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Factors Contributing to the Development of Graduate Teaching Assistant Self-Image

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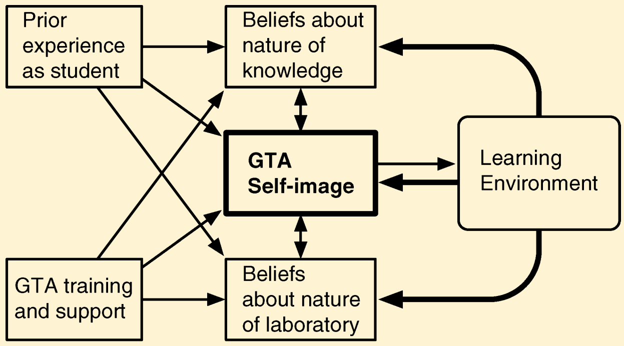
S *Supporting Information*

ABSTRACT: Laboratory graduate teaching assistants (GTAs) play a prominent role in undergraduate chemistry education. Although the success of a laboratory program relies significantly on the performance of GTAs, only rarely have they been considered actual partners in instruction or have their experiences in the academic lab been investigated. This paper reports on an embedded multiple case study designed to investigate how chemistry graduate students in two independent and very different learning environments constructed their GTA self-image and what aspects contributed to this process. Participants in this study included 13 GTAs from an expository-based program and 11 GTAs from an inquiry-based program. Interviews, memos, training artifacts, laboratory manuals, and course syllabi were collected to generate case reports for each program. Findings suggest that GTAs' construction of their self-image is shaped through the interaction of several factors: prior experiences, training, beliefs about the nature of knowledge and about the nature of academic laboratory work, and involvement in the laboratory setting. Findings from this study encourage laboratory coordinators to reconsider GTA participation in instruction in a new and different light and, when applicable, to look at their training and support from a new angle. Instead of focusing exclusively on what and how to teach, lab coordinators may design training and support programs that also target the factors that influence construction of GTA self-image. A more fruitful experience is attainable for students and GTAs insofar as the graduate students develop a teaching assistant self-image consistent with the specific instructional objectives.



KEYWORDS: *TA Training/Orientation, Graduate Education/Research, General Public, Laboratory Instruction*

■ INTRODUCTION

Chemistry laboratory instruction has been viewed as an integral component of the chemistry curriculum since Liebig's introduction of the apprenticeship model of student training.[1] Perhaps no area in chemistry education has seen as much attention, particularly in the past half-century with the appearance of science curricula that emphasize the processes of science and the development of higher-order cognitive skills.[2] In spite of this thriving interest, learning in the college chemistry laboratory continues to be an underinvestigated topic.[3,4] Certainly, articles addressing the pedagogic value of laboratory instruction and implementation and design of experiences are abundant, as are reports of novel laboratory experiments, often dating back to times preceding the creation of this *Journal*. However, in our opinion, this historic interest in laboratory instruction has not effectively translated into comparable educational research endeavors. In 1998 Hilosky, Sutman and Schmuckler[4] stated that "reporting on research related to the impact of laboratory experiences on student learning and attitudes seems minimal in light of the level of funding" available to advance reform in college chemistry. Moreover, the role of graduate teaching assistants (GTAs) in chemistry laboratory education has too often been completely overlooked in educational research.[5]

The prominent role of GTAs is indisputable, even more so at large research universities where GTAs teach virtually all of the laboratory courses.[5−7] Not surprisingly, already in 1994, Lazarowitz and Tamir[8] suggested that GTAs are the most influential factor affecting laboratory instruction, and, more recently, Herrington and Nakhleh[5] argued "that the lack of progress in laboratory teaching is our failure to consider the laboratory instructor". These assertions constitute a firm argument for more research-oriented studies in this area. Consideration of chemistry GTAs has traditionally revolved around their abilities to perform their responsibilities in compliance with a well-established curriculum or in tune with a given instructional innovation.[7,9−12] That is, an instrumentalist view of the role of GTAs has prevailed, and only rarely have they been considered actual partners in instruction or has attention been paid to the impact that teaching experiences may have on their professional development. Seldom has "TAing" been actively seen as integral part of chemistry graduate education, and often it seems to be reduced to a necessary evil to secure graduate researchers' financial support.[13]

There are some significant exceptions to this approach in the sciences in general. For instance, Seymour and collaborators have conducted ethnographic studies on science graduates and undergraduates involved in laboratory and small-group facilitation to investigate the benefits of teaching.[14] In 2002, French and Russell[15] posed an intriguing question that has influenced our prior research: "Can teaching inquiry-based labs complement other activities through which GTAs learn to conduct research?"[15] By using a pre- and postsemester questionnaire, French and Russell[15] provided evidence that the GTAs participating in an inquiry-based introductory biology course perceived that facilitating the learning environment contributed to their research abilities. More recently, Feldon et al.[16] compared written proposals of students holding teaching assistantships and research assistantships and found those who held a TA position showed improved abilities to generate testable hypotheses and design valid experiments. However, a specific focus on benefits available for the chemistry GTA is missing for these studies. Using qualitative methods, Roehrig and collaborators[7] first approached the task of understanding new chemistry GTAs' experiences when engaged in inquiry-based instruction. Their discipline-specific findings and insights led to a series of suggestions to address some of the obstacles faced by these GTAs through training and staff meetings.

Similarly, other authors[10,17−24] have provided descriptions of GTA training at different levels of detail and sometimes in the context of a teaching course linked to the GTA experience. Such is the case of Bond-Robinson and Bernard Rodriques,[11] who provided a detailed description of a GTA course based on their Laboratory Teaching Apprenticeship model. Understanding the factors that influence GTAs' performance is pivotal in developing their effectiveness in accomplishing the laboratory instruction goals that chemistry educators value and national reports[25] recommend. As part of a larger research program, we have conducted phenomenological studies to explore the lived experiences of two groups of GTAs engaged in instruction in two substantially different general chemistry programs: one inquiry-based,[13] the other expository.[26] This prior work, which also includes phenomenological study of students' lived experiences,[27] sheds light on the essence of the GTA experience in each program and the nature of gains and benefits available to them. Moreover, from these studies, the construction of a self-image as instructor and its impact on the learning environment emerged as an influential factor in GTAs' experience. The research described here derives from this prior work, and its purpose is to investigate how graduate students in two independent and very different learning environments constructed their GTA self-image and what factors were associated with this process.

■ METHOD

Study Design and Context

We chose an embedded multiple case design to gain understanding of the processes associated with GTAs' construction of their self-image as instructors and the factors influencing these processes. Case study is a qualitative tradition that has gained increased use since the 1980s.[28] Our selection of case study was guided by the stance that case studies are the "preferred strategy when 'how' and 'why' questions are being posed, when the investigator has little control over events, and when the focus is on a contemporary phenomenon within some real-life context".[29] In an embedded multiple case study, researchers conduct independent case studies and make comparisons within each case and across the cases.

The cases in this study are the experiences of GTAs in two diverse general chemistry laboratory programs at two research-intensive U.S. universities in the Southeast. By defining the cases in this manner, the units of analysis are the GTAs within each case. In our view, the multiple-case approach is justified, given the significant differences in the instructional context of each program. Based on common criteria to classify laboratory experiences,[30] the first program can be described as traditional, deductive, and verification based, hereafter referred to as the expository program. In the expository program, students worked in groups to complete weekly experiments and individually completed weekly reports. (For a detailed description, see Sandi-Urena et al.[26]) Using the same classification scheme,[30] the second program would be classified as inquiry. In this program, students worked cooperatively on multiweek projects, and each project was followed by either a laboratory report or group presentation. (For a detailed description, see Sandi-Urena et al.[13])

Data Collection

Primary data collection for both cases used a semistructured interview protocol divided into three main parts. GTAs were given the opportunity to describe their prior experience as general chemistry students, their perceptions of their current students' experiences, and finally, their experience teaching in the laboratory. Interviews were conducted with 11 GTAs with teaching experience ranging from one to four semesters in the expository program; 13 first-semester GTAs participated from the inquiry program. Table 1 provides characteristics of the GTA participants. Interviews lasted approximately one hour, were audio-recorded, and were later transcribed and cataloged with pseudonyms. Additional interviews with the laboratory coordinators focused on the coordinators' goals for laboratory instruction, GTA training, and typical GTA duties. These interviews helped clarify references that GTAs made to features of their training.

Table 1. Distribution of Participants by Program Type

Participants' Demographics[a]	Expository Program, $N = 11$[b]	Inquiry Program, $N = 13$[b]
Female	6	5
Domestic	6	8
Prior teaching experience	6	5

[a]The participants' ages ranged from 20s to early 30s. [b]These data sources were used: interviews (GTAs and lab coordinators); interview memos; laboratory manual; course syllabus; training artifacts.

In addition to these interviews, laboratory manuals, course syllabi, GTA training materials, and interviewer memos were collected for each case (Table 1). These materials were used to supplement information that was not clear during the original interviews (e.g., a reference to a specific lab project).

Data Analysis

Data analysis followed the explanation-building strategy described by Yin.[31] This strategy involves comparing findings of an initial case to theoretical propositions, revising the propositions, if needed, and checking the evidence of the case

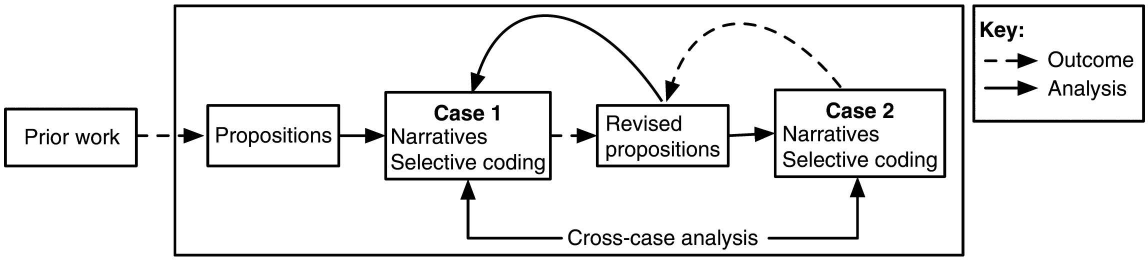


Figure 1. Data analysis scheme.

against the revised propositions. The revised propositions can then be checked with the facts of multiple cases, repeating the steps as necessary. The use of multiple cases also allows for cross-case analysis: comparing and contrasting evidence across the individual cases. Figure 1 presents the sequence we followed during data analysis. These steps are described in the following paragraphs.

In accord with case study methodology, we developed a set of propositions to guide our research. In the process, we considered propositions related to advisors' influence, personal interests, departmental culture, and other similarly relevant domains. However, we decided to keep only those propositions that fell directly within the impact range of the lab experience. These propositions were based both on our own prior studies and on literature.

Proposition 1: GTAs' teaching performance is associated with the way they see themselves as instructors, that is their GTA self-image.[13,26]

Proposition 2: In the absence of any other factor, GTAs will base the construction of their GTA self-image on their perception and interpretation of prior experiences.[7]

Proposition 3: Training and staff meetings influence GTAs' construction of their self-image.[5,7,11]

Testing against these propositions involved multiple steps (Figure 1). First, we generated a narrative of each GTA's experience. A sample narrative is provided in the Supporting Information. Next, we selectively coded each interview, based on our propositions, looking for instances in the interviews that related to GTAs' self-image, prior experiences, and training. Analysis of the narratives and coding results were checked against the propositions, using a pattern-matching strategy.[29] At this stage, the initial propositions can be expanded in depth and number to account for any emerging evidence. All propositions were checked again against the case evidence before moving on to the analysis of the second case, the inquiry-based program. For the second case, we replicated the analysis procedures used for the first case, except the selective coding included items related to the revised propositions. After the completion of the second case, we carried out a cross-case analysis by contrasting and comparing the individual case findings. The cross-case analysis helped us refine the model presented in the findings. A discussion of findings from each case and the cross-case analysis follow.

FINDINGS AND DISCUSSION

The model presented in Figure 2 condenses findings from the cross-case analysis and addresses our revised propositions.

In this model, there is a recursive interaction between the learning environment and the GTA self-image. At first the way that the graduate students perceive themselves as instructors

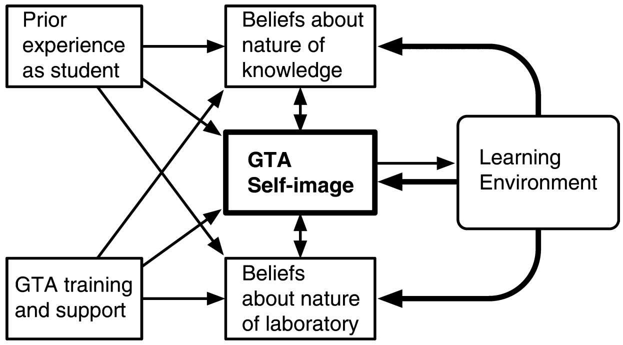


Figure 2. Factors associated with GTA self-image development.

shapes the learning environment; however, the learning environment may influence GTAs' self-image either by reinforcing it or by creating a conflict (e.g., cognitive, affective, or epistemological). In the latter case, the disequilibrium introduced by the conflict may engage the GTAs in a continuous reflection that informs the reconstruction of their self-image. Two components of the model are consistent with and support Propositions 2 and 3, which were initially drawn from literature: GTAs' prior experiences as students and their current training and staff meetings. Emerging evidence allowed us to put forth a mechanism through which these initial factors may exert influence on GTAs' self-image and practice. Our model postulates that the impact of these factors derives from their influence on GTAs' beliefs about the nature of knowledge (Proposition 4), and GTA's beliefs about the nature of the academic laboratory (Proposition 5).

We have chosen to first present this model and subsequently detail aspects related to its components along with quotes that support its construction. In the following paragraphs, we substantiate our final propositions by case. Although differences across the cases will be apparent, it is important to emphasize that the model captures features that are independent of the negative or positive judgment that individuals make for the individual cases. It is also important to note that we are not making claims related to GTAs' effectiveness in their perceived roles. Rather, we focused on how they viewed themselves as GTAs and components associated with those views.

Proposition 1

GTAs' teaching performance is associated with the way they see themselves as instructors, that is, their GTA self-image.

GTAs in the expository program viewed themselves as providers of knowledge and managers of time and safety.[26] The interactions they described with their students were a reflection of this perception of themselves. For example, Avery, in relation to her self-image as a provider, discussed giving explanations to the students: "I went into the class and I taught my students, I could explain everything to them, it was much easier for me."

Similarly, Dylan describes providing an abundance of information to the students:

> *I try to be really, really thorough about saying everything. And that helps, I think. They really kind of need, like, before the lab almost like 30 to an hour of really describing what they're going to do before they do it.*

Avery and Dylan's actions of explaining everything and telling students what they were going to do before they did it, even though it was not a strategy promoted in GTA training, was consistent with their self-image as providers. Elaine even classified her role as the "interpreter of the laboratory manual".

GTAs from the inquiry-based program viewed themselves as mentors and facilitators,[13] and these views were reflected in their reported teaching. Reflecting her image as a mentor and facilitator, Ursa chose to guide students through problem-solving behaviors:

> *You do not tell them the answer but kind of make them think, then you know they are actually problem solving during the lab, all the time pretty much. And also they need to think about it, so they need to reflect upon their answers because I told them, you know....*

Similarly, Larry described the mentoring process that occurred when his students faced difficulties in the laboratory:

> *You know, making sure that when someone is stressing out... [I say:] "Sit down, stop, what are you stressed out about?" If you are stressed out you do not learn anything.*

Guiding students through problems and modeling problem solving behaviors were staples of these GTAs' practices, and these practices were associated with their views of mentoring and facilitating learning.

Through cross-case analysis and the previous studies,[13,26] we see that GTAs in these programs viewed themselves differently. However, the relevance is that in both cases the way GTAs viewed themselves was related to their reported practice.

Proposition 2

In the absence of any other factors, GTAs will base the construction of their GTA self-image on their perception and interpretation of prior experiences.

GTAs in the expository program frequently compared their current experience with that of their prior lab instructors and used them as models of appropriate pedagogy. Perhaps the clearest example is one of Avery's comments:

> *I tried my level best for my students, to do it the same way [as my professors]. My professors helped us in everything that we did. If we had a doubt, we went up to them, and they were there to tell us.*

GTAs in the inquiry-based program reported on the notable differences between what they were being asked to do and the actions of their previous laboratory instructors. They were also aware that their previous laboratory experiences differed from the ones they provided for their students. In line with the other GTAs from this case, Naomi described the differences in the following way:

> *[T]he students are more active...they have to think a lot, that is something that I did not have during the experiments [as a student], I did not have to understand everything [...] as I told you, I could have answered the questions about the lab at the beginning without having to do the experiment but in this case they have to actually go through the experiment to actually be able to answer the questions.*

All of the GTAs in the inquiry-based program experienced expository type laboratories as students, and they were unable to rely on their prior lab instructors as an acceptable model for their teaching performance. Rather, they were likely to include prior mentors, such as research advisors, as models for behavior, as Nate mentioned: "[Y]ou basically are trying to mimic, I'd say when I sit down with my professor and say 'how can we solve this problem'."

We envision this proposition as a manifestation of what Lortie[32] described in teacher education as the notion of "apprenticeship of observation". For many, this term condenses the idea that as product of having experienced instruction as students, individuals are prone to teach the way that they were taught. This default option is intuitive and imitative, and it generates the false sense of expertise that many discipline-based science educators will promptly agree abounds in our departments. In this study, GTAs called upon different exemplars to base their self-image and practices, and although these images were not always based on how they were taught, the images were grounded in the prior experiences of the GTAs.

Proposition 3

Training and staff meetings influence GTAs' construction of their self-image.

GTAs in the expository lab viewed their training, particularly completing the experiments before their students, as serving function for their managerial and providing roles:

> *Like when you do that practice lab, you know what to expect from the student's point of view. So if something does happen, you know, they get something that is only supposed to take 11 mL to titrate and it is taking 22 mL.... If I had that experience or some other TA had that experience, "well did you clean out your buret?" Oh yeah, you know, 20/20 hindsight. (Jaylen)*
>
> *You [GTAs] do the experiment so you will understand or realize...when your student [is] doing the experiment, what kind of difficulty they will meet. Or what kind of result they will have. (Hayden)*

Through these quotes, GTAs imply they would know what obstacles may arise and could attempt to prevent them, or at least have an answer ready to provide to the students. Interestingly, this was not the purpose of the training activities as described by the laboratory coordinator. The coordinator expected GTAs to use their knowledge of the projects to help students think through their problems. Yet, that design was not enacted as training and staff meetings were interpreted by GTAs as ways to gain knowledge that could later be transferred to the students.

GTAs in the inquiry case discussed their training and staff meetings in a manner consistent with their mentoring image. The inquiry GTAs were not required to perform the laboratories before they facilitated them for the students; however specific project procedural aspects were addressed during weekly meetings. The main difference was in how GTAs viewed and used that information. They used the information as a guide and starting point to consider how they could get students to think: "Every time I go...before the lab, I thought about it for a few minutes, you know, what kind of questions I could ask to make them think" (Ursa). Time spent planning carried over into the laboratory as GTAs sought to guide their students through the thought processes.

The nature of the training was different across the cases, and the specifics of the training programs have been previously reported.[13,26] The importance here is that across the cases there was an association between the perceived nature of the training activities and the way the GTAs view themselves as instructors. Similar associations have been noted with college science faculty[33] and preservice science teachers.[34]

Proposition 4

GTAs' beliefs about the nature of knowledge are associated with their construction of their self-image.

Emerging evidence from the expository case led us to propose that beliefs about the nature of knowledge were associated with GTAs' self-image. GTAs in this case exhibited naive views of knowledge as related to instruction.[26] For example, Avery, whose earlier quote addressed "explaining everything" to her students, described the need to accumulate knowledge:

> *And there are numerous questions they can ask. Some students ask such weird questions, they come from different things. So, you need to accumulate all the knowledge and then come for the class, so it is a huge thing. I think it was really good. It was a good process.*

Conceptions of accumulating knowledge to later transfer to students were central features to these GTAs' experience. These beliefs in the certainty of knowledge and dualistic and authoritarian ways of knowing corresponded with their self-image as providers and managers. Training and teaching events were interpreted as reinforcement of their prior beliefs.

Evidence for GTAs in the inquiry-based program was consistent with more "sophisticated" views of knowledge.[35] GTAs focused on students' understanding, and they viewed students as having an active role in meaning making. For example, Ben stated:

> *[T]hey [students] have more ideas, maybe someone can come with something they did not think about, they can go with that kind of things, working in groups, understanding that research or science is not like a cookbook that, you know, oh this is expected to happen but we did it in the lab and it did not happen, so why did not it happen, that kind of reasoning should help them, I think.*

Likewise, Frank stated:

> *You know, cooperative lab is, it is very good, you know, like knowledge is not put in one person's head, ok. We all have different experiences based on where we have been before....*

Inquiry GTAs often experienced epistemic conflicts and reflected on their prior beliefs,[13] which together serve as precursors for the adoption of more sophisticated beliefs.[36] They perceived leading an environment that recognized "different perspectives" and the construction of knowledge as a challenging task that often conflicted with their prior experiences. One GTA described it as being "dropped into boiling water". This difficult process of confronting preconceived beliefs promoted reflection that may have contributed to their adoption of mentoring and facilitating self-images.[13]

GTAs from each case held different views of knowledge in relation to laboratory instruction. However, these differences were associated with their self-image and described practices thus underscoring the importance of attending to GTAs beliefs about the nature of knowledge. Interestingly, students in both programs worked in groups, yet GTAs perceived this "teamwork" as serving different functions. The expository GTAs viewed teamwork as a way to conserve resources, whereas the inquiry GTAs viewed teamwork as a way to promote understanding of concepts and problem-solving skills.

Proposition 5

GTAs' beliefs about the nature of the academic laboratory are associated with their construction of their self-image.

GTAs from the expository program viewed the laboratory as a place for students to apply learned concepts and verify known theories. Elaine explained that although each lab session involves different concepts or equipment, the nature of all laboratories is the same:

> *I hope they take away, basically, how to get through a lab class. And I do not mean that in a... in a performing sense so much as... You know, I try to tell them all the laboratories are the same. You start out with a theory, you try to test it, and that at the end you... you let 'em know if... if your data matches the theory. Sure, you have to learn different concepts, you have to learn different equipment, but, you know, between that and safety and protocol, it is... it is... every lab class is the same.*

Elaine's comment was aligned with other expository GTAs who saw the purpose of the general chemistry laboratory as preparing students for future laboratory classes through technical competence. For example, when asked if students could learn to think through problems in the lab, Dylan was "not sure they knew enough" or "had enough tools". When prompted on the tools, he responded, "How to be in a lab, what to do, how to measure, or...do whatever, you know." Later he reaffirmed that "working in a lab, insofar as, you know, how to use certain basic tools" as the primary goal for laboratory instruction. Expository GTAs placed less emphasis on conceptual development or meaningful learning. They viewed the lab as a place for students to "see" concepts already learned and to develop technical skills.

GTAs in the inquiry program viewed the laboratory as a setting to develop problem-solving and scientific skills:

> *Well, problem-solving skills is the best way [...] for such a collection of students, so that is what science is about, being critical, ask[ing] questions to solve a problem. (Frida)*

They recognized variation and ambiguity in experimental methods and viewed lab experiences as having multiple pathways and outcomes:

> *I do not know what it is but it is the general fear that they [students] have to be accurate. That chemistry is an exact science, and it is not. And ...once my students realized that chemistry is not an exact science and nothing in chemistry is exact that it can always be varied.... (Naomi)*

Finally, the inquiry GTAs were concerned more with the processes of learning and experimentation than they were with final answers or products: "Reassuring that we are not really worried about right or wrong answers because I reassured them so many times...Not the product but the process.... (Ursa)

Apparently, the behavior of GTAs was tied to the nature of the tasks they were facilitating. Parsons[37] observed a similar effect, although in elementary literacy teachers. In this case, evidence indicated that teachers implementing challenging, open tasks adapted their instruction in more thoughtful ways than teachers limited to closed tasks, such as worksheets.[37] In our two cases, GTAs' beliefs of the nature of the laboratory were associated with their self-image and the tasks they were facilitating.

■ CONCLUSIONS

In summary, the five propositions supported by this embedded multiple case study provided evidence that GTAs' construction of their self-image is associated with several factors: prior experiences; training; beliefs about the nature of knowledge and laboratory work; and teaching experiences. Across the two cases, we observed vastly different GTA self-images. It is unlikely that GTAs entered their respective programs with such diverse views. Rather, we postulate that the differences may be attributed to the presence, or lack thereof, of conceptual, epistemological, and affective conflicts and to the ways GTAs framed their training and teaching experience. To test this proposition, we are currently analyzing data gathered for similar cohorts of GTAs before their engagement in laboratory instruction and after their first semester in these two programs.

Bendexin[36] proposed epistemic doubt—the process of doubting one's beliefs about knowledge and knowing[38]—as a precursor to development of more sophisticated beliefs about knowledge. Epistemic doubt may be triggered by, but not limited to, exposure to differences, independence, and beliefs not matching with experiences, and is often experienced and evident as frustration, confusion, and feelings of not knowing.[36] We postulate that the intense differences between the inquiry GTAs' prior experiences and what they were being asked to do likely resulted in greater instances of epistemic doubt. Likewise, GTAs' experiences in the expository program may have reaffirmed and strengthened their prior beliefs of knowledge, teaching, and learning, thus leading toward counterproductive epistemologies.[39]

Another reason GTAs exhibited such different views is likely a result of how they framed what they were being asked to do. Framing is the ongoing process of interpreting, "what is it that's going on here",[40] and a frame is "a set of expectations an individual has about the situation in which she finds herself that affect what she notices and how she thinks about it".[41] These expectations are based on organized prior experiences and are activated when one recognizes "new situations as being similar to previous, familiar, situations".[42] GTAs in the expository program recognized what they were being asked to do as similar to their prior laboratory experiences. However, GTAs in the inquiry program recognized differences between their teaching experiences and their laboratories as students. They began to frame their teaching experience from the reference of mentors and advisors. Because of the need to adopt new frames, they likely experienced more epistemological and affective conflicts related to their teaching and had greater opportunity for development.

■ LIMITATIONS

This study used a strictly purposeful sampling approach to choose the two cases investigated. A relevant aspect of the selection was that these cases were exemplars of quite different instructional approaches and, as such, they might shed light about principles applicable to a broad spectrum of lab settings. Nevertheless, findings must be interpreted in the context of small, purposeful samples, and assumptions about transferability must be judged carefully. We ascribe to the stance that treats findings from case studies as propositions for future use and testing rather than as definite generalizable claims.[43] We invite readers to consider extrapolations of our findings to similar conditions and to test their applicability. As part of our own research program we intend to extend our approach to include additional laboratory programs.

The design of this study honed in on the graduate students' lived experience as GTAs. Consequently, the only data collection point occurred after one semester of participating in instruction. We realized that this retrospective approach might have limited our understanding of the factors that influence development of GTA self-image; therefore, in a follow-up study, we gathered information from new cohorts of GTAs before the teaching appointment started and after the completion of the semester. Through the ongoing analysis of these data we aim at elucidating changes experienced by individual GTAs in the factors that we postulate influence their self-image development. It is worth reiterating here that we limited consideration of propositions to those that fell directly within the impact range of the lab experience. That is, we excluded, for instance, those linked to interactions with research advisors and departmental culture and norms. In our view, such highly specific idiosyncratic aspects may render findings less transferable.

■ IMPLICATION FOR LABORATORY INSTRUCTION

In this report, we argue that GTAs' self-image is associated with their instructional decision-making and thereby the nature of their students' laboratory experience and learning. We contend that regardless of how crystallized it may appear to be, this self-image is susceptible to transformation. The model that we present describes factors that may catalyze this transformation in order to accomplish specific goals of laboratory instruction[25,44] and to support graduate student professional development.[6,45] Instruction is a complex process, and we do not intend to provide a prescriptive model to conduct GTA training. However, we believe this model may prompt laboratory coordinators to reconsider GTA participation in instruction in a new and different light, and to look at training and support from a new angle. In this model, the fidelity of implementation of the learning environment is influenced by the GTA self-image, which in turn is shaped by GTAs' beliefs about the nature of knowledge and their beliefs about the nature of laboratory instruction. Instead of focusing exclusively on what and how to teach, GTA training and support programs may target these two factors in a way that is conducive to a self-image in accord with the specific instructional objectives. For example, how GTAs' incoming beliefs may hinder or facilitate what they are asked to do could become a focal point of training programs.[46,47] To this end, a laboratory coordinator may, for instance, survey graduate students' beliefs about the purpose of academic laboratories. If their responses strongly point at technical competence and verification of lecture concepts as fundamental, training can be designed to address potential conflicts with the goals of the designed laboratory. Evidently, this is more relevant when implementing reform-based instruction.[7,14,47−49] Lab coordinators may succeed in guiding GTAs' behavior by telling them how to teach and by closely monitoring them. However, as Goertzen and collaborators[46] exemplified, "helping TAs learn to ask questions will not necessarily help them share [...] motives for questioning". One may think of this as adding a new dimension to GTA training—why to teach—that may assist laboratory coordinators to find ways to help GTAs engage more fruitfully in facilitating laboratory.

In addition, GTA training programs rarely consider the impact that teaching has on GTAs. This model calls specific attention to the recursive interaction of GTAs' self-image and their experiences in the laboratory environment. If indeed "the lack of progress in laboratory teaching is our failure to consider the laboratory instructor",[5] this holistic picture of GTA self-image development may be a step forward in shifting attention to the most influential factor affecting laboratory instruction, the GTA.[8] We hope the present research contributes in placing this aspect at the forefront of general chemistry laboratory instructional design.

■ ASSOCIATED CONTENT

Supporting Information

Sample GTA case narrative created during data analysis. This material is available via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

■ REFERENCES

(1) Elliott, M.; Stewart, K.; Lagowski, J. J. *J. Chem. Educ.* **2008**, *85*, 145−149.
(2) Meester, M. A. M.; Maskill, R. *Int. J. Sci. Educ.* **1995**, *17*, 575−588.
(3) Hofstein, A. *Chem. Educ. Res. Pract.* **2004**, *5*, 247−264.
(4) Hilosky, A.; Sutman, F.; Schmuckler, J. *J. Chem. Educ.* **1998**, *75*, 100−104.
(5) Herrington, D. G.; Nakhleh, M. B. *J. Chem. Educ.* **2003**, *80*, 1197−1205.
(6) National Research Council, Board on Chemical Sciences and Technology, Chemical Sciences Roundtable. *Graduate Education in the Chemical Sciences: Issues for the 21st Century: Report of a Workshop*; The National Academies Press: Washington, DC, 2000.
(7) Roehrig, G. H.; Luft, J. A.; Kurdziel, J. P.; Turner, J. A. *J. Chem. Educ.* **2003**, *80*, 1206−1210.
(8) Lazarowitz, R.; Tamir, P. Research on Using Laboratory Instruction in Science. In *Handbook of Research on Science Teaching and Learning*; Gabel, D., Ed.; Macmillan: New York, 1994; pp 94−130.
(9) Birk, J. P.; Kurtz, M. J. *J. Chem. Educ.* **1996**, *73*, 615−617.
(10) Nurrenbern, S. C.; Mickiewicz, J. A.; Francisco, J. S. *J. Chem. Educ.* **1999**, *76*, 114−119.
(11) Bond-Robinson, J.; Bernard Rodriques, R. A. *J. Chem. Educ.* **2006**, *83*, 313−323.
(12) Burke, K.; Hand, B.; Poock, J.; Greenbowe, T. *J. Coll. Sci. Teach.* **2005**, *35*, 36−41.
(13) Sandi-Urena, S.; Cooper, M. M.; Gatlin, T. A. *Chem. Educ. Res. Pract.* **2011**, *12*, 92−100.
(14) Seymour, E. *Partners in Innovation*; Rowman & Littlefield Pub Inc.: 2005.
(15) French, D.; Russell, C. *BioScience* **2002**, *52*, 1036−1041.
(16) Feldon, D.; Peugh, J.; Timmerman, B.; Maher, M. *Science* **2011**, *333*, 1037−1039.
(17) Abraham, M. R.; Craolice, M.; Graves, A. P.; Aldhamash, A. H.; Kihega, J.; Gal, J.; Varghese, V. *J. Chem. Educ.* **1997**, *74*, 591−594.
(18) Brooks, D. W.; Devous, M.; Johnson, G. R.; Lewis, J. D.; Limbacker, P.; Sarquis, A. M.; Shapiro, M.; Skowronski, R. *J. Chem. Educ.* **1972**, *49*, 622−623.
(19) Garland, J. K. *J. Chem. Educ.* **1969**, *46*, 621.
(20) Jones, L. L.; Liu, C. F. *J. Chem. Educ.* **1980**, *57*, 356.
(21) Mellon, E. *J. Chem. Educ.* **1971**, *48*, 674−675.
(22) Tanner, M. W.; Selfe, S.; Wiegand, D. *Innovative Higher Educ.* **1993**, *17*, 165−181.
(23) Marbach-Ad, G.; Schaefer, K. L.; Kumi, B. C.; Friedman, L. A.; Thompson, K. V.; Doyle, M. P. *J. Chem. Educ.* **2012**, *89*, 865−872.
(24) Pentecost, T.; Langdon, L.; Asirvatham, M.; Robus, H.; Parson, R. *J. Sci. Teach. Educ.* **2012**, *41*, 68−75.
(25) Singer, S.; Hilton, M.; Schweingruber, H. *America's Lab Report: Investigations in High School Science*; The National Academies Press: Washington, DC, 2005.
(26) Sandi-Urena, S.; Gatlin, T. A. *Educ. Quim.* **2012**, *23*, 141−148.
(27) Sandi-Urena, S.; Cooper, M. M.; Gatlin, T. A.; Bhattacharyya, G. *Chem. Educ. Res. Pract.* **2011**, *12*, 434−442.
(28) Merriam, S. B. *Qualitative Research: A Guide to Design and Implementation*; Jossey−Bass: New York, 2009.
(29) Yin, R. K. *Case Study Research: Design and Methods*, 1st ed.; Sage Publications, Inc: Beverly Hills, 1984.
(30) Domin, D. S. *J. Chem. Educ.* **1999**, *76*, 543−547.
(31) Yin, R. K. *Case Study Research: Design and Methods*, 4th ed.; Sage Publications, Inc: Beverly Hills, 2009.
(32) Lortie, D. C. *Schoolteacher: A Sociological Study*; University of Chicago Press: Chicago, 2002.
(33) Hutchins, K. L.; Friedrichsen, P. J. *J. Sci. Teach. Educ.* **2012**, *23*, 867−887.
(34) Pilitsis, V.; Duncan, R. G. *J. Sci. Teach. Educ.* **2012**, *23*, 909−936.
(35) Baxter Magolda, M. B. *Educ. Psychol.* **2004**, *39*, 31−42.
(36) Bendixen, L. D. A Process Model of Epistemic Beliefs Change. In *Personal Epistemology: The Psychology of Beliefs about Knowledge and Knowing*; Hofer, B. K., Pintrich, P., Eds.; Lawrence Erlbaum Associates Publishers: Mahwah, NJ, 2002; pp 191−208.
(37) Parson, S. A. *Case Studies of Four Teachers: The Openness of the Tasks They Implement, the Adaptations They Make, and the Rationales They Offer for Adapting*; University of North Carolina: Greensboro, NC, 2008.
(38) Hofer, B. K.; Pintrich, P. *Rev. Educ. Res.* **1997**, *67*, 88−140.
(39) Hammer, D.; Elby, A. On the Form of Personal Epistemology. In *Personal Epistemology: The Psychology of Beliefs about Knowledge and Knowing*; Hofer, B. K., Pintrich, P., Eds.; Lawrence Erlbaum Associates Publishers: Mahwah, NJ, 2002; pp 169−190.
(40) Goffman, E. *Frame Analysis: An Essay on the Organization of Experience*; Harvard University Press: Cambridge, MA, 1974.
(41) Hammer, D.; Elby, A.; Scherr, R. E.; Redish, E. F. Resources, Framing, Transfer. In *Transfer of Learning from a Modern Multidisciplinary Perspective*; Mestre, J., Ed.; Information Age Publishing: Charlotte, NC, 2005; pp 89−120.
(42) Berland, L. K.; Hammer, D. *J. Res. Sci. Teach.* **2011**, *49*, 68−94.
(43) Patton, M. Q. *Qualitative Research and Evaluation Methods*; Sage Publications: Thousand Oaks, CA, 2002.
(44) Bruck, L. B.; Towns, M. H.; Lowery Bretz, S. *J. Chem. Educ.* **2012**, *87*, 1416−1424.
(45) Loshbaugh, H. G.; Laursen, S. L.; Thiry, H. *J. Chem. Educ.* **2011**, *88*, 708−715.
(46) Goertzen, R. M.; Scherr, R.; Elby, A. *Phys. Rev. Spec. Top.—Phys. Educ. Res.* **2010**, *6*, 010105−1−010105−17.
(47) Smith, L. K.; Southerland, S. A. *J. Res. Sci. Teach.* **2007**, *44*, 396−423.
(48) Luft, J. A.; Kurdziel, J. P.; Roehrig, G. H.; Turner, J. *J. Res. Sci. Teach.* **2004**, *41*, 211−233.
(49) Southerland, S.; Sowell, S.; Blanchard, M.; Granger, E. M. *Res. Sci. Educ.* **2011**, *41*, 299−317.