight responses identified potential value in developing a heightened understanding of learners. Participants like Amanda and Natalie shared insights into the intricacies of teaching mathematics in a student-centered approach:

> I am also baffled by how easy it is for a student to look like they know the material when they really have no clue what is going on. It is challenging to identify those students and to make it a priority to engage them in the learning process. (Scholar Amanda, 2018)

> It was neat to really see the growth of the students in the class (compared to the beginning of the semester) and how they are really embracing the IBL [Inquiry Based Learning] style. All of the groups were talking and working together on the problems really well. (Intern Natalie, 2019)

These statements elicit the complexities of teaching mathematics with learners as a central focus. Amanda's comments directly link to utilizing effective formative assessment and recognizing that engagement in an active learning classroom provides less opportunity for students to just "look like" they are learning. Natalie's comments show that active learning and IBL-structured classrooms are learning environments that take collaboration and commitment on the part of both students and teachers but can be rewarding for teachers to see how students can grow (Cook-Sather et al., 2016; Healey et al., 2014; Huber & Hutchings, 2005). Unlike some practicum or classroom field experiences, LAs work with faculty and students for an entire semester. Natalie's statement reveals how this structure enabled her to notice longer-term effects of instructional practice on student learning and engagement in the active learning classroom over time.

LAs as Reflective Practitioners

Within the data, the researchers coded aspects of participant responses as simultaneously expressing both immediate and potential value. In these instances, participants expressed LA experiences that often did not go as planned or caused them to reflect back on their previous experiences. The concurrent identification of value both in the moment and indicating potential implications or meaning in the future provide insight into the types of experiences that participants grappled with the most. For example, Micah reflected on his responsibility and role as an LA after causing confusion when writing a proof, even though he did the work correctly:

> It turns out there was in fact, an easier way to do the proof, but regardless, it is my responsibility to make the information I present clear. I should have taken a little more time to walk through each step in the logic, and I should have written a bit more organized. In teaching, I know I will need to anticipate confusion, and prepare ways to make foggy things clearer. This week I didn't do that well, but I certainly will take more time on it next time. (Intern Micah, 2019)

Micah drew on his own understanding of proof writing to make his initial instructional decision (Cady et al., 2006). As he continued, he recognized students were confused and challenged whether his proof write-up was accurate. Within this reflection, Micah took responsibility for his part in the learning process. The mathematics was correct, but his comment highlights his understanding of how teachers' instructional practices can impact student learning. Within this active learning classroom, students were empowered to push back on the representation of his proof, and he was forced to think deeply not only on the mathematics, but his approach to the proof. Along with a new way of thinking about the proof, this experience invited Micah to critically consider how his actions impacted student learning alongside his students (Cook-Sather et al., 2016; Sherin, et al., 2011), and he ultimately saw this opportunity as a chance to learn and grow the next time.

Like Micah, Moriah also leveraged prior experiences to inform her new role as an LA and to cue modifications in her own instructional support for students. In her case, she recalled when she was a student in the course and her experience interacting with an LA.

> I often caught myself from just telling them the answer. I thought back to when Steven was my TA [Learning Assistant] in Calculus and how he really encouraged me to learn the steps and be more independent with Calculus. Therefore, I have to step back and let the students be more confident in their work. (Intern Moriah, 2018)

Moriah had vicariously learned the value of supporting student independence and productive struggle (NCTM, 2014) from Steven's example. As a student, she may not have considered the instructional importance of her LA stepping back so that she could gain confidence as a mathematical thinker. Now as an LA, she is able to reflect on her own experiences as a learner and apply them in an active learning environment. Similarly, Mason noted how an active learning approach "is rewarding to not only the students but to myself because though I am familiar with all the concepts, each student brings a unique perspective to the problems." Both students see student participation and input as a valuable component in a mathematics classroom (Healey et al., 2014; Laursen et al., 2019) and see that they have a role in ensuring the environment is set up to foster student-centered learning experiences.

Discussion and Conclusion

In this study, undergraduate students reflected about their experiences and the nuances of how being an LA made them: 1) think about mathematics concepts in new ways, 2) teach so that students can learn, 3) see learning beyond their own thinking, and 4) develop in their role as an LA. While learning assistantships have been shown in the past to be advantageous to undergraduate student outcomes in some fields (Close et al., 2016; Weidert et al., 2012), the research team sought to examine more granular aspects of value to identify how mathematics learning assistantships influence undergraduate students' development and how these experiences could be beneficial for preservice teachers.

The majority of undergraduate STEM student participants had not committed to teaching as their intended degree major or endorsement prior to their LA experience, yet they found similar value engaging as LAs. This suggests that situating all students, especially those undeclared, in positive, active learning environments can help them see potential future STEM career pathways, including as STEM educators. As one participant shared,

> My most memorable Noyce experience this past semester would have to be getting to work as a TA for a Calculus I class. I think that this was the closest to being a student-teacher you can get without taking a Practicum/ being an Education major. This will definitely weigh in strongly when deciding whether or not I want to switch my major. (Intern Angela, 2019)

Students can learn about content in engaging contexts that promote a depth of understanding that goes beyond traditional undergraduate experiences. However, not all novel experiences promote deep learning. These findings suggest that acting as an LA promotes content mastery for undergraduates. Twenty-first century learners need to develop these types of skills to be competitive in the STEM workforce pipeline (Hattie, 2009; Davis et al., 2015). This content mastery can build both professional competence and specialized mathematical knowledge and competence (Ball et al., 2008; Herrera et al., 2012).

According to Ball et al. (2008), "Knowledge for teaching must be detailed in ways unnecessary for everyday functioning ... a teacher needs to know more, and different, mathematics" (p. 396). Not only do mathematics teachers need to understand the mathematical content deeply, they must also be able to engage with the thinking of students and provide modeling and explanations that go beyond simply "doing math." The intersection of these knowledge types leads to effective student-centered, problem-based mathematics teaching where teachers can adapt and respond in the moment (Ball, et al., 2008; Sherin, et al., 2011). Finding that participants' value most often related to learning about mathematics, learning about teaching, and reflecting on practice creates a strong argument for providing similar experiences specifically targeted at preservice teachers.

Specifically, the LAs in this study noticed the need to understand content more deeply in order to provide explanations, and, through teaching mathematical content, they better understood the mathematics itself. LAs identified the importance of helping students learn to explain and examine their own thinking as a means of developing a deeper understanding of content. In doing so, LAs began to develop their own pedagogical knowledge in terms of finding ways to pose questions and explain concepts to learners. These skills align with the Four Pillars of active learning (Laursen & Rasmussen, 2019) in that LAs found ways to deepen their own mathematical understanding by explaining and posing questions, to facilitate reasoning and sense making. They saw the benefit of students collaborating to solve inquiry tasks, and how the role of the teacher can shift when engaging in active learning. Additionally, LAs learned to ask questions to help probe students' mathematical thinking, rather than stepping in and "telling" steps and solutions for problems. LAs identified the importance of understanding students' mathematical thinking, as well as being able to anticipate misconceptions to help them prepare to mitigate confusion in the moment (Sherin, et al., 2011). Each of these takeaways aligns with the types of mathematics and pedagogical content knowledge that preservice teachers need to develop in their teacher preparation programs. The development of such knowledge can similarly help undergraduate students' identity development (Chickering & Reisser, 1993).

The current literature on the impact of LA programs as an early teacher preparation experience is sparse, particularly in the area of mathematics. Our preliminary findings suggest that intentional LA partnerships with mathematics faculty who employ active learning practices in their undergraduate courses could present potential benefits for teacher preparation. Learning assistantships afford additional and early opportunities for preservice teachers to engage deeply with mathematics content, and to experience active learning from the perspective of the teacher. Situating such partnerships within teacher education and mathematics teaching programs can potentially provide powerful opportunities for students to engage within the discipline and develop reflective teaching praxis early on. Additional research needs to investigate the possible benefit of such programs. Within our own program, examination of these initial data has led the grant leadership team to become more intentional about providing LA experiences for each of our Interns and Scholars in addition to engagement in STEM outreach. We continue to explore ways to refine and improve upon the training and support for undergraduate LAs, and look to existing projects, such as Vandergrift et al. (2020), who have robust LA and TA programs in place. We have also begun to consider the potential for our dual enrolled secondary mathematics teaching majors to engage as LAs in the teacher education department as well as with mathematics faculty. It is our hope that our continued data collection and research can continue to inform the field as our project evolves.

References

Association of Mathematics Teacher Educators (AMTE). (2017). Standards for preparing teachers of mathematics. https://amte.net/standards

Ball, D. L., Thames, M., & Phelps, G. (2008). Content knowledge for teaching: What makes it special? *Journal of Teacher Education*, *59*(5), 389–407.

Bowen, C. W. (2000). A quantitative literature review of cooperative learning effects on high school and college chemistry achievement. *Journal of Chemical Education, 77*(1), 116–119.

Cady, J., Meier, S. L., & Lubinski, C. A. (2006). Developing mathematics teachers: The transition from preservice to experienced teacher. *The Journal of Educational Research, 99*(5), 295–306.

Carlone, H., & Johnson, A. (2007). Understanding the science experiences of successful women of color: Science identity as an analytic lens. *Journal of Research in Science Teaching, 44*(8), 1187–1218.

Charmaz, K. (2008). Constructionism and the grounded theory method. In J. A. Holstein & J. F. Gubrium (Eds.), *Handbook of constructionist research* (pp. 397–412). The Guilford Press.

Chen, C., & Yang, Y. (2019). Revisiting the effects of project-based learning on students' academic achievement: A meta-analysis investigating moderators. *Educational Research Review, 26,* 71–81.

Chickering, A., & Reisser, L. (1993). *Education and identity* (2nd ed.). Jossey-Bass.

Close, E. W., Conn, J., and Close, H. G. (2016). Becoming physics people: Development of integrated physics identity through the learning assistant experience. *Physical Review Physics Education Research, 12*(1). https://doi.org/10.1103/PhysRevPhysEducRes.12.010109

Cook-Sather, A., Abbot, S., Silvers, H. (2016). Translating partnerships: How faculty-student collaboration in explorations of teaching and learning can transform perceptions, terms, and selves. *Teaching & Learning Inquiry, 4*(2), 1–14.

Davis, B., Sumara, D., & Luce-Kapler, R. (2015). *Engaging minds: Cultures of education and practices of teaching* (3rd ed.). Routledge.

Dolan, E. (2015). Biology education research 2.0. *CBE Life Sciences Education, 14*(4), 1–2.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences, 111*(23), 8410–8415.

Gibbs, G. R. (2007). *Analysing qualitative data.* Sage.

Goff, C., & Lahme, B. (2003). Benefits of a comprehensive undergraduate teaching assistant program. *Problems, Resources, and Issues in Mathematics Undergraduate Studies, 13*(1), 75–84.

Graham, M. J., Frederick, J., Byars-Winston, A., Hunter, A.-B., & Handelsman, J. (2013). Increasing persistence of college students in STEM. *Science, 341,* 1455–1456.

Gray, K. E., Webb, D. C., & Otero, V. K. (2016). Effects of the learning assistant model on teacher practice. *Physical Review Physics Education Research, 12,* 020126.

Haak, D., HilleRisLambers, J., Pitre, E., & Freeman, S. (2011). Increased structure and active learning reduce the achievement gap in introductory biology. *Science, 332,* 1213–1216.

Hall, G. (1974). *The concerns-based adoption model: A developmental conceptualization of the adoption process within educational institutions* [Paper presentation]. Annual meeting of the American Educational Research Association 1974, Chicago, Illinois.
Hattie, J. (2009). *Visible learning: A synthesis of over 800 meta-analyses relating to achievement.* Routledge.
Healey, M., Flint, A., & Harrington, K. (2014). *Engagement through partnership: Students as partners in learning and teaching in higher education.* HE Academy. https://www.heacademy.ac.uk/sites/default/files/resources/engagement_through_partnership.pdf
Healey, M., Flint, A., Harrington, K. (2016). Students as partners: Reflections on a conceptual model. *Teaching & Learning Inquiry, 4*(2). http://dx.doi.org/10.20343/teachlearninqu.4.2.3
Herrera, F., Hurtado, S., Garcia, G. A., & Gasiewski, J. (2012). *A model for redefining STEM identity for talented STEM graduate students.* University of California, Los Angeles.
Hrabowski, F. & Henderson, P. (2017). Toward a more diverse research community models of success: A forward-looking group of colleges and universities are demonstrating effective ways to educate underrepresented minorities for careers in science and engineering. *Issues in Science & Technology, 33*(3), 33–40.
Huber, M. T., & Hutchings, P. (2005). *The advancement of learning: Building the teaching commons.* Jossey-Bass.
Jakopovic, P., & Gomez Johnson, K. (2021). Beyond traditional teacher preparation: Value-add experiences for preservice secondary mathematics teachers. *Mathematics Teacher Education and Development, 23*(1). https://files.eric.ed.gov/fulltext/EJ1295255.pdf.
Jaworski, B., & Gellert, U. (2011). Educating new mathematics teachers: Integrating theory and practice, and the roles of practicing teachers. In A. J. Bishop, M. A. Clements, C. Keitel, J. Kilpatrick, & F. K. S. Leung (Eds.), *Second international handbook of mathematics education* (pp. 829–875).
Laursen, S., Andrews, T., Stains, M., Finelli, C. J., Borrego, M., McConnell, D., Johnson, E., Foote, K., Ruedi, B., & Malcom, S. (2019). *Levers for change: An assessment of progress on changing STEM instruction.* American Association for the Advancement of Science.
Laursen, S., & Rasmussen, C. (2019). I on the prize: Inquiry approaches in undergraduate mathematics. *International Journal of Research in Undergraduate Mathematics Education, 5,* 129–146.
Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation.* Cambridge University Press.
Litster, K., MacDonald, B. L., & Shumway, J. F. (2020). Experiencing active mathematics learning: Meeting the expectations for teaching and learning in mathematics classrooms. *Mathematics Enthusiast, 17*(2), 615–640.
McDonnough, J., & Matkins, J. (2010). The role of field experience in elementary preservice teachers' self-efficacy and ability to connect research to practice. *School Science and Mathematics, 110*(1), 13–23.
Merriam, S. (2009). *Qualitative research: A guide to design and implementation.* John Wiley & Sons.
Miles, M. B., Huberman, A. M., & Saldaña, J. (2014). *Qualitative data analysis: A methods sourcebook* (3rd ed.). Sage.

National Council of Teachers of Mathematics (NCTM). (2014). *Principles to actions: Ensuring mathematical success for all.*

Nolan, K. (2006, April 7-11). *A socio-cultural approach to understanding pre-service teachers' negotiated journeys through theory/practice transitions.* [Paper presentation]. Annual Meeting of the American Educational Research Association (AERA), San Francisco.

Nolan, K. (2010). Playing the field(s) of mathematics education: A teacher educator's journey into pedagogical and paradoxical possibilities. In M. Walshaw (Ed.), *Unpacking pedagogy: New perspectives for mathematics classrooms* (pp. 153–173). Information Age.

Otero, V., Pollock, S., & Finkelstein, N. (2010). A physics department's role in preparing physics teachers: The Colorado learning assistant model. *American Journal of Physics, 78*(11), 1218–1224.

Philipp, S. B., Tretter, T. R., & Rich, C. V. (2016). Partnership for persistence: Exploring the influence of undergraduate teaching assistants in a gateway course for STEM majors. *Electronic Journal of Science Education*, *20*(9), 26–42.

Rieger, A., Radcliffe, B. J., & Doepker, G. (2013). Practices for developing reflective thinking skills among teachers. *Kappa Delta Pi Record, 49*(4), 184–189.

Saldaña, J. (2016). *The coding manual for qualitative researchers* (3rd ed.). Sage.

Sherin, M., Philipp, R., & Jacobs, V. (2011). *Mathematics teacher noticing: Seeing through teachers' eyes.* Taylor & Francis.

Talbot, R. M., Hartley, L. M., Marzetta, K., & Wee, B. S. (2015). Transforming undergraduate science education with learning assistants: Student satisfaction in large-enrollment courses. *Journal of College Science Teaching, 44*(5), 24–30.

Thomas, J. W. (1998). *Project-based learning overview.* Buck Institute for Education.

Tunks, J., & Weller, K. (2009). Changing practice, changing minds, from arithmetical to algebraic thinking: An application of the concerns-based adoption model (CBAM), *Educational Studies in Mathematics, 72*(161). https://doi.org/10.1007/s10649-009-9189-x

Vandegrift, E., Barber, N., Vitale, A., & Ward, T. (2020). Supporting science graduate teaching assistants and undergraduate learning assistants' teaching professional development. *Transformative Dialogues: Teaching and Learning Journal, 13*(3), 60–86.

Weidert, J., Wendorf, A., Gurung, R., & Filz, T. (2012). A survey of graduate and undergraduate teaching assistants. *College Teaching, 60,* 95–103.

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity.* Cambridge University Press.

Wenger, E., Trayner, B., & de Laat, M. (2011). *Promoting and assessing value creation in communities and networks: A conceptual framework.* Open University of the Netherlands.

Wenger-Trayner, E., & Wenger-Trayner, B. (2014). Learning in a landscape of practice: A framework. In E. Wenger-Trayner, M. Fenton-O'Creevy, S. Hutchinson, C. Kubiak, & B. Wenger-Trayner (Eds.), *Learning in landscapes of practice: Boundaries, identity, and knowledgeability in practice-based learning* (pp. 13–29). Routledge.

Werder, C., & Otis, M. (2010). *Engaging student voices in the study of teaching and learning.* Stylus.

Yin, R. (2018). *Case study research and applications: Design and methods* (6th ed.). Sage.

Corresponding Author
Kelly Gomez Johnson, Assistant Professor of STEM Education, 6001 Dodge St., RH406N, Omaha, NE 68182. Email: kgomezjohnson@unomaha.edu

Acknowledgements
We thank our Noyce leadership team and faculty mentors. We also thank our Noyce Scholars and Interns. We acknowledge the work presented in this paper was supported by National Science Foundation Grant No. 1852908. Any opinions expressed herein are those of the authors and do not necessarily reflect the views of the foundation.