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Supporting Science Graduate Teaching Assistants and Undergraduate Learning Assistants' Teaching Professional Development

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Abstract
Despite evidence of the need to improve student achievement through active learning implementation across undergraduate STEM disciplines, many students struggle to meet academic expectations in college science courses. Additionally, many science instructors receive inadequate or inconsistent pedagogical training. Improved training in active learning is one of several elements that may support improved student learning outcomes in sciences. Our institution, like many others, relies on graduate teaching assistants (TAs) and undergraduate learning assistants (LAs) to co-teach science courses. However, like other instructors, TAs and LAs may not receive adequate pedagogical training on implementation of evidence-based, student-centered pedagogies. Our program was designed to purposefully support trainees with professional development in scientific teaching through experiential education, faculty mentorship, and a science education community of practice. We found that consistent and structured pedagogical training provided LAs and TAs with an early introduction to best practices for inclusivity, active learning, and regular assessment. Through quantitative and qualitative responses, TAs and LAs reported that mentorship, a structured weekly journal club focused on pedagogy, and opportunities to practice new teaching techniques provided a valuable experience and prepared them for future professional opportunities.

Keywords
graduate teaching assistants; undergraduate learning assistants; professional development; scientific teaching; experiential education; community of practice; mentorship

Introduction

In spite of a wealth of data about innovative teaching strategies that dramatically increase student learning and success, college science courses remain overwhelmingly lecture-based (Freeman et al., 2014; National Academies of Sciences, Engineering, and Medicine, 2018; Stains et al., 2018). This phenomenon is commonly understood to result from a persistent culture of traditional lecture teaching, along with inadequate training for faculty, graduate teaching assistants (TAs), and undergraduate learning assistants (LAs) (Freeman et al., 2014; NASEM, 2018). The persistence of lecture-based science instruction in higher education is partly due to the self-perpetuating model of incoming instructors and faculty teaching in the same way they were taught. Pre-tenure and contingent faculty may feel it is risky to try new pedagogical models in case students or colleagues respond negatively through evaluations to a non-lecture experience. This is compounded by instructors' scarcity of time and a lack of incentives for teaching excellence. To interrupt this generational cycle and instigate effective systemic change in higher education, we built a model to train future educators—namely science TAs and LAs —in effective teaching theory and practice of evidence-based pedagogy.

There is reason to believe that creating a broad community of practice with structured training, experiential education opportunities, direct faculty mentorship, and ongoing support for TAs and LAs could improve trainee preparation and outcomes. This approach aligns with research on improving student outcomes, which shows that faculty training in evidence-based student-centered practices leads to positive impacts on student experiences. Faculty who are trained provide students with opportunity to engage more deeply with their learning and move beyond surface level rote memorization (Bathgate et al., 2019; Cavanagh et al., 2018; Roberts, 2015; Wenger-Trayner & Wenger-Trayner, 2015; Wieman, 2017). Providing graduate students with opportunities to read science education literature, observe teaching, and talk with faculty teaching mentors can provide an entry into higher education STEM teaching (Baiduc et al., 2016). However, there is limited research about programs that specifically address training of future STEM educators, and researchers call for more programs to address this ongoing need (Winberg et al., 2019).

We anticipated trainees would have improved personal and professional gains as a result of participating in a structured training program for STEM teaching. Additionally, well-trained TAs and LAs should better be able to support faculty implementation of evidence-based practices in college science courses, which could ultimately lead to improved undergraduate student learning outcomes (Otero et al., 2010; Reeves et al., in review). As others have found, ongoing, structured professional development can lead to a change in teaching culture that focuses on improving student learning (Reeves et al., in review; Wieman, 2017).

Theory of Change

Systemic change in STEM education is needed 1) to address persistent equity gaps and retain students from groups underrepresented in STEM, who demonstrate interest in STEM majors but who leave these fields in disproportionally large numbers and 2) to improve community-wide science literacy (Eddy & Hogan, 2014; Freeman et al., 2014; Riegel-Crumb et al., 2019; Theobald et al., 2020). While systemic change may lead to improved outcomes for all students, numerous factors influence an institution's ability to enact and sustain systemic change (Olson & Riordan, 2012; Weaver et al., 2015; Wieman, 2017). Some of these factors include promotion and tenure policies, hiring practices, teaching evaluation processes, classroom structures, student-centered active learning, and availability of high quality and targeted professional development for educators. As visualized in Figure 1, these factors, when activated, collectively can act as levers to impact systemic change with the aim of ultimately improving student learning and science literacy, improving student persistence in STEM fields, and reducing equity gaps.

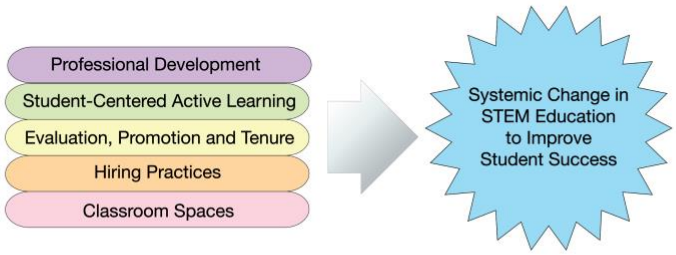

Figure 1: Representation of several elements (professional development; student-centered active learning; evaluation, promotion, and tenure; hiring practices; and classroom spaces) that support systemic change in STEM education to improve student success. Together these evidence-based elements provide the larger context of national and institute-wide efforts to transform STEM education that informed our work.

In developing our theory of change, we focused on the types of change that were reasonable to enact on our campus, taking into account the full institutional context. Our theory of change, which is visualized in Figure 2, was built around the following questions:

1. Why was the change needed?
2. Who was the target audience?
3. What programmatic opportunities could we offer?
4. Where and when would our program be situated?
5. What were the expected outcomes for participants?
6. What were the anticipated impacts on STEM education on our campus?

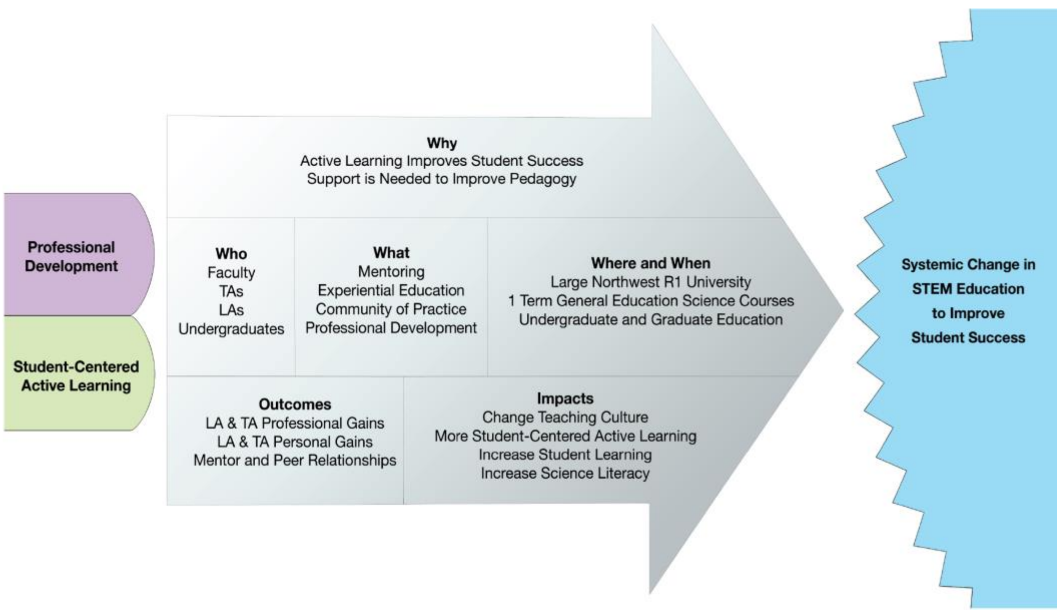

Figure 2: Our theory of change illustrates how our program was designed to transform STEM education by providing trainees (graduate TAs and undergraduate LAs) with professional development, a community of practice, experiential education, and mentorship opportunities.

Answering these questions helped program leadership determine ways we could impact STEM education reform on our campus. After reviewing the potential levers for change on our campus, we developed a program focused on professional development for early career science educators to interrupt a cycle where science educators receive limited-to-no pedagogical training. Professional development focused on changing STEM courses from lecture-focused to student-centered active learning using principles from cognitive science research shown to improve student learning (Freeman et al., 2014; Handelsman et al., 2007). Based on our institutional context and needs, we developed the program to provide science educator trainees (graduate TAs and undergraduate LAs) with experiential learning, build an intersectional cross-campus community of practice among science faculty and trainees from varied disciplinary backgrounds, support direct mentorship between faculty and trainees, and offer ongoing professional development training.

Research demonstrates that support for implementation of student-centered active learning, communities of practice, and professional development are important for improving student learning outcomes, which in turn reduces equity gaps (Bathgate et al., 2019; Theobald et al., 2020; Wenger-Trayner & Wegner-Trayner, 2015). While training programs at our institution often separate TAs and LAs in discrete disciplines, we purposefully combined trainees within one program to create a more well-rounded educational experience. Our hope was that TAs and LAs who participated in the program for one term would have increased excitement about teaching, demonstrate increased teaching confidence, and forge high quality mentor and peer relationships that could move knowledge gained during one term directly into practice as TAs and LAs in college science classrooms. Ultimately, our goal was to begin to change the culture of teaching at our institution. To meet these many needs, we conducted ongoing program evaluation as described below and iteratively modified the program based on trainee and faculty feedback.

Graduate Teaching Assistants (TAs)

At our university, 17% of all lectures, 83% of all labs, and 93% of all discussion sections of undergraduate courses across all disciplines are taught by graduate TAs (unpublished data Graduate Teaching Fellows Federation). Since TAs provide such a high percentage of undergraduate instruction, the teaching and learning environments they cultivate in classrooms and labs can significantly impact undergraduates' educational experiences. For TAs, however, teaching is a part-time job. While many TAs want to excel in their teaching, they often have competing demands for their time from their own graduate programs of study. Each department places varied emphasis on the importance of teaching, resulting in varying levels of TA training. For example, at our institution, trainings range from a week of intensive teacher training to a single one-hour workshop on widely varied topics. Our university holds a general TA training at the beginning of each academic year, but individual departments make decisions about additional training to meet the perceived needs of their TAs. Trainings might include how to grade homework or content refreshers on individual labs. Additionally, graduate students may have a difficult time learning about or participating in training programs, especially if teacher training is not supported by their graduate advisor (NASEM, 2018). The combination of these factors leaves TAs with inconsistent levels of skill development and undergraduates with inconsistent quality of teaching.

Recently, the National Academies and others have called for improved professional development for science graduate students with training that expands beyond skills needed for a specific discipline (Pavelich & Streveler, 2004; NASEM, 2018; Ross Manzo & Mitchell, 2018). A broader scope of professional development is especially important considering that the majority of students who receive science PhDs do not continue in research-exclusive careers (Wilson, 2018). By one metric, over 60% of STEM PhDs do not go on to academic research (NASEM, 2018). TA trainings that focus on skill development in active learning, communications, and collaboration not only support students in their current teaching assignments, but also build skills that are useful for future career options (Pavelich & Streveler, 2004). A well-rounded graduate experience can prepare trainees with skills for a diversity of future career opportunities. Such skills may include teaching, public speaking, science communication, and interacting with non-scientists.

Intentionally designed TA training programs have positive impacts on trainees. Trainees show increased self-efficacy, confidence in their teaching abilities, and improved public speaking skills (Boman, 2013). Training programs can also be designed to improve knowledge, skills, practices, attitudes, and beliefs about teaching, as well as to improve student learning outcomes (Baiduc et al., 2016; Reeves et al., 2016). As trainees' confidence increases, their motivation and interest in teaching may increase, too. They feel better prepared to teach and support student learning.

Unstructured teaching opportunities, where students do not receive regular feedback on their teaching or the training is not situated in pedagogical theory, may experience increased time to degree and decreased faculty advisors' support for training (Connolly et al., 2018). However, trainees who participate in structured teaching programs, where they receive specific mentorship and training, such as the NSF Graduate STEM Fellowship in K-12 Education, did not have an increased time to degree (NASEM, 2018; Shortlidge & Eddy, 2018). In fact, trainees in structured teaching programs demonstrated an improvement in science skills outcomes compared to peers who exclusively served as research assistants (Feldon et al., 2011; Trautmann & Krasny, 2006). While relatively few studies exist related to STEM graduate teacher training, those available demonstrate that structured pedagogical training programs can support graduate TAs' development as well-rounded scientists, provide future career opportunities, and improve trainees' confidence as science educators (Winberg et al., 2019).

Undergraduate Learning Assistants (LAs)

Growing evidence demonstrates the value of recruiting undergraduate LAs to support their near peers in the classroom. Student learning gains are higher in courses with LAs, perhaps due to an increase in faculty's ability to implement active learning activities and the decreased student to teacher ratios (Otero et al., 2010). In one study, introductory STEM courses supported by LAs were associated with significant reductions in failure rates for enrolled students (Alzen et al., 2018). LAs also may have a closer connection with undergraduate students enrolled in a course because they are perceived more as peers than as instructors (Bichy & O'Brien, 2014; Webb et al., 2014). Being closer in age and experience to undergraduate students, LAs may seem less intimidating than faculty or graduate TAs, and may encourage students to share their ideas more freely and engage more fully in active learning activities (Alzen et al., 2018; Fingerson & Culley, 2001).

Although LAs working in courses where they were recently students may have closer proximity to content knowledge than TAs, LAs may not receive formal training in evidence-based teaching. Lack of training can limit the effectiveness of their support in the classroom. Training in evidence-based teaching, such as active learning (Freeman et al., 2014; Handelsman et al., 2007) and classrooms with regular and consistent feedback for students (Tanner, 2013), helps LAs develop a clear understanding of and ability to support student learning in inclusive and active classroom environments. Consequently, student experiences in courses can be improved with well-trained LAs (Sana et al., 2011). When implemented, training helps LAs build their skills in "helpfulness, accessibility and perceived qualification" to best support their near peers (Filz & Gurung, 2013, p. 48).

In addition to improving student outcomes, LAs, much like TAs, are better prepared for their future professional endeavours. Trained LAs are well prepared for future careers as teachers, including as graduate TAs (Otero et al., 2010). LAs also have improved scientific content knowledge and ability to communicate complex scientific concepts (Otero et al., 2010).

Program Development and Design

Program Overview and Background

We launched the University of Oregon Science Literacy Program (SLP) in 2010. The program was housed in the College of Arts and Sciences between 2010-2019 in collaboration with five natural science departments: Biology, Chemistry & Biochemistry, Earth Sciences, Human Physiology, and Physics. We focused on reform of general education courses for non-science majors to achieve three goals:

1. Support teaching professional development and mentorship for TAs and LAs in the sciences.
2. Improve and support faculty implementation of evidence-based, student-centered pedagogies to improve student learning outcomes in the sciences.
3. Improve science literacy for non-science majors enrolled in affiliated general education courses (see Vandegrift et al., 2020 for a full description of the science literacy aims of the program).

By providing focused training for LAs and TAs, we hoped to create a pipeline for future post-secondary science educators, provide well-rounded science education training for TAs and LAs, and improve classroom experiences for undergraduate students in our courses. Program development was guided by the hypothesis that if TAs and LAs could learn the theory of evidence-based teaching combined with the opportunity to practice newly acquired skills and regular mentor feedback in a college science classroom, they could build teaching efficacy.

To test this relationship between teacher training and teaching efficacy, we provided TAs and LAs with two-pronged training: 1) pedagogical professional development within a community of practice including a weekly science education journal club, and 2) experiential learning by co-teaching a science course alongside a faculty mentor as part of a teaching team. Although TAs and LAs typically fulfill different important roles in an undergraduate classroom, we recognized they had overlapping professional development needs and saw value in a community of practice that included teaching team members across academic ranks.

Our author team includes people with varied roles within the program to support the training and evaluation of trainees. First, a biologist and STEM education professional developer led the program from 2012-2019. As program leader, she selected TAs and LAs, provided direct mentorship through one-on-one teaching discussions, observed TA and LA teaching and provided feedback, conducted the interviews that were the basis for the qualitative analysis described here, led the weekly science education journal club sessions, facilitated longer pedagogical trainings such as courses and workshops, organized events with outside speakers, taught SLP-affiliated courses, and mentored TAs and LAs in affiliated courses (e.g. Vandegrift & Cavanagh, 2019). Second, a biologist and science education researcher provided mentorship and training to TAs and LAs, facilitated pedagogical professional development, directed program evaluation, taught an SLP-affiliated course, and mentored TAs and LAs for that course. Third a non-profit education management specialist recruited and assisted with selection and mentorship of TAs and LAs and supported program evaluation. Lastly, an educational research specialist in program review and qualitative analysis conducted the original qualitative program evaluation about trainees' experiences, which served as the basis for the qualitative analysis presented here.

***Program Structure for Graduate TAs and Undergraduate* LAs**

Over the course of one academic term, graduate TAs and undergraduate LAs were selected through a competitive application process and assigned to a teaching team. Those selected co-taught an undergraduate science course with a faculty mentor. Faculty mentors from the participating departments volunteered to teach a science literacy-focused course in which they implemented evidence-based, student-centered pedagogy appropriate for the course context (see Vandegrift et al., 2020 for a full description), and mentored TAs and/or LAs as part of their regular teaching load. Faculty mentors ranged from assistant professors to career instructors to full professors, all of whom wanted to teach courses emphasizing science literacy and mentor TAs and/or LAs. Some teaching teams had one TA or LA, and others had multiple TAs and/or LAs. Some courses included faculty and TAs/LAs from the same discipline. For some interdisciplinary courses, the teaching teams included TAs and/or LAs from different disciplines (e.g., Physics of Life was taught by a teaching team that included physicists and biologists) (Parthasarathy, 2015).

In some teaching teams, TAs and LAs worked on development of new general education science literacy-focused courses. In many of these instances, trainees were engaged in all aspects of course development, from aligning learning objectives with assessments to creating course activities to leading the class sessions. In other teaching teams, trainees worked with a faculty mentor on an established course and had fewer opportunities to develop new and novel course content. In established courses, trainees might spend more time developing new clicker questions or writing exam questions. One requirement was that each TA or LA had at least one opportunity to lead an entire class session independently with direct guidance from their faculty mentor and program staff for structure, planning, practicing, and delivery.

TAs and LAs simultaneously attended a weekly science teaching journal club (described below) to explore research on evidence-based teaching practices that would support them in leading class sessions with their teaching teams. This combination of theory and practice offered students opportunities to learn about and try out non-lecture-based teaching methods; in short, it offered experiential education (Roberts, 2015). Direct mentorship from faculty and program leadership supported students' experiential learning, while professional development supported their theoretical understanding of science education research. As described more fully below, we revised the trainings and structured teaching opportunities as we better understood our trainees' needs.

During the first five years, the program was funded by a grant that allowed us to provide participating TAs with a stipend and tuition. Participating LAs received a one-term scholarship. Between 2015 and 2019, LAs received course credit for a teaching practicum or volunteered to participate. TAs continued to receive a stipend and tuition. Between 2011 and 2019, 112 TAs and 121 LAs participated. Trainees were recruited through their home departments, graduate recruitment weekends, and research advisors. A clear majority of departments and research advisors were supportive of these opportunities for students to expand their teaching skills.

Pedagogical Professional Development to Build a Community of Practice

As part of a teaching team, TAs and LAs had many opportunities to engage in distinct types of pedagogical professional development. Our professional development explicitly modeled the evidence-based pedagogies we encouraged instructors to practice in their teaching. Examples of these pedagogies include adding clicker questions to lectures to provide students with immediate feedback or creating opportunities for students to collaborate on activities during class. Importantly, professional development was designed to support people associated with our program's teaching teams and the campus-wide community. All training opportunities were open to the entire campus from undergraduate students to full professors. This was an intentional decision to expand the science education community of practice and support an inclusive and diverse teaching culture.

In cooperation with the campus center for teaching and learning, we offered a weekly science education journal club, which was attended by more than 360 participants between 2010 and 2019. The journal club provided a community of practice for faculty, TAs, and LAs across the sciences interested in exploring science education. In many traditional science journal clubs, attendees practice developing critical and close reading of literature in their field. However, our journal club focused on implementation of classroom practices described in the science education research. Our goal was to introduce a wide variety of evidence-based techniques, as described in the research, demystify the literature, and model the pedagogies. This approach helped to bridge the theory-practice gap because attendees did not merely discuss evidence-based pedagogy; instead, they saw the activities modeled, engaged in them actively, and then had opportunities to practice the activities in their respective courses (Tallman & Feldman, 2016). For example, when reading a paper on "random call," in which faculty use a randomized class list as an inclusive way to have students answer questions during class, we practiced "random call" during the journal club session and debriefed the experience (Knight et al., 2016). In another example we practiced the steps of a critical reading method with the acronym "C.R.E.A.T.E" that describes the reading steps in which students 1) Consider the topic, 2) Read, 3) Elucidate hypotheses, 4) Analyze and interpret the data, and 5) Think of the next experiment (Hoskins, 2010). Because we practiced these strategies together, trainees could later implement the ideas that they learned from journal club when they developed and taught an activity in their own course.

We regularly used principles of scientific teaching and strategies designed to improve inclusive learning environments throughout the journal club sessions (Handelsman et al, 2007; Tanner, 2013). Every participant, regardless of rank or discipline, was invited to share reflections and provide feedback to each other. We also encouraged inclusion by inviting our trainees to lead sessions on topics of interest to them, such as developing screencasts, improving physics demos, and using games to teach science. Our journal club also served as professional development for faculty members, helping them to better mentor their TAs and LAs.

Individual TAs and LAs had very different experiences with the journal club depending on which term they participated. Although some trainees participated in the journal club until they graduated (sometimes for multiple years), many only attended during the one term in which they participated in our program. The themes varied from term to term (e.g., large class teaching, teaching with technology, or teaching emphasizing diversity, equity, and inclusion).

In some cases, the journal club articles aligned well with TA and LA experiential teaching experiences, but in others, there was a disconnect because the theory was unrelated to their practical experience (e.g., the theme was large class teaching, but the TA or LA was co-teaching a class with 25 students). Additionally, the longer that we facilitated the journal club, the greater we perceived a gap between novice TAs and LAs attending their first journal club and faculty and graduate students who had been attending and reading the literature for five or more years. The participants may have aligned with the "EPIC model" (with Exposed-Persuaded-Identified-Committed stages), which describes the development of faculty implementation of evidence-based teaching (Aragón et al., 2017). In the model, individuals move through four stages: Stage 1) Exposed to the research literature on evidence-based teaching; Stage 2) Persuaded that evidence-based teaching could work for some instructors in some situations but not convinced that it can work in all situations or for them; Stage 3) Identified personally that "I can" implement evidence-based teaching strategies; and Stage 4) Committed to using evidence-based teaching in all teaching endeavors (Aragón et al., 2017). With our educator trainees and returning participants representing different points along the EPIC model continuum, we began to suspect that the journal club did not adequately meet the needs of all TAs and LAs.

Based on feedback from TAs and LAs, and paying attention to the iterative nature of professional development design (Vandegrift et al., 2018), we instituted a standardized orientation session to introduce all TAs and LAs to principles of active learning and science literacy. Through ongoing formative feedback and evaluation, we realized that the experiential education could be strengthened by providing TAs and LAs with opportunities to reflect on their learning. We added in weekly reflections on the journal club articles and created scaffolding for trainees as they developed an activity to lead in class. This was especially important when trainees joined a teaching team for a class that was already established and did not participate in course design decisions.

In a later iteration of training, we developed a more focused practicum course for TAs and LAs based on the models of inclusive teaching, backwards design, active learning, and assessment as described in *Scientific Teaching* (Handelsman et al., 2007). This change allowed us to provide more targeted reflection and curriculum development opportunities. During this practicum, TAs and LAs read science education literature and used the tools to develop and teach a "microteaching" activity. The practicum scaffolded the creation of teaching activities that aligned with their faculty mentors' course goals and provided multiple opportunities for trainees to receive feedback.

Experiential Education through Co-teaching and Mentorship

TAs and LAs applied to our program through a competitive application process. Applicants who were accepted to the program were paired with a faculty mentor and a course from one of five affiliated science departments. Faculty recruited and/or selected trainees who best matched the teaching or development needs for their particular course. Most often, students worked with a faculty member in their own discipline, but we made accommodations for background, experience, and course needs. After being placed, TAs and LAs worked closely with their faculty mentor to implement evidence-based practices in their assigned course. While not the focus of this article, faculty members were supported in their mentorship roles by the program director through regular opportunities to check-in and by the science education learning community maintained by the journal club.

Co-teaching experiences varied for TAs and LAs. Some trainees worked with a teaching team to develop new general education courses from the ground up. Others worked with faculty in well-established courses to develop and implement new, evidence-based microteaching activities. We observed each trainee as they led their microteaching activity, and we implemented the Classroom Observation Protocol for Undergraduate STEM (COPUS) to facilitate follow-up conversation about the classroom and teaching experience (Smith et al., 2013). Faculty and program leaders provided mentorship and support as trainees learned about the "behind-the-scenes" of undergraduate science teaching, such as how assessments align with class activities, design principles used in course planning, and the varied challenges of meeting the needs of diverse learners.

Evaluation of Impact

Mixed Methods Design

Participating TA and LA trainees were interviewed about their experiences with all the programmatic elements immediately following their first term using newly acquired teaching skills in the college science classrooms. Their answers to questions described later were key to understanding trainee perceptions (Williamson & Johanson, 2017). Coupled with quantitative data collected in other survey questions, this mixed method design yielded both broad descriptive and deep perception of experience data. Taken together, our qualitative and quantitative data are a comprehensive measure of the program's impact.

Quantitative Analysis

To evaluate the impact of our program on TAs and LAs, trainees completed surveys at the conclusion of each term in which they participated in the program. Faculty teaching mentors were not included in this specific evaluation but were evaluated separately. Survey data collected from TAs and LAs (n=73; 77% response rate of 94 trainees) over six terms during academic years 2013-14 and 2014-15 revealed the program's positive impact on students (Table 1).

Table 1
TA and LA Survey Responses After Program Participation

Survey Question (1-5 scale: absolutely not/negative/poor to definitely/positive/excellent)	Mean ± standard deviation (n=73, unless otherwise noted)
Did you gain valuable experience from being a TA or LA?	4.71 ± 0.22
Did your teaching experience with the program influence your views on science and teaching?	4.59 ± 0.25
Did it give you insight into yourself and your career and life goals?	4.25 ± 0.08
Was your time well spent as a TA or LA?	4.15 ± 0.36
Did the journal club improve your teaching this term?	4.42 ± 0.22 (n=31)
Did you receive adequate mentoring?	4.30 ± 0.23
Would you recommend a TA or LA position to potential TAs or LAs?	4.82 ± 0.15

As the program grew and the grant funding ended, the program evaluation changed, so we only include results here from terms that used a consistent format for the evaluation survey. Trainees were asked to reflect on their experience with the program using Likert-type ordered categorical scale items (*1-5, absolutely not/negative/poor to definitely/positive/excellent*). On average, survey respondent trainees reported between *positive (4)* and *excellent (5)* for each question listed in Table 1. Trainees reported that the experience was valuable and gave them important personal and professional insights. They also reported that they would recommend the program to others. TA and LAs received identical types of training and were provided the same types of opportunities to co-teach in their assigned courses. In both cases, the training was much greater than typical TAs and LAs in each of the affiliated departments. The key difference in their roles was that LAs were not allowed to grade undergraduate work or hold independent office hours. Because TAs and LAs were treated equally in terms of training and classroom expectations, they are combined in the analysis. The TAs and LAs in the sample period are representative of TAs and LAs across all years of the program in terms of standing in their academic program, disciplinary fields, and experiences as a co-instructor.

Qualitative Analysis

To better understand how the program (including the teaching experiences, mentorship, and professional development) impacted trainees, program staff collected qualitative data during one-on-one exit interviews with participants (n=117; 52 TAs (98% participation), 66 LAs (100% participation)) at the immediate conclusion of each of 10 terms from Fall 2012 through Summer 2015. Interviewers asked the following questions:

1. What did you gain from participation in the program?
2. What are the positive aspects of the program?
3. What would you change?
4. What did you do during a typical week?

Two interviewers conducted face-to-face sessions with each of 117 interviewees and captured all responses into word processed documents during each individual session. In consultation with researchers at University of Oregon's Center for Assessment, Statistics and Evaluation (CASE), we analyzed the qualitative data into emergent themes using spreadsheets and codes for each comment (Ryan & Bernard, 2003). Program staff and interviewers worked in tandem with CASE researchers reviewing and checking the coding during the process to ensure that the codes and emergent themes accurately and appropriately reflected student experience (Lincoln & Guba, 1985). Researchers coded 2,350 comments which were sorted into six overarching, repetitive themes (Ryan & Bernard, 2003). Themes were further subdivided into 29 subcategories, and representative comments across the themes were chosen as example illustrations.

The analysis was guided by three hypotheses that trainees would have more positive experiences; 1) if they attended journal club, 2) had a positive mentor relationship with their faculty member, and 3) had more authentic teaching responsibilities. General support was found for each of these hypotheses.

Qualitative analysis of exit interviews found six major themes that trainees emphasized in their responses. We describe each theme below with representative trainee comments and situation of the comments within the larger program or lived experience:

1. Curriculum (broadly defined as course content, course planning and development, course structure and duties)
2. Suggested improvements
3. Journal club
4. Personal gains
5. Professional development
6. Program structure

Curriculum

Participants' comments about curriculum discussed both the ways that the faculty taught the courses and their own experiences with designing, planning, and teaching. When discussing the curriculum of their course, trainees focused on course content, course planning and development, and course structure and duties. Some students were unable to distinguish between their experiences working with a mentor as a co-instructor and the actual course content delivery.

> *"This class was not from my major so it was fun to learn something new; Learned a lot about physics and the internet" - LA, Spring 2014*

Comments revealed that, in some courses, tension developed between faculty mentors and trainees regarding the amount of new information that was developed and how the courses were taught. As a general trend, trainees were eager to develop and deliver material they had built for the course, but faculty were more cautious.

> *"Sometimes wanted to add in more information but was discouraged from adding more. Structure and content stayed the same as last year rather than new development." - LA, Winter 2014*
>
> *"Would have liked to help more related to course material" - TA, Fall 2013*
>
> *"Didn't get a sense of planning a course because it's a repeated course" -TA, Fall 2013*
>
> *"Course Critique: Class would benefit from noting how each day fits into the overall theme of the course and course needs more organizational structure within the planning phase" - TA, Winter 2013*

When provided, the experience of developing and delivering new course material was overwhelmingly positive for trainees, giving them ownership and an understanding of what goes into preparing and teaching a college course. TAs, in particular, articulated how the experience as a co-instructor was different than their typical TA roles in their home departments.

> *"What I liked the best was to work on the parts of class that you don't get to do as a GTF* [Graduate Teaching Fellow, typical TA position*]—structure and format lecture, find information, write exam questions, come up with activities for students either 300 or 30 people." – TA, Winter 2015*
>
> *"[Instructors] let students [TAs and LAs] choose what they wanted to teach and make it fit with syllabus—lots of freedom in choosing what would be taught" - TA, Spring 2013*

Being involved in course planning was particularly valuable for undergraduate LAs who had never experienced a course from this perspective.

> *"We had the power to change the class and really add content and that was nice." - LA, Winter 2015*
>
> *"I had no idea how much went into planning a course like that—to do that was amazing." - LA, Spring 2015*

> *"It was exactly what I wanted to learn what goes on behind the scenes to see what it goes into assessment. Loved that it was SLP and we were trying to use creative and fun approaches to learning" - LA, Spring 2015*

Suggested Improvements

Participants offered many ideas for ways to improve the program, but none suggested dismantling or discontinuing it. In fact, comments were unanimously positive and many suggested innovative ways to make the program stronger, accessible to more students, and more consistently implemented.

> *"More one-on-one check-ups with [LAs] and [TAs] throughout the term..." - LA, Winter 2013*

> *"Want venue where grad students can practice techniques, want opportunities to go sit in on other [program] courses." - TA, Fall 2013*

Most critiques centered on course content that was chosen by the faculty, issues working with particular faculty mentors, or when trainees' expectations (for designing and delivering new content or level of responsibility) did not align with the experience.

> *"Wanted more responsibility. Wanted more practice teaching. Learned a lot of strategies but didn't implement them due to lack of opportunity to do so - idea – learn new technologies in Journal Club and apply those techniques in the next week' s teaching" - LA, Winter 2015*

> *"Jumped into working with the class that is maintenance phase and not much room to contribute new ideas;" -TA, Winter 2013*

> *"Felt surprised about the experience when I jumped into the term and didn't know what I was supposed to do, some pre-training could have helped, didn't know responsibilities at first . " -LA, Fall 2012*

> *"Want venue where grad students can practice techniques, want opportunities to go sit in on other SLP courses, grad student recruitment in geology, mini workshop on writing multiple choice questions because it' s so hard." - TA, Fall 2013*

Good mentorship from faculty and a positive experience working with the entire teaching team was important to trainees' overall experience in the program.

> *"At first I thought there were too many of us working at the same class—was worried there wouldn't be enough to do—at first wanted more explicit expectations of what we would do each week, sometimes I wasn't sure if I wasn't doing enough, but at the end it was a big fun team, and really great to work with, worked with [instructor] to make sure that [other TA] and I had enough to do' - TA, Winter 2015*

> *"Faculty member was nice but difficult to work with because there were not clear expectations for what we were to do in the class" - LA, Fall 2013*

Graduate students had more positive experiences when they had teaching appointments with more hours each week. The range of appointments, based on departmental norms, was between 8-18 hours per week. Based on student feedback, the program evolved to make all TA appointments 16-18 hours per week standard practice.

> *"Miscommunication on workload, [instructor] thought I [had] a full appointment [16 hours per week appointment] rather than half [8 hours per week]. Problem of time—wasn't much time left after all the required things class, journal club, grading, 2 office hours, and reviewing papers. Wasn't much time left for designing class—class design suffered and* [8 hours per week] *insufficient to get full experience of teaching a class—still very good experience." TA, Spring 2014*

Some students were able to participate for more than one term. Although not all trainees participated for multiple terms, those that did reported great value in this.

> *"Positive to be part of program for two terms…the second term, we were able to implement [more] ideas." - LA, Spring 2015*

Journal Club

Many trainees remarked on journal club's interesting, beneficial discussions and activities related to teaching techniques and articles. Unlike typical science journal clubs that focus on the critique of a study, the focus of this scientific teaching journal club was on building a learning community, demystifying science education literature, and modelling best practices from the literature. Each week, participants practiced with different teaching techniques, and many commented on this positively.

> *"Liked reading the book with cohesive themes...I wouldn't have read the book on my own but learned a lot from it." - LA, Winter 2013*

> *"Favorite part of the program was the journal club. Helpful and enjoyable. Loved journal club." - LA, Winter 2013*

> *"Nice to apply ideas from journal club in a real class and not just as a good idea..." - TA, Winter 2014*

> *"...going through the different examples of teaching styles and doing them in journal club—thought this was really helpful..." - TA, Spring 2014*

> *"I enjoyed the journal club...I had never appreciated that you could look at teaching and education as a science to study." - TA, Winter 2015*

Trainees overwhelmingly thought they got more out of their experience if they prepared by reading the material, although many were not always able to do so because they did not make time for the reading in their individual schedules. Journal club was also initially only suggested, but trainees found the experience valuable enough that they thought it should be required for both trainees and faculty mentors. Based on trainees' feedback, we made this change in later years.

> *"We should require going to journal club. [It] helped me think…more deeply and learn from more experienced people." - LA, Spring 2014*

Trainees also appreciated that discussions included a wide range of attendees from different disciplines and academic ranks, and they commented on the environment where everyone was welcomed and encouraged to participate.

> *"I'd never been in a journal club with so many different people where we were all equal, even the undergrads spoke a lot." - LA, Spring 2014*

> *"Really enjoyed the teaching activities we got to do in the journal club. It was a better way to truly understand what type of technique you're dealing with and experiencing it from the other side so when you're teaching you know the student side too." - TA, Spring 2014*

Personal Gains

Participating TAs and LAs reported personal gains across a wide range of domains, including empowerment, inspiration, intellectual involvement, introspection, mentor relationships, peer relationships, student interactions, and self-image.

> *"I feel so much more confident. I know techniques, strategies, and theories."* - TA, Fall 2013

> *"Huge learning experience. As the term went on, I got better at having that teacher mindset." - LA, Winter 2015*

Students felt empowered by the responsibility they were given in a course and the opportunity to engage with teaching in meaningful and personal ways. The experience positively impacted many students' self-image and self-efficacy. Trainees were inspired by interacting with others who care deeply about science education, and were in turn excited to inspire students in the classroom. They described value in engaging intellectually with their teaching team and reflected on their own roles in the classroom as both students and teachers.

> "*It was great to have a comfortable environment where we could try new things, and it was a great group to work with. We all had different experiences coming into the class and [the faculty member] let us rule the class." - TA, Winter 2015*

Both peer and mentor relationships were critical to the program success, and trainees valued working on teaching teams that included faculty, graduate TAs, and undergraduate LAs. Trainees reported that working with students in their courses was rewarding, and they enjoyed seeing students make learning gains.

> *"Strength to have undergrad [LA]s and graduate [TAs] working together."* - LA, Fall 2012

> "*Also really liked working with graduate student [TAs]. They were just as good mentors as [the professor]*." - LA, Fall 2014

Professional Development

Professional development of trainees was a central program goal and the bulk of participants' comments in exit interviews spoke to this aspect of their experience. These extensive comments were overwhelmingly positive.

> *"Learned a lot that I didn't know and made me keep an open mind to different ways of teaching and learning, and learning about research." - LA, Fall 2014*

> *"Liked [program staff] class observation...it was nice to have feedback...would like to continue getting feedback from other faculty during grad school..." -TA, Fall 2012*

Participants' comments included evaluation of teaching, future teaching training, pedagogical approaches, student assessment, teaching skills, and team communication. Trainees recognized that even when the experience was difficult, they could identify positive outcomes.

> *"This is such a unique opportunity for graduate students and undergraduates and it sets us apart and it's nice to be able to have those opportunities to pursue teaching from a rigorous academic viewpoint before graduating. Fantastic! ... Really glad I've had this opportunity to learn how to teach before teaching my own class." - TA, Winter 2015*

> *"Experience invaluable for training teachers." - LA, Winter 2015*

Trainee comments frequently analyzed pedagogical approaches and choices in a thoughtful way that applied to their program training.

> *"In previous terms, when I just taught [as a regular department TA], I wanted to comment on things but I wasn't looking at ways we could enhance the class overall..." -TA, Spring 2014*

> *"I was shocked what grading was like from the faculty perspective." -LA, Spring 2014*

Trainees also identified components of the program and their experience that could be important to future professional success within scientific careers. In many cases, trainees also identified that they could be successful teachers in the future.

> *"Developed skills that will go beyond the [the program]." - LA, Fall 2012*

> *"For first time considering that teaching could be part of career and not only research..." – TA, Winter 2013*
>
> *"It has changed...how I interact with the public scientifically." - TA, Fall 2014*

Program Structure

Although prompted "What would you change?", few participants offered much in the way of constructive critiques of how the structure of the program could be improved in administration or organization. As described above, most improvement comments focused on workload, mentorship, and expectations. Mostly trainees gave examples of why the program should continue, how well the program coordinator organized it and resolved issues, and how unique the opportunity was on campus for both graduate TAs and undergraduate LAs. Several trainees remarked that they would like more opportunities to engage with the program. One LA suggested a national network of similar programs would be a powerful way that trainees could continue to engage throughout their academic training.

> *"Would be nice to have multiple quarter fellowship." - TA, Fall 2013*
>
> *"Recommended to three friends..." - LA, Winter 2014*
> *"I think [the program] is awesome and something to take to other schools, because if you could get this program to be a network—LA at one school and then get involved in another program at another school [as a graduate TA]." - LA, Spring 2014*

Reflections

Continuum of Previous Experience

Trainees entered the program with a range of exposure to, and experience with, evidence-based teaching (Aragón et al., 2017). For some trainees, the program marked the first time they experienced active learning or inclusive teaching. Some were wary of active learning ideas in which, for example, students completed group problem sets during class or responded to clicker questions, because they did not match their own undergraduate experiences of lecture-based courses. Many had not previously been exposed to the STEM education research literature or ideas of evidence-based teaching in which discipline-based education researchers and faculty who conduct the scholarship of teaching and learning have examined student engagements that best support student learning. Other trainees were excited to try something new. Some trainees had prior experience as students or TAs in active learning classrooms and wanted to further their knowledge and teaching abilities.

Trainees may follow a pathway and be at different stages of buy-in to, and implementation of, evidence-based teaching. As described in relation to the journal club, the "EPIC model" (Exposed-Persuaded-Identified-Committed) describes this development of educators as: Stage 1) trainees are first exposed to the STEM education research literature on evidence-based teaching and active learning; Stage 2) trainees are persuaded that evidence-based teaching could work for some TAs, LAs, or faculty mentors in some situations, but may not believe that it can work in their course or for their students; Stage 3) trainees identified personally that they have the skills and support to be able to implement evidence-based teaching strategies; and Stage 4) trainees are committed to using evidence-based teaching practices in all of their teaching opportunities (Aragón et al., 2017). During one term of the program, trainees may not move along the continuum to a point where they are committed to leading with evidence-based teaching in course design and implementation. However, based on the trainees' exit interview comments, the program did boost trainees' confidence in their teaching ability, which is applicable to many future careers.

> *"Learned a lot that I didn't know and made me keep an open mind to different ways of teaching and learning and learning about research" - LA*, Fall 2014

It is our hope that this experiential education will ignite trainees' growth and development as educators, and that they will continue to implement inclusive, active learning experiences for their future students.

Growth Mindset

In our experience, providing direct mentorship with theoretical and practical experience supported trainees' skill development as educators. In many exit interviews, trainees reflected deficit thinking about students (e.g., that students are "lazy" or "can't learn the science content").

> *"Tried to go for groups during class who were just 'sitting there'" - LA, Winter 2013*

This type of deficit thinking can have negative impacts on student learning experiences (Canning et al., 2019). As we explored science education literature in the journal club, we had opportunities to unpack many assumptions and biases held by our trainees. While we found that it was difficult to dispel all of these beliefs in one 10-week term, many trainees *did* have experiences that challenged their assumptions. For example, numerous trainees reported having students in class who trainees didn't think could learn the material because of their non-science background; however, TAs and LAs saw that these students were successful with support. Other trainees realized that their personal experiences as science majors were quite different from the experiences of non-science majors students enrolled in general education courses. When their students did not understand course material, our trainees began to see this not as a failure on the part of the students, but rather as an opportunity to inform course changes that could improve the learning experience for everyone.

> *"[Professor] lectured on Monday then developed a couple of hard questions to present on Wednesday's class. Students did great on Monday, but were stumped on Wednesday. Provided everyone with good feedback"* - TA, Winter 2013
>
> *"[Students] who were really struggling ended up doing well" – LA,* Spring 2014
>
> *"Really hard throughout—when you're having an interaction with the students hard to know if they are learning the material. I appreciate that kind of subtle knowledge that I gained from doing this teaching. Knowing how to listen to people and how to talk to people." - TA*, Spring 2014

Several trainees continued to attend journal club after the completion of their TA or LA term, and they continued to explore their long-held biases and confront their own misconceptions about students.

Pedagogical Professional Development and Community of Practice

TAs and LAs benefited from being part of a community of practice that was intentionally intersectional across the university, including faculty, graduate students, and undergraduate students, at one count from 22 separate campus units. Trainees commented on how powerful it was to interact with faculty and mentors in a non-hierarchical environment and learn about the behind-the-scenes of teaching. LAs especially commented on how positive it was to be in a learning space where their voice and experience was as respected as that of faculty.

> *"Nice to try and write homework and get feedback from faculty" -LA*, Fall 2012

> *"Gave really good feedback about my performance as a lecturer and doing demos. Would have liked more feedback on questions I wrote for homework and question. Also really liked working with graduate students they were just as good mentors as [instructor]" - LA*, Fall 2014

This community of practice created opportunities for each person to learn from each other, explore new teaching ideas in a safe environment, and feel supported in their teaching endeavours. However, in leading the journal club and working with trainees, as described above, we learned that creating a learning community was not enough to adequately train all TAs and LAs to feel prepared to teach. Additionally, each mentor had slightly different teaching expectations for their TA or LA. Several students requested additional training, structure, and clear expectations to feel adequately prepared to teach.

Much like we modify our classrooms iteratively to reflect feedback from student assessments and better support learning, so too did we modify the learning experiences for our trainees to better support their experiences and continue to meet their training needs (Vandegrift et al., 2018). Therefore, we continued to modify the program to provide additional workshop training for TAs and LAs to aid in the preparation of their classroom teaching. We also codified requirements for developing and leading at least one microteaching activity during the term and included transparently designed instructions to clearly articulate the microteaching goals and process (Winkelmes et al., 2016). Collectively, these changes were designed to make trainees feel sufficiently confident and supported in their teaching.

Experiential Education Through Co-teaching and Mentorship

As described in the qualitative comments, the mentorship and experiences that TAs and LAs received through the program had a positive impact on many trainees. They had opportunities to listen to and participate in discussions of best practices in teaching with faculty mentors both through reading research literature for journal club and teaching team meetings. Beyond reading the science education literature, trainees also had opportunities to observe faculty modeling teaching practices from theoretical conversations. Then, trainees taught their own class activities to practice with immediate application of what they had learned from reading the literature, conversations, and observing other teachers. This immersive experiential education supported trainees' teaching development by meaningfully integrating research and practice. Many mentioned this in their interviews.

> *"Course had lots of elements of active learning (clicker, flipped classes, tutorial) a lot more interacting with students in discussing physics."* - *LA*, Winter 2015
>
> *"Tried out CREATE activity* [(Hoskins, 2010)] *with teaching staff and it went well" – TA*, Fall 2013
>
> *"I did a concept map, brought up questions and had them talk together in groups"* - *TA*, Spring 2015

Faculty provided varying levels of mentorship based on their own philosophy and trainees' needs. It was important to be sensitive to the fact that faculty have prior experience as mentors and have developed their own style and approach to mentorship. Over time, we learned that additional orientation could support faculty as they mentored a diversity of trainees (e.g., content background, teaching experience, etc.). We thought about this as a "meta-mentorship" role from program leadership to faculty (and then faculty to TAs and LAs). We learned that providing clear expectations for mentors was as important as providing clear expectations for TAs and LAs.

We did not anticipate the additional positive mentor role that many TAs would play as part of their experiential education. LAs saw TAs as mentors in the course and future academic pathways. TAs did not always acknowledge or realize the role they played in mentorship of undergraduate LA colleagues. This experience likely helped prepare TAs to mentor undergraduates in future teaching positions.

Sustainability

The program was funded by a science education grant for five years and then by a provost strategic initiative proposal. Grassroots support from faculty and TAs and LAs, as cultivated through the intersectional community of practice, was key to program longevity. In addition to grassroots support, we also had administrative support from STEM department heads, college leadership, the provost's office, the graduate school, and the office of the vice president for research and innovation. The program was situated to "lead change from the middle" across administrative structures and disciplinary units and was well-positioned to interact with faculty and administrators (Nickerson, 2014). For long-term STEM education reform to continue, a program such as ours requires buy-in across the university.

Future Work

For future work, researchers might more deeply explore the faculty experience of mentoring graduate TAs and undergraduate LAs. This could help improve understanding of the ways in which faculty may feel supported or unsupported as mentors; this could inform future structures and programmatic elements for supporting trainees teaching professional development. Some faculty expressed reticence with allowing trainees to participate in the program, mentoring undergraduate LAs (favoring instead to only work with graduate TAs), or allowing trainees to creatively implement new practices from journal club into the co-taught course. The EPIC model provides a scaffolding for future exploration of faculty experiences (Aragón et al., 2017). Are there commonalities among faculty who show reticence? Are they at the level 2 stage: "persuaded" this type of teaching will "work for others but not for me"? How does that impact their mentorship of TAs and LAs?

Researchers could also explore more how the development of trainee education development programs fit within a model of Systems Change. One model of Systems Change as used by the Partnership for Undergraduate Life Sciences Education Northwest (PULSE NW) includes the following seven elements (Seven Lessons for Leaders in Systems Change):

1. Foster community and cultivate networks.
2. Work at multiple scales.
3. Make space for self-organization.
4. Seize breakthrough moments when they arise.
5. Facilitate—but give up the illusion of directing change.
6. Assume change takes time.
7. Be prepared to be surprised.

In leading the program, we experienced each of these elements. However, researchers could more systematically explore the ways that this model aligns with ours and others' lived experiences and perceptions of working with faculty who choose to opt in or out of mentoring students. Additionally, longitudinal tracking of former TAs and LAs could be informative as to whether the short-term experiences and gains of the trainees lead to long-term improvement in STEM education outcomes in their future careers as educators—exploring the notion that change takes time.

Final Thoughts

In developing this program, we hoped that TAs and LAs who participated for one term would demonstrate increased excitement about teaching, personal gains such as increased teaching confidence or high-quality mentor and peer relationships, and an ability to apply their program learnings directly in college science classrooms. We did see that, collectively, pedagogical training, a supportive community of practice, experiential education, and direct mentorship can have a positive impact on science TAs and LAs. They were not set in their teaching habits, were willing to learn new skills, and were excited to build their career portfolios.

Our past trainees have begun to move into faculty, teaching, research, and industry positions and report anecdotally that the science communication and teaching skills they developed in our program have prepared them well for their varied next career steps. While we have been unable to track the future outcomes of every single trainee, we know that the high-quality experiences we provided matter to the individuals who keep in touch with us. These experiences are meeting the call for improved, coordinated training for graduate TAs and undergraduate LAs as one step on the path towards improving STEM education. Training of future educators has the potential to result in long-lasting impacts to undergraduate STEM education. Graduate TAs and undergraduate LAs can be a key leverage point for systemic change.

In fact, one afternoon as we were writing this paper, a past LA—who was then in his fourth year of graduate school—stopped by to express his gratitude for the ways that participating in the program prepared him to lead class activities, write assessments, and communicate with students. Participating in the program allowed him to feel confident in his teaching abilities and create meaningful learning experiences for his own students. Stories like these illustrate how our program's effect on just one LA could positively impact STEM learning experiences for hundreds of future undergraduate students. Unlike so many professors thrown into the classroom with no training, our alumni need not automatically turn to lecture. Instead, they can draw from their experience in our program to explore the rich, burgeoning scholarship of teaching and learning. They can follow our journal club model to build communities of practice that support and engage this complex work. And they can continue the cycle of systemic change in STEM education by mentoring their own students to become excellent, inclusive educators.

References

Alzen, J. L., Langdon, L. S., & Otero, V. K. (2018). A logistic regression investigation of the relationship between the learning assistant model and failure rates in introductory STEM courses. *International Journal of STEM Education, 5(1)*, 56. https://doi.org/10.1186/s40594-018-0152-1

Aragón, O. R., Dovidio, J. F., & Graham, M. J. (2017). Colorblind and multicultural ideologies are associated with faculty adoption of inclusive teaching practices. *Journal of Diversity in Higher Education.* https://psycnet.apa.org/record/2016-26875-001

Baiduc, R. R., Linsenmeier, R. A., & Ruggeri, N. (2016). Mentored discussions of teaching: an introductory teaching development program for future STEM faculty. *Innovative Higher Education, 41*(3), 237–254. https://doi.org/10.1007/s10755-015-9348-1

Bathgate, M. E., Aragón, O. R., Cavanagh, A. J., Waterhouse, J. K., Frederick, J., & Graham, M. J. (2019). Perceived supports and evidence-based teaching in college STEM. *International Journal of STEM Education, 6*(1), 11. https://doi.org/10.1186/s40594-019-0166-3

Bichy, C., & O'Brien, E. (2014). Course Redesign: Developing peer mentors to facilitate student learning. *Learning Assistance Review (TLAR), 19*(2). https://nclca.wildapricot.org/resources/Documents/Publications/TLAR/Issues/19_2.pdf#page=47

Boman, J. S. (2013). Graduate student teaching development: Evaluating the effectiveness of training in relation to graduate student characteristics. *Canadian Journal of Higher Education, 43*(1), 100–114. https://doi.org/10.47678/cjhe.v43i1.2072

Canning, E. A., Muenks, K., Green, D. J., & Murphy, M. C. (2019). STEM faculty who believe ability is fixed have larger racial achievement gaps and inspire less student motivation in their classes. *Science Advances*, *5*(2), 1–7. https://doi.org/10.1126/sciadv.aau4734

Cavanagh, A. J., Chen, X., Bathgate, M., Frederick, J., Hanauer, D. I., & Graham, M. J. (2018). Trust, growth mindset, and student commitment to active learning in a college science course. *CBE Life Sciences Education, 17*(1). https://doi.org/10.1187/cbe.17-06-0107

Chism, N. V. N. (1998). Evaluating TA programs. *The Professional Development of Graduate Teaching Assistants*, 249–262.

Connolly, M. R., Lee, Y.-G., & Savoy, J. N. (2018). The effects of doctoral teaching development on early-career STEM scholars' college teaching self-efficacy. *CBE Life Sciences Education, 17*(1). 1–15. https://doi.org/10.1187/cbe.17-02-0039

Eddy, S. L., & Hogan, K. A. (2014). Getting under the hood: How and for whom does increasing course structure work? *CBE Life Sciences Education, 13*(3), 453–468. https://doi.org/10.1187/cbe.14-03-0050

Feldon, D. F., Peugh, J., Timmerman, B. E., Maher, M. A., Hurst, M., Strickland, D., … Stiegelmeyer, C. (2011). Graduate students' teaching experiences improve their methodological research skills. *Science, 333*(6045), 1037–1039. https://doi.org/10.1126/science.1204109

Filz, T., & Gurung, R. A. R. (2013). Student perceptions of undergraduate teaching assistants. *Teaching of Psychology , 40*(1), 48–51. https://doi.org/10.1177/0098628312465864

Fingerson, L., & Culley, A. B. (2001). Collaborators in teaching and learning: Undergraduate Teaching assistants in the classroom. *Teaching Sociology, 29*(3), 299–315. https://doi.org/10.2307/1319189

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 of the United States of America*, *111(*23), 8410–8415.

Handelsman, J., Miller, S., Pfund, C. (2007). *Scientific teaching*. W.H. Freeman.

Hoskins, S. G. (2010). “But if it's in the newspaper, doesn't that mean it's true?” Developing critical reading & analysis skills by evaluating newspaper science with CREATE. *The American Biology Teacher, 72*(7), 415–420. https://doi.org/10.1525/abt.2010.72.7.5

Knight, J. K., Wise, S. B., & Sieke, S. (2016). Group random call can positively affect student in-class clicker discussions. *CBE Life Sciences Education, 15*(4), 1–11. https://doi.org/10.1187/cbe.16-02-0109

Lincoln, Y.-G., & Guba, E. G. (1985). *Naturalistic inquiry.* SAGE Publications.

National Academies of Sciences, Engineering, and Medicine, Policy and Global Affairs, Board on Higher Education and Workforce, & Committee on Revitalizing Graduate STEM Education for the 21st Century. (2018). *Graduate STEM education for the 21st century*. National Academies Press.

Nickerson, J. (2014). *Leading change from the middle: A practical guide to building extraordinary capabilities.* Brookings Institution Press.

Olson, S., & Riordan, D. G. (2012). Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics. Report to the President. Executive Office of the President. https://eric.ed.gov/?id=ED541511

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.

Parthasarathy, R. (2015). “The physics of life”: An undergraduate general education biophysics course. *Physics Education, 50*(3), 358.

Pavelich, M. J., & Streveler, R. A. (2004). An active learning, student-centered approach to training graduate teaching assistants. 34th Annual Frontiers in Education, 2004. FIE 2004. https://doi.org/10.1109/fie.2004.1408571

Reeves, P. M., Bobrownicki, A., Bauer, M., & Graham, M. J. (n.d.). Communicating Complex STEM Program Evaluation to Diverse Stakeholders.

Reeves, T. D., Marbach-Ad, G., Miller, K. R., Ridgway, J., Gardner, G. E., Schussler, E. E., & Wischusen, E. W. (2016). A conceptual framework for graduate teaching assistant professional development evaluation and research. *CBE Life Sciences Education, 15*(2). https://doi.org/10.1187/cbe.15-10-0225

Riegle-Crumb, C., King, B., & Irizarry, Y. (2019). Does STEM stand out? Examining racial/ethnic gaps in persistence across postsecondary fields. *Educational Researcher, 48*(3), 133–144. https://doi.org/10.3102/0013189X19831006

Roberts, J. W. (2015). *Experiential education in the college context: What it is, how it works, and why it matters.* Routledge.

Ross Manzo, W., & Mitchell, K. M. W. (2018, September 11). We Need to Rethink Training for Ph.D.s. Retrieved April 24, 2019, from Inside Higher Education website: https://www.insidehighered.com/advice/2018/09/11/academic-training-phds-needs-focus-more-teaching-opinion

Ryan, G. W., & Bernard, H. R. (2003). Techniques to identify themes. *Field Methods, 15*(1), 85–109. https://doi.org/10.1177/1525822X02239569

Sana, F., Pachai, M., & Kim, J. A. (2011). Training undergraduate teaching assistants in a peer mentor course. *Transformative Dialogues: Teaching and Learning Journal, 4*(3), 1–10. https://journals.kpu.ca/index.php/td/article/view/1257/711

Seven Lessons for Leaders in Systems Change. (n.d.). Ecoliteracy.org. Retrieved April 23, 2020, from https://www.ecoliteracy.org/article/seven-lessons-leaders-systems-change

Seymour, E. (2005). *Partners in innovation: Teaching assistants in college science courses.* Rowman & Littlefield.

Shortlidge, E. E., & Eddy, S. L. (2018). The trade-off between graduate student research and teaching: A myth? *PloS One, 13*(6), e0199576. https://doi.org/10.1371/journal.pone.0199576

Smith, M. K., Jones, F. H. M., Gilbert, S. L., & Wieman, C. E. (2013). The Classroom Observation Protocol for Undergraduate STEM (COPUS): A new instrument to characterize university STEM classroom practices. *CBE Life Sciences Education, 12*(4), 618–627. https://doi.org/10.1187/cbe.13-08-0154

Stains, M., Harshman, J., Barker, M. K., Chasteen, S. V., Cole, R., DeChenne-Peters, S. E., … Young, A. M. (2018). Anatomy of STEM teaching in North American universities. *Science, 359*(6383), 1468–1470. https://doi.org/10.1126/science.aap8892

Tallman, K. A., & Feldman, A. (2016). The use of journal clubs in science teacher education. Journal of Science *Teacher Education, 27*(3), 325–347. https://doi.org/10.1007/s10972-016-9462-7

Tanner, K. D. (2013). Structure matters: twenty-one teaching strategies to promote student engagement and cultivate classroom equity. *CBE Life Sciences Education, 12*(3), 322–331. https://doi.org/10.1187/cbe.13-06-0115

Theobald, E. J., Hill, M. J., Tran, E., Agrawal, S., Arroyo, E. N., Behling, S., Chambwe, N., Cintrón, D. L., Cooper, J. D., Dunster, G., & Others. (2020). Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math. *Proceedings of the National Academy of Sciences, 117*(12), 6476–6483.

Trautmann, N. M., & Krasny, M. E. (2006). Integrating teaching and research: A new model for graduate education? *Bioscience, 56*(2), 159–165. https://doi.org/10.1641/0006-3568(2006)056[0159:ITARAN]2.0.CO;2

Vandegrift EVH, Beghetto RA, Eisen JS, O'Day PM, Raymer MG, Barber NC. (2020). Defining science literacy in general education courses for undergraduate non-science majors. *Journal of Scholarship of Teaching and Learning, 20*(2) 15–30. https://doi.org/10.14434/josotl.v20i2.25640

Vandegrift EVH, Cavanagh A J. (2019). Building student literacy and metacognition through reading science in the news. *CourseSource*. https://doi.org/10.24918/cs.2019.37

Vandegrift, E. V. H., Mulnix, A. B., Yates, J. R., & Chaudhury, S. R. (2018). Workshopping a workshop: Collaborative design in educational development. *To Improve the Academy, 37*(2), 207–227. https://doi.org/10.1002/tia2.20080

Weaver, G. C., Burgess, W. D., Childress, A. L., & Slakey, L. (2015). *Transforming institutions: Undergraduate STEM education for the 21st century*. Purdue University Press.

Webb, D. C., Stade, E., & Grover, R. (2014). Rousing students' minds in postsecondary mathematics: The undergraduate learning assistant model. *Journal of Mathematics Education at Teachers College, 5*(2), 39–47. https://doi.org/10.7916/jmetc.v5i2.653

Wenger-Trayner, E., & Wenger-Trayner, B. (2015). *Communities of practice: A brief introduction.* https://www.ohr.wisc.edu/cop/articles/communities_practice_intro_wenger.pdf

Wieman, C. (2017). *Improving how universities teach science.* Harvard University Press.

Williamson, K., & Johanson, G. (2017). *Research methods: Information, systems, and contexts*. Chandos Publishing.

Wilson, C. (2018). Status of Recent Geoscience Graduates, 2017. American Geological Institute.

Winberg, C., Adendorff, H., Bozalek, V., Conana, H., Pallitt, N., Wolff, K., Olsson, T., & Roxå, T. (2019). Learning to teach STEM disciplines in higher education: A critical review of the literature. *Teaching in Higher Education, 24*(8), 930–947. https://doi.org/10.1080/13562517.2018.1517735

Winkelmes, M.-A., Bernacki, M., Butler, J., Zochowski, M., Golanics, J., & Weavil, K. H. (2016). A teaching intervention that increases underserved college students' success. P*eer Review: Emerging Trends and Key Debates in Undergraduate Education, 18*(1/2), 31–36. https://www.aacu.org/peerreview/2016/winter-spring/Winkelmes

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