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Development of Undergraduate Teaching Assistants as Effective Instructors in STEM Courses

By Stephanie B. Philipp, Thomas R. Tretter, and Christine V. Rich

This study examined the development of peer mentoring skills and deepening of content knowledge by trained and supported undergraduate teaching assistants (UTAs) working with students in entry-level STEM courses across nine departments at a large research-intensive U.S. university. Data were collected from two sources: a survey with 10 items requesting 5-point Likert-type responses and an open-ended reflection written by each UTA to process their experiences. The survey responses were analyzed by comparing rates of agreement across the 10 items. Statements from the reflections were categorized by research question and descriptively labeled to capture the essence of implied or explicit meaning. UTAs reported developing stronger pedagogical skills and fostering metacognitive approaches to learning, as well as benefitting personally from improved communication skills. UTAs also indicated they have deepened their own knowledge of content in their discipline and learned to use more strategies for becoming a better learner.

Like many postsecondary institutions, our university has a mandate to improve the retention of students majoring in STEM (science, technology, engineering, and mathematics) disciplines. We are addressing this challenge by implementing, evaluating, and refining a student-centered instructional program (Kober, 2015; Labov, Singer, George, Schweingruber, & Hilton, 2009). This study is contextualized in a STEM retention improvement initiative that integrates key leverage points highlighted in the literature: It is focused on engaging interventions in introductory STEM courses (Kober, 2015; Perez, Cromley, & Kaplan, 2014); it aims to directly impact actions in the classroom including research-based support for student learning and informal career guidance (Abdul-alim, 2011; Chapin, Wiggins, & Martin-Morris, 2014; Sheppard et al., 2010); and, most important, it is embedded in a university-wide effort to identify and institutionalize successful STEM retention strategies (Henderson, Beach, & Finkelstein, 2011).

The main objective of this initiative was to design a program that could prepare cohorts of undergraduate teaching assistants (UTAs) to serve as the linchpins for elevating instructional practices in STEM introductory courses at a research-intensive university. What distinguishes this UTA program is that it seeks to meet the learning needs of thousands of introductory-level STEM students across nine STEM disciplinary departments. Reproducibility and sustainability necessitated the development of a joint UTA training and support program that is nonetheless tailored to prepare each UTA with a common skill set as they assume roles and responsibilities unique to the teaching needs of the nine participating departments (described next). The UTAs are trained and mentored by a multidisciplinary team of science education faculty and STEM disciplinary faculty from each participating STEM department. We postulated that the active involvement of STEM faculty would validate the program for the UTAs as an important professional development experience, and the participation of science education faculty would ensure that research-based student-centered instructional strategies were integrated into the training. The envisioned collaboration of faculty across three colleges was ambitious, but it demonstrated the interdisciplinary support for improved STEM learning and student retention by our university.

The purpose of this study was to

examine the initial experiences of the UTAs involved in such a broad-based program. We describe the training and support program, as well as an analysis of both survey responses and open-ended reflections by the UTAs. Subsequent studies will report on the comparison of student outcomes for students who have trained and supported UTAs and those who have traditional, untrained graduate teaching assistants (GTAs).

UTA programs

At our university, busy GTAs rarely opt for formal training in learning theory or discipline-specific pedagogy. In contrast, undergraduate STEM students are not under pressure to publish a dissertation, so their motivation to participate in a teaching opportunity comes from wanting professional development and to help their peers. One UTA stated, "I just wanted my students to have a better learning experience than I had in general chemistry."

UTAs have been used to engage students in learning and to act as intermediaries between a course professor and students in that course. UTAs can serve as an effective social comparison for their less-experienced peers because they have been recently successful in the same introductory STEM courses (Wheeler, Martin, & Suls, 1997). Our UTA program integrates features from previously successful UTA and peer mentoring programs using engaging learning activities (e.g., Amaral & Vala, 2009; Chapin et al., 2014; Gafney & Varma-Nelson, 2007; Gosser et al, 1996; Otero, Finkelstein, McCray, & Pollock, 2006; Otero, Pollock, & Finkelstein, 2010; Popejoy & Asala, 2013; Romm, Gordon-Messer, & Kosinski-Collins, 2010; Schalk, McGinnis, Harring, Hendrickson, & Smith, 2009; Tien, Roth, & Kampmeier, 2002; Weidert, Wendorf, Gurung, & Filz, 2012). Not only can UTAs support learning by less-experienced students, UTA programs can be beneficial for the UTAs themselves. Benware and Deci (1984) showed that when people learned material to teach it to someone else, they were more intrinsically motivated, had higher conceptual learning scores, and perceived themselves to be more engaged in the material. The UTA programs mentioned here also report evidence that correlates improved self-confidence and communication skills, deeper content knowledge, and more well-defined career goals with participation as a UTA.

Because the effectiveness of UTAs for student learning was critical to the success of our STEM retention improvement program, we deemed the development of skillful UTAs who perceived themselves as able to teach less-experienced peers a necessary preliminary target outcome of the program. Specifically, we wanted to know in what ways UTAs changed in teaching skills and as learners due to participation. To that end, the following research questions were addressed:

1. What learning assistant skills did the UTAs consider to be most important for being an effective UTA?
2. In what ways, if any, did UTA learning assistant skills change over the course of the semester?
3. In what ways, if any, did the UTAs recognize deepening of their own content knowledge and/or self-learning approaches as a result of their experience?

Preparation and support for UTAs

To offer strong learning assistance to less-experienced peers, UTAs need both content knowledge support and pedagogical training. For our program, UTAs and STEM disciplinary faculty participated in pedagogical training guided by science education faculty. This training consisted of two parts: (a) a 3-day workshop immediately prior to the teaching semester that highlighted learning theory readings (e.g., Bransford, Brown, & Cocking, 1999), four key pedagogical strategies, and best teaching practices for STEM learning and (b) bimonthly hour-long seminars over the course of the teaching semester, each focusing on one of the four pedagogy strategies: formative assessment strategies, convergent/divergent questioning, mental models and preconceptions, and development of metacognitive skills. Workshop activities were interactive and led by both science education and STEM faculty. Topical examples used to model learning theories and pedagogical strategies were spread over the various science, mathematics, and engineering disciplines represented by the UTAs. The bimonthly seminars began with the UTAs sharing, in both small groups and to the whole group, reflections on their successes and obstacles in implementing a learning theory–based strategy (e.g., increasing use of divergent discussion questions) with their assigned students during the previous 2 weeks. After that, the UTAs were reintroduced to another learning theory and a corresponding, concrete set of strategies that had been demonstrated and discussed in the presemester workshop. They planned, in small groups, how they might implement the new theory-based strategy with their students during the coming weeks. At the next seminar, they were expected to have reflected on their successes or obstacles in implementing the new strategy and be ready to discuss and implement another learning theory. UTAs were paid a stipend and received one course credit in exchange for their work.

An additional support for UTAs was through weekly meetings with STEM faculty in their home departments. Content concerns and strategies for increasing student learning were discussed in discipline-specific cohorts. STEM faculty shared their experiences with common content struggles by students in their courses and discussed common student misconceptions; the UTAs then applied newly learned pedagogical strategies to help overcome those obstacles.

How UTAs were used as instructors

To retain maximum flexibility and relevance of UTA work for each of the nine participating STEM departments, the context of the UTA work varied. Some departments chose to use UTAs to lead weekly 25-student recitation sections that were attached to a large (e.g., 300-student) lecture class. Others used UTAs to lead laboratory sections. Others used UTAs embedded in classes where there was structured time for the UTAs to lead small-group, problem-solving sessions as a scheduled activity within the normal course time (e.g., 15 minutes of a 75-minute course). Still other departments used UTAs to hold scheduled supplemental instruction for students who voluntarily wished to take advantage of this resource.

Methods

This descriptive study of the UTA experience used a single group design, with data collection (survey and reflection) from the UTAs taking place at the end of the teaching semester, when the experience was both fresh in their minds yet largely completed for the semester.

Sample

The UTAs were selected by STEM departmental faculty based on a departmental GPA > 3.0, an application demonstrating interest in teaching, and recommendation from a professor vouching for the applicant's communication skills and ability to connect with peers. Faculty chose 95 unique UTAs over the course of two semesters, with 17 UTAs participating both semesters, for a total of 112 UTA experiences. A departmental breakdown of the UTA sample for this study is shown in Table 1.

TABLE 1

Undergraduate teaching assistants (UTAs) by department (*n* = 112).

Department	Spring 2012 UTAs	Fall 2012	
		New UTAs	Returning UTAs
Bioengineering	2	0	0
Biology	11	10	0
Chemistry	11	4	8
Chemical Engineering	0	5	0
Civil Engineering	0	7	0
Engineering Fundamentals	4	5	0
Geography/Geosciences	5	5	3
Mathematics	6	4	4
Physics	9	7	2
Total number of UTAs	47	48	17

Instruments

UTA experience survey

The experience survey (see Table 2) had 10 Likert-type items (5 = *strongly agree* to 1 = *strongly disagree*) with responses received from a total of 97 UTAs (87% response rate) from spring (n = 44) and fall 2012 (n = 53) semesters. The survey questions were adapted from a similar survey used by Hug, Thiry, and Tedford (2011), which were in turn adapted from the Science Teaching Efficacy Belief Instrument (Riggs & Enochs, 1990). Although self-reported measures are not the only way to assess the impact a program has on its participants, these items directly asked the UTAs about their perceptions of their abilities, so the survey was a valuable data source for our research questions.

UTA end-of-semester reflection

We received 99 UTA responses

(88% response rate of the possible 112 responses) from spring (n = 42) and fall 2012 (n = 57) semesters from a written reflection consisting of open-ended prompts relating to their UTA experience. The prompts were developed specifically for this program by the researchers as a written assignment. UTAs individually reflected on their experiences during the teaching semester, and these reflections were used to help the faculty improve the experience for future UTAs. UTAs were directed to answer the prompts in essay form with enough detail to clearly communicate their thoughts. The open-ended nature of this instrument enabled the possibility for uncovering any strong trend of UTA-generated ideas that converged around similar themes. Given the universe of possible responses, any trend that was identified across this sample of UTAs suggested that the underlying construct may be quite strong to be independently highlighted by multiple UTAs. Reflection prompts asked UTAs to do the following:

- list the most important qualities of an instructor based on their experiences,
- describe successes and challenges they experienced in the classroom,
- discuss any skills they improved or want to improve as a result of being a UTA, and
- give examples of how they have changed as a scholar.

Analyses

UTA experience survey

The number of UTAs rating each item *agree* or *strongly agree* is reported in Table 2. Differences in responses across the items are examined and discussed next.

UTA end-of-semester reflection

A stratified random sample of 21 of the 99 open-ended response sets of the six prompts (balanced across semesters and departments) were independently read and analyzed by two researchers. The independent analysis consisted of first reading the response set, identifying all statements judged as relevant to one of the three research questions, and categorizing each relevant statement within a research question. The researchers compared the statements they had independently selected and categorized within a specific research question to determine interrater reliability. The overall categorization agreed on 82% of the statements, ranging from 75% to 96% across each separate research question. The researchers reconciled differences and came to consensus on explicit criteria for identifying and categorizing state-

TABLE 2

End-of-semester experience survey for undergraduate teaching assistants (UTAs; *n* = 97).

Item no.	Statement	Percentage of UTAs rating item as *agree* or *strongly agree*
16	I am typically able to answer students' questions.	99
15	I understand discipline concepts well enough to be a UTA.	96
2	I am confident in my ability to help students understand concepts in the discipline.	95
1	Being a UTA has improved my teaching skills.	92
9	Being a UTA has improved my ability to better understand the perspectives of others.	89
11	The UTA experience has strengthened my ability to communicate ideas in my discipline.	89
3	I facilitate my UTA session effectively.	86
17	I question whether I have the skills necessary to be an effective UTA. (reverse coded)	86
18	Being a UTA has increased my discipline knowledge.	72
12	Being a UTA has improved my ability to cooperate with others.	63

ments within research questions. The researchers then split the remaining reflection sets to independently identify and categorize statements.

Once open-response statements were categorized within research questions, descriptive labels were assigned to capture the essence of the inferred or explicit meaning expressed in UTA statements. These labels were developed through an inductive process across the two researchers to result in an agreed-on set of labels characterizing the nature of the UTA statements.

Results

UTA experience survey

Results from the survey (Table 2) indicated that over 90% of UTAs were confident in their content knowledge including their ability to answer students' questions, personally understand discipline concepts, and help students understand concepts in the discipline. The results from these three items help to answer Research Question 3 in that they demonstrate a UTA's confidence in his or her content knowledge. Most UTAs agreed or strongly agreed with statements on the survey that indicated they perceived a change in their skills (Research Question 2), namely improvement in their teaching skills, their ability to understand the perspective of others, and their communication skills. UTAs as a group felt less sure about whether the experience helped to increase their content knowledge (Research Question 3), with 70 out of 97 respondents agreeing or strongly agreeing with that statement. This seems surprising, given what we know about the positive relationship between preparing to teach content and the deepening of content knowledge (Benware & Deci, 1984; Otero, Pollock & Finkelstein, 2010. UTAs as a group were less willing to agree or strongly agree with the statement that being a UTA improved their ability to cooperate with others (Research Question 2), with 61 out of 97 respondents agreeing or strongly agreeing with that statement.

UTA end-of-semester reflection

Combining spring and fall semesters, we received a total of 99 end-of-semester reflections (88% of 112 possible reflections). From the structured, inductive coding process implemented by the two researchers, the most frequent descriptive labels were tabulated and reported in Tables 3, 4, and 5.

Research Question 1

If a UTA wrote about a topic that was categorized into Research Question 1, such as adaptable teaching styles, in response to more than one prompt, it was only counted once. So each UTA could write about more than one skill, but each skill mentioned was counted

TABLE 3

Important learning assistance skills frequently reported by undergraduate teaching assistants (UTAs).

RQ1: Important learning assistance skill	Frequency mentioned (out of 99 UTAs)	Representative quotes
Engaging teaching	37	Able to incorporate some real-life scenarios, which made the material a bit more interesting and applicable. [Spring 2012]
Patience	35	Patience—you have to be willing to understand that not everyone has had the same background. [Fall 2012]
Develops student rapport	27	Be approachable for a student to ask questions and the students must feel comfortable with the instructor. [Fall 2012]
Content knowledge	24	You must certainly know the material! [Fall 2012]
Enthusiastic about subject	22	Instructors need to be passionate about what they are teaching. [Spring 2012]
Adaptable teaching styles	21	An effective instructor must be able to change their teaching approach when they identify that it is not effective for a student. [Spring 2012]
Assesses prior knowledge	19	[use of] a pretest to see where everyone stands in these courses. [Fall 2012]

only once, regardless of how many times an individual mentioned the skill.

Research Question 2

The open-ended reflection prompts directly asked about change over the semester, as well as other prompts that led to responses from which researchers could infer change in UTA skill. The results reported in Table 4 include all of the categorized and labeled statements from the full set of six reflection prompts.

Research Question 3

UTA responses that were categorized as relevant to Research Question 3 emerged across a number of the reflection prompts, particularly the prompt asking them to reflect on their growth as a scholar. We found that UTA responses could be characterized as either a comment on their change in content knowledge depth because of their UTA work, or a statement about how they had a greater understanding of the learning process because of their UTA work and how that proved helpful to their becoming a stronger learner themselves. Some UTAs mentioned only one of these constructs, whereas other UTAs mentioned both constructs. Table 5 highlights the frequency of these two response types.

Discussion

Research Question 1: Important teaching skills

The most popular skill that UTAs thought that STEM instructors should have was the ability to teach in an engaging style. Consistent with the literature cited earlier (e.g., Kober, 2015), this skill was expressed as teaching that gets students interested and as clear communication, breaking down complex ideas into manageable ones. UTAs often mentioned real-world examples as helpful for learning new concepts. This is characteristic of an instructor who works within Vygotsky's (1978) zone of proximal development, in that the instructor can engage the students at their current level of development using realistic examples and familiar ideas and guide the student from that foundation to higher levels of development.

The next most frequently suggested skills by the UTAs were patience and ability to build student rapport, which could easily characterize an effective "More Knowledgeable Other" in Vygotsky's (1978) theory and Wheeler, Martin, and Suls' (1997) proxy social comparison model for self-assessment. For a learner to maximally benefit from a more knowledgeable peer, de-

TABLE 4

Change in peer learning assistance skills.

RQ2: Learning assistance skills change	Frequency mentioned (out of 99 UTAs)	Representative quotes
Improved public speaking skills	40	I personally do not like getting up in front of people I do not know, and talking to them. This experience helped me get much more comfortable in these situations. [Spring 2012]
Improved explanatory skills	23	This position forced me to take what was in my head and put it into words. [Fall 2012]
Improved questioning skills	15	I'm already learning how to ask the right kinds of questions. [Fall 2012]
Improved other pedagogical strategies	15	My experience has helped me learn more about the strategy of wait time. [Fall 2012]
Improved communication skills	10	I learned how to communicate effectively when trying to describe a process. [Fall 2012]
Improved metacognition skills	8	Thinking about thinking was something new that I had never thought about before. This helped me determine how my students learned. [Fall 2012]
Patience	7	This program helped me with my patience while teaching someone. [Spring 2012]

veloping a supportive relationship would be critical. The remainder of the skills UTAs identified as important for a STEM instructor revolved around both knowing the content at an appropriate depth and interacting with the learners in enthusiastic and appropriate ways. Collectively, the UTA perspective data present a spectrum of instructor skills that have been well-established in the literature as important for enhancing STEM retention. This underscores an outcome that supports the possibility of these UTAs being able to positively impact STEM retention of the students they work with, which is the ultimate goal of the program.

Research Question 2: Improved teaching skills

Across the data sources, UTAs strongly reported improvement in their own teaching skills. From the experience survey, UTAs agreed with items representing improvement in teaching. In the open-response reflection, UTAs independently generated a number of key skills that represented their improvement in teaching over the course of the semester. These included general skills such as public speaking and formulating clear explanations, as well as a number of specific skills such as questioning and use of other pedagogical strategies. These areas in which they improved align well with effective STEM instruction, suggesting that the combination of program elements was successful in supporting UTA development of effective skills.

In particular, several of the teaching skills the UTAs highlighted were direct elements of the UTA training, including use of concepts such as *metacognition, formative assessment,* and *questioning techniques*. This is additional evidence that the UTA training was a key element to skill improvement because these particular strands were the structural emphases of the workshop and seminars.

Research Question 3: Deepening of content knowledge and self-learning

Outcomes for the UTAs captured by Research Question 3 were probably the most surprising to them (based on comments on open-response reflection) but were the most expected by the faculty designing the UTA program. Because the selection process ensured that UTAs were not only majors in the department but also academically strong students, it was reasonable for UTAs to conclude that they had already mastered the foundational content material. A number of them expressed surprise at how this UTA experience deepened their existing knowledge, with a full 50% (Table 5) explicitly mentioning this aspect when queried to write about how this experience affected them as a scholar. The slightly lower overall rating for the survey item "increased content knowledge" reported in Table 2 suggests that when responding to this question, UTAs likely were thinking of "increased" in the sense of "new content knowledge" and had not considered the possibility of "deepening foundation you already know" as one way to increase content knowledge.

Along with the benefit of deeper content knowledge, UTAs reported even more strongly that they deepened their process knowledge base for becoming an even stronger learner, with 61% of them (Table 5) indicat-

TABLE 5

Deepening of content knowledge and of self-learning approaches.

RQ3: UTAs recognize deepening of their own content knowledge and/or self-learning approaches	Frequency mentioned (out of 99 UTAs)	Representative quotes
Self-learning approaches	61	[UTA experience] has allowed me to understand the process of learning as opposed to just learning knowledge . . . I am more conscious of how I come to understand a topic. [Fall 2012]
Content knowledge	50	While you're teaching others a subject it parallels topics that are being brought back up in current [upper level] courses; therefore you are not only benefitting the students, you are benefitting yourself. [Fall 2012]

ing this outcome for how this experience affected them as a scholar. The deepening of content knowledge and strategies for learning will undoubtedly serve these students well in future professional endeavors.

Conclusions

These results show that the UTA program has resulted in positive outcomes for UTAs, preparing them to be effective instructors for other STEM students and also benefitting them professionally. Although UTAs are not a population targeted for retention concerns, beneficial experiences from being a UTA could help even strong STEM students become more productive and facilitate their future growth as valuable contributors to the field.

After participating in this program, UTAs have indicated agreement with statements inquiring about improvements in their teaching in general and in their abilities to teach their content domain in particular. Although the UTAs recognized the importance of strong content knowledge for effective teaching, they collectively ranked other skills higher, such as engaging teaching, patience, and developing rapport. This outcome highlights their recognition that content knowledge alone, while certainly necessary, isn't always sufficient to be a good instructor. Moreover, the UTAs were very focused on their students' learning rather than demonstrating their own mastery of content knowledge, with statements illustrating a strong sense of responsibility for student learning. Notably, the UTAs often wrote about how they had improved their teaching skills but realized they could take steps in the future to continue improving their practice.

The UTAs have also benefitted more personally from improved public speaking and other communication skills. In addition, they recognized that they deepened their knowledge of foundational content in their discipline. The UTAs overwhelmingly reported that they have learned and begun to use strategies for becoming a better learner themselves. These changes in content depth and approaches to self-learning were the most universally noted changes that UTAs reported experiencing as a result of being in the UTA program.

With this set of improvements and strengths documented for the UTA group, the first link of the retention initiative appears to be functioning. If UTAs become effective as instructors, then positive impacts on the students they work with is a viable possibility. Future studies will describe the UTA classroom practice in detail as well as explore impacts on their students' learning and attitudes.

Independently of whether the UTAs are or are not having a measurable impact on the learning of the students they are working with, the strengthening of the UTAs themselves has additional spinoff positive benefits for STEM learning in society. Many of the 95 STEM undergraduates in this study will eventually be training or teaching or leading others in their futures, perhaps through corporate training programs, formal or informal mentoring of new hires into their work unit, or working with and mentoring future university cooperative education engineering students in industry. There are likely some among this group who will eventually become faculty in a STEM department at an institution of postsecondary education, where their UTA skills will make them a more effective instructor for the next generation of college STEM students. Some of them may choose to become high school or middle school science teachers. Some may volunteer with local groups to support student learning in tutoring contexts such as after-school programs or as a parent of a child who is participating in the school learning experiences. In fact, we know from informal communication with UTA alumni that 38% of the UTAs in this study who graduated in a science or mathematics discipline are currently enrolled in a graduate school program in a STEM field, over 20% are in professional school (medical, dental, veterinary), 5% are employed in a STEM field, and 3% are teaching secondary science. We have been unable to reach 34% of the UTA alumni, so their current careers are unknown. Given the many and varied ways in which a well-educated STEM person will have opportunities to support the learning of others in the future, the program's success in strengthening UTA learning and their ability to help others learn is likely to have ripple impacts for many years. ■

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