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Experimental Chemistry Teaching: Understanding Teaching Assistants' Experience in the Academic Laboratory

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ABSTRACT
Research in chemistry laboratory instruction has rarely focused on the lived experience of graduate teaching assistants (GTAs) and how it influences the pedagogic value of laboratory work. A phenomenological study was undertaken to explore the meaning that eleven GTAs ascribed to their teaching experience. Phenomenological reduction and analysis of interviews produced three core dimensions that describe GTAs' experience: *Doing*, *Knowing*, and *Transferring*. The perceived GTA role emerged as the interconnecting factor among them. In this study, findings suggest that GTAs viewed themselves as providers of knowledge and managers of time and safety and that GTA self-image shaped their instructional decisions about the learning environment. The gains accessible to these GTAs (content mastery, communication skills, and personal satisfaction) are not exclusive to laboratory teaching. Gains related to the development of more sophisticated views of knowledge and science were not evident. Implications for laboratory reform and GTA training are highlighted.

KEYWORDS: Chemistry laboratory instruction, graduate students, teaching assistants, phenomenology

Resumen (Enseñanza de la química experimental: Comprendiendo la experiencia de los Instructores Asistentes en el laboratorio académico)
La investigación del aprendizaje en los laboratorios de química se ha enfocado muy poco en las experiencias de los estudiantes de posgrado que fungen como instructores (Instructores Asistentes) y sobre como éstas afectan el aprendizaje. Un estudio fenomenológico fue realizado para explorar el sentido que once IAs asignaron a su tarea de instrucción. La reducción y el análisis fenomenológicos de entrevistas produjeron tres dimensiones fundamentales que describen la experiencia de los IAs: *Hacer*, *Saber* y *Transferir*. El rol percibido de los IAs emergió como el factor que interconecta estas tres dimensiones. Los resultados sugieren que los IAs se ven a sí mismos como proveedores de conocimiento y administradores del tiempo y la seguridad, y que su auto-imagen determina sus decisiones sobre la instrucción y el ambiente de aprendizaje. Los beneficios accesibles para los IAs (dominio de los contenidos, habilidades de comunicación y satisfacción personal) no son exclusivos de la instrucción en el laboratorio. No fueron evidentes los beneficios relacionados con el desarrollo de perspectivas más sofisticadas sobre el conocimiento y la ciencia. En este artículo se discuten implicaciones para la instrucción y el entrenamiento de asistentes.

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Palabras clave: Instrucción de laboratorio de química, estudiantes de posgrado, instructors asistentes, fenomenología

Introduction

There is little doubt that chemistry educators and researchers regard introductory chemistry laboratory instruction as an indispensable component of tertiary level education. Although many benefits have been attributed to experimental instruction, the debate about its purpose and its effectiveness in accomplishing the desired learning outcomes may be as old as the assumed merits. This is reflected by the publication almost a century ago of reports underlining the "Problems in the experimental pedagogy of chemistry" (Spear, 1915) and calling attention to the need for systematic investigation of experimental learning outcomes (Wiley, 1918). This timely special issue of *Educación Química* is evidence of the persistent need to examine research in this field and to make strides to address the issues and concerns expressed in multiple review reports (Hofstein, 2004; Nakhleh, Polles, & Malina, 2003; Reid & Shad, 2007).

Entry level college chemistry courses without a laboratory component would probably be unacceptable for most chemists and chemistry instructors. However, as Elliott, Stewart, and Lagowski (2008) sharply pointed out, this stance may be more the product of a deeply entrenched assumption than that of scientific understanding of the role that the lab plays in learning. In these authors' words "precious little *evidence* exists that such instruction provides a useful function in the way(s) students learn chemistry" and yet "almost everyone has an *opinion* or a theory" on this topic (p. 145). Similar statements have become staple comments in reviews of science laboratory instruction (Hodson, 2005; Hofstein, 2004; Hofstein & Lunetta, 2004; Lazarowitz & Tamir, 1994; Nakhleh, Polles, & Malina, 2003; Reid & Shad, 2007). From another standpoint, this controversy puts forth the need of sound research that will significantly increase understanding of the role of laboratory instruction in learning chemistry. Higher education institutions continue investing considerable resources sometimes in an apparent *act of faith* that as a consequence of the laboratory activities something, somehow, at some point happens that leads to significant chemistry learning improvement. In some way, this assumption is analogous to the *illusion of learning* held by so many students who think that keeping themselves busy studying will necessarily translate into learning. Not surprisingly, the question of the inherent merit of laboratory instruction has been reported previously in the literature (Hawkes, 2004; Hilosky, Sutman, & Schmuckler, 1998; Reid & Shad, 2007).

Notwithstanding, in avoiding confusion, we second Hodson's (2005) clarification that criticism of laboratory instruction is "not so much an attack on practical work *per se* as a criticism of the kind of practical work we choose to do, and the way in which we implement it" (p. 30). Ironically, quite often those directly involved with general chemistry laboratory instruction seem unaware of this profound controversy. In our view, the inherent merit of laboratory instruction is not challenged where challenging is needed the most: from within the General Chemistry Laboratory programs. In the US, large research institutions hire (post)graduate chemistry students to serve as laboratory graduate teaching assistants (GTAs) whereas liberal colleges tend to have faculty in these instructional positions. This set up is not universal and in other countries even at large, research-oriented institutions it is faculty members who actually instruct students in the introductory laboratories. Likewise, in some other countries institutions of similar characteristics utilize undergraduate teaching assistants throughout their undergraduate curriculum. US laboratory instructor or GTA coordinator positions rarely encompass expectations such as formal educational background and training and acquaintance with current pedagogies or educational research literature. Under these circumstances it is understandable that instructional decisions—including instructional design—may be based on personal experiences and naïve assumptions that may perpetuate counter-productive practices in lab instruction. Recently, Bruck, Towns and Bretz (2010) investigated faculty perspectives of undergraduate chemistry laboratory and reported instructors' goals, strategies, and assessments for different kinds of institutions (community colleges, liberal arts institutions and research universities). Even though the authors did not investigate where the interviewed faculty drew from to make those decisions, it is apparent that the reported goals and objectives were not entirely consistent with reference sources such as the National Research Council America's Lab Report (Singer, Hilton, & Schweingruber, 2006).

A majority of papers in chemistry laboratory literature intend to engage in the introduction of *innovative* ideas and lament the use of expository style of laboratory teaching. Domin (1999) exposes a more holistic perspective and gives more weight to instructional design over fashionable trends. In his view, each style of laboratory format may have value for different learning outcomes. For example, expository labs provide procedures therefore they are probably better suited for teaching procedural and technical skills than other *non-traditional* approaches. Another apparent assumption in the scant college chemistry laboratory literature is the ubiquitous perception that the proposed curriculum and what happens in the laboratory are one and the same or as suggested by Briggs (2011), the idea "that students will undergo specific experiences when certain information is or is not provided" (p. B). This assumption has led to an overemphasis in research that has focused on the designed curriculum rather than what is enacted. Furthermore, the use of GTAs introduces an additional level of complexity in the enactment of the designed curriculum (Roehrig *et al.*, 2003). In response to this reality, our research program pursues the study of learning in the laboratory as it occurs and not as it is meant to happen. In this naturalistic view, we conceive the GTAs not as mere facilitators or intermediaries of student learning but as active participants in the learning environment. Underlying this view is the principle that GTAs are the single most influential factor affecting laboratory instruction (Lazarowitz & Tamir, 1994) and that failure to consider their role prevents progress in advancing learning in the laboratory (Herrington & Nakhleh, 2003; Pickering, 1988). The importance we place on the GTAs, however, is not in function of the students or instruction as has been customary (Birk & Kurtz, 1996; Harris & McEwen, 2009; Roehrig *et al.*, 2003; Kurdziel & Libarkin, 2003; Luft *et al.*, 2004). In our approach the GTAs are not instruments of instruction but engaged agents in the learning process.

In light of this view, where others refer exclusively to the students in the laboratory we include GTAs as well. Such is the case of Hodson's (1990) proposal that "we are unlikely to have a definitive answer to our questions about the pedagogic value of laboratory work" if we don't focus more sharply on what students are *actually* doing in the laboratory (p. 39). Hodson's emphasis on the need to understand the actual experiences is echoed by Casey (2007) in her proposal of a methodological approach to inquire about college chemistry learning: "Perhaps if we could understand the meaning of the students lived laboratory experiences, we would be able to clarify what purpose the laboratory currently serves" (p. 130). We strongly agree with this stance, however, consider its scope incomplete in the case of tertiary science education laboratories unless GTAs are also considered in clarifying the pedagogical value of laboratory instruction. To that purpose, we have already reported an investigation that addressed GTAs' epistemological and metacognitive development when they engaged in a cooperative, problem-based General Chemistry Laboratory program (Sandi-Urena *et al.*, 2011).

Research goal

The purpose of this study was to use a phenomenological approach to generate a rich description of a General Chemistry Laboratory learning environment as lived by GTAs. By means of this description, we intended to enhance understanding of the GTA experience and how it influences the pedagogic value of academic laboratory work. In turn, this description will allow access to factors that may be necessary to consider in designing instruction in this kind of setting.

The Study

Context and design

This study took place at a research-intensive university in the United States of America; it is part of a larger research program whose ultimate objectives are to enhance understanding of learning in the academic chemistry laboratory and to ascertain gains accessible to students and GTAs through varied approaches to laboratory instruction. We have decided to use phenomenology (Moustakas, 1994; Patton, 2002) to investigate diverse laboratory learning environments. We make the methodological case here for this approach based on its distinct ability to provide access to understanding of "the meaning of a chosen human experience by describing the lived experience or phenomenon as perceived by the participants" (Casey, 2007, p. 118). In synthesizing this idea, van Manen (1990) proposes that "phenomenology asks for the very nature of a phenomenon, for that which makes a some-"thing" what it is—and without which it could not be what it is". Phenomenological methods intend to uncover the internal and invariant structure of the phenomenon not in its empirical individuality but in its essence (Patton, 2002, p. 482). Although phenomenology was proposed by Casey (2007) as potential research tool to study the academic laboratory experience, it has only rarely been utilized for this purpose (Sandi-Urena *et al.*, 2011; Sandi-Urena *et al.*, in press).

According to the course syllabus, the General Chemistry laboratory in this study is "the first semester of a beginning course in laboratory methods and techniques" that is concerned with teaching "how to analyze information working in a group or alone, how to organize data and methods of problem solving". In addition, it is intended to facilitate "understanding of the lecture material and support the concepts taught in the lecture course." The General Chemistry program serves approximately 1500 students per semester and employs about 30 chemistry graduate students acting as teaching assistants. GTAs were invited to volunteer for this study via email. Confidentiality was stressed at all times. The GTA coordinator, chemistry instructors and faculty advisers did not have access to the data collected for this study and participants were not identified. Eleven GTAs volunteered: Six participants were male, six were US-born, the age range spanned from early 20's to early 30's and five of the GTAs were teaching for the first time. Each GTA taught two lab sections with up to 24 students. GTAs attended weekly staff meetings led by the GTA faculty coordinator. The meetings provided a venue for discussion of logistics and contents of upcoming experiments. First time GTAs also attended a two-day campus wide workshop before the semester began. Additionally, first time GTAs were required to attend weekly meetings in which they would complete the upcoming experiments as if they were students. These meetings were optional for returning GTAs due to their familiarity with the experiments. The laboratory course used weekly experiments in which students worked in pairs or groups of four depending upon availability of equipment. Based on the reading of the laboratory manual, students were expected to generate questions that could frame their experimental work. GTAs were required to facilitate a discussion of each group's questions at the beginning of the period, and help the class decide on the most appropriate question to frame their work. Once a question was chosen, students began work following the general procedure provided in their laboratory manual. Students were expected to answer the question in their weekly written reports. These reports were required to follow the guidelines of the Science Writing Heuristic. GTAs, in turn, assessed students' reports as well as students' pre-lab questions and laboratory notebooks. In addition to the responsibilities involved with the two lab sections, all GTAs were required to proctor during the General Chemistry exams and be available for weekly tutoring sessions.

Members of the research team did not have any direct interactions with instructors, GTAs and students other than the collection of data and did not participate at any level of course design, implementation or evaluation. For all practical purposes, the research team is not only independent from the investigated laboratory program but also unaffected by its success or failure.

Data collection and analysis

Data collection used a semi-structured interview protocol divided into three main parts. First, participants were asked to describe their own experience as general chemistry students and any previous experience as GTAs. Next, the GTAs were prompted to describe their students' experience in the laboratory and their own experience as a GTA. Finally, they were invited to share ideas they had about how students learn in a general chemistry lab. Interviews were conducted at the beginning of the second semester to assure that all GTAs interviewed had completed at least one full semester of teaching. Three participants met with both co-authors while the remaining eight participants met with one co-author. Interviews lasted for approximately one hour, were audio recorded and archived using pseudonyms. Transcription took place once all interviews had been completed.

The data analysis protocol followed the modified phenomenological methodology proposed by Moustakas (1994) and is the same we have used for other reported studies (Sandi-Urena *et al.*, 2011). The main steps are (a) analysis of the transcribed interviews to identify significant statements;

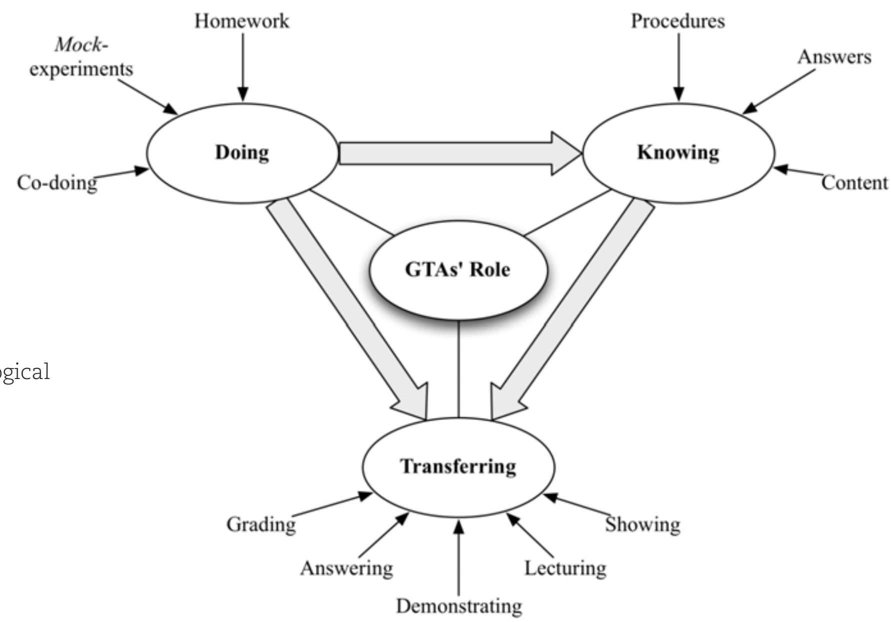

Figure 1. Phenomenological outcome space.

(b) clustering of significant statements based on their meaning to create invariant constituents to which we refer as codes; (c) collapsing of codes based on thematic similitude to generate 'themes'; (d) validation of themes by checking against transcriptions; (e) categorization of themes into dimensions by means of imaginative interpretation; (f) construction of an outcome space to describe the meanings and essence of the experience representing the group as a whole.

For the first three interviews, both researchers worked independently identifying significant statements, and clustering the statements into codes. Weekly meetings were held to discuss the relevance and terminology of the codes, and eighty-two codes resulted from this process. The first three interviews were re-coded and future interviews were coded using the agreed upon terminology. In subsequent meetings, our discussions focused on the thematic experience of the GTAs and led to the creation of a first draft of the outcome space that integrated the textual and structural description of the experience as lived by the participants. The outcome space presented here was refined through subsequent research discussions.

Results

Outcome space and interpretation

Phenomenological reduction and analysis of the data produced the outcome space shown in Figure 1. This outcome space, representing GTAs' experience, consists of three core dimensions: Doing, Knowing, and Transferring. These dimensions revolve around a central interconnecting factor: GTAs' Role. Structurally, this interconnecting factor is the one element that holds the model together and without which the experience is no longer 'what it is'. The centrality of this factor sheds light on the essence of the GTAs experience: They see themselves as central and indispensable; they orchestrate the functioning of the laboratory and without them the experience crumbles, it ceases to be. Another relevant aspect, but inherently difficult to represent graphically, is the time component. In this case, the description of the experience is static in the sense that snapshots taken at different times during the semester-long experience would be mostly indistinguishable. By this we mean that a progression of the nature or qualities of the lived experience did not surface to participants' awareness when describing it. Interviewees made not explicit or implicit references to changes over the course of the experience. Trajectories of change are associated with opportunities for learning and reflection and we have observed them in non-traditional laboratory programs that challenge GTAs' beliefs about learning (Sandi-Urena *et al.*, 2011). The core dimensions of the outcome space are discussed separately in the sections below.

Doing: This dimension reflects GTAs' engagement in a series of actions that are directed at fulfilling their perceived role. Most of the things GTAs do are related to basic chemistry content or technical laboratory procedures. They read the manual, perform the laboratory experiment 'as students' the week before their own students perform it, and do their students' lecture homework. Underlying these actions, is a deeply held premise that 'doing is knowing'. Undoubtedly, GTAs engage in conscientious preparation; however, further analysis reveals that the motivation behind these actions is to master the contents and procedures so that they can provide them as flawlessly as possible to their students and thereby eliminate possible 'errors' that may delay the appropriate performance and completion of the laboratory exercise. The following quotes are examples of statements directly related to the purpose of doing in this dimension:

"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 its taking 22 mL. If I had that experience or some other TA had that experience, "well did you clean out your burette?" Oh yeah, you know, 20/20 hindsight." (Jaylen)

"…you [GTAs] already 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. I mean even the experiment is already designed for some kind of subject, but maybe it has some fault you know. (Hayden)

The GTA becomes a source of information comparable to reading a book chapter whose role is to provide information to the students so that they are not held back by having to 'figure out' what to do next:

"If they already know what… what's going to happen, they just come in and… or you can tell them, you know, read this chapter and come in and do it. And, they don't spend a lot of time sitting there, trying to figure out "what I'm going to do next"". (Dylan)

Clearly, Bailey agrees with this view when referring to their duties as GTAs:

"My overall duties, I think, are to make sure that they're getting, you know, I think is to make sure they're doing the experiments accurately, make sure the experiments are running on time, get them to learn how to do time management and keep them safe."

The premise that doing is knowing translates into how GTAs view students' actions and judge students' understanding based on whether they are doing the experiments "correctly" and "accurately".

Knowing: The *Knowing* dimension involves the things GTAs feel they must know in order to be successful in their role in the laboratory environment. The focus of GTAs' thoughts gravitates around knowing procedural, technical, and conceptual information related to each week's experiment. Evidently, this dimension is intimately related to the first one, *Doing*, and sometimes participants' statements show that relation; we acknowledge the occasional overlap in the meaning behind the quotes.

The motivation for knowing this information is the desire to answer students' questions during the laboratory exercise. Avery explains this in referring to doing the experiments and writing reports pretending to be students before teaching a lab session:

"And there are numerous questions they can ask. Some students ask such weird questions. They come from different things. So, you [GTAs] 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."

Avery identifies the purpose of their preparation as an opportunity to 'accumulate' knowledge that can then be transferred to their students and that is *really good*. There were occasions though where GTAs did not have all the answers and those occasions were seen as a source of frustration, as indicated by Casey:

"For the TA that… that's frustrating, especially for the TA, because I don't know what the answer [is]."

In many cases, GTAs justify their desire to *know* as a way to overcome students' lack of understanding. Dylan provides an example of this when he address taking on responsibility of making sure students has the data they need:

"Also, some… at the end of the lab… making sure that everyone has gotten the data and they've processed it. Because my experience has been that a lot of people, when they leave the lab, don't necessarily know what to do with what they did. They don't know… They don't know how to think about what they did."

Efficiency is another driving factor in GTAs' preparation. GTAs feel that if they *know* of the problems that may arise, they may better assist their students or remove the obstacles altogether, thus allowing for a more efficient laboratory experience:

"I just let them go, and I usually stand off and look and watch and I don't really interact unless I think something's going wrong." (Bailey)

"If you go in to teach the lab, and this group over here that has something that's not working out and that's your first experience with that, I think a lot of people would feel anxious or stressed like oh my gosh how are we going to fix this. Where as if you know that that might happen [due to performing the lab as a student], you can be like… I don't know, its less stressful… maybe warn the kids before they do lab… now don't do this, do this." (Jaylen)

Transferring: This dimension is representative of GTAs' interactions with students and what GTAs do with the knowledge previously discussed. This transferring or 'providing' is a driving force for what GTAs feel they must *do* and *know* as part of their being a GTA. As noted before, GTAs feel it is their responsibility to know all the answers. The instructional interactions represented by this dimension seem to be shaped by the purpose of *transferring knowledge*. GTAs resort to strategies such as answering questions, demonstrating procedures, creating handouts and even going to the extent of lecturing at the beginning of the lab session:

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

Having the answer to students' questions and intervening if problems arise was another common practice:

> *"If they seem to be having trouble, you know, trying to correct them and show them what to do. Always asking, being there for… If they have questions, they always come up with questions and ask."* (Dylan)

Some GTAs such as Casey seemed to struggle with helping the students as much as possible without actually doing the experiments with or for them:

> *"they [the students] are supposed to do the experiment, I give them guidance. I… I try to help them as much as I can for their own experience and for my experience to… to step-by-step guide them through, but I'm not doing the experiments with them… for them, you know, that's what I mean."*

Emerson, a veteran GTA, seemed to have found the solution to the challenge faced by less experienced GTAs. He was comfortable enough with his position to fix where, in his view, the manual fell short and provide the students the information they needed that was not readily available otherwise:

> *"So I found… I… I have my own little hand-out now… heh… heh… telling them precisely what I would like, that I think is not being conveyed by the lab manual."*

We must stress that the GTAs were not necessarily trying to cut corners or shortchange the students in any way. Quite the contrary, they demonstrated willingness and desire to help their students the best they could. Transferring just happened to be their best way of doing so.

> *I like interacting with the students. And... I like to think that I... you know, that I... that I'm sort of helping them along in this, you know not to be cliché but like this journey, or whatever, you know?* (Dylan)

> *"… I tried my level best for my students, to do it the same way* [compared to own experience as student]. *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."* (Avery)

Evidence for the three emergent dimensions—Doing, Knowing and Transferring—can be found throughout the data for all participants. And as we pointed out, quotes sometimes overlap in serving as evidence for these dimensions. Interestingly, however, we came across a single statement from a participant that in retrospective exemplifies all three dimensions and essentially condenses them into the view of the experience as lived by the GTAs:

> *"**We basically do** the entire experiment including the analysis part so that it is easier for us to explain it to the students because there are… there might be a couple of things which we might not… so that… **so that everybody [GTAs]** knows that looks… this is what we have to do… and it's good because when I went into the class and I taught my students, I could **explain everything to them**, it was much easier for me."* (Avery)

Discussion and Conclusion

This study documents the experience of chemistry graduate students engaged in laboratory instruction in a General Chemistry program. Deep textual analysis of the interviews led to the construction of an outcome space (Figure 1) that describes GTAs' experience in terms of three fundamental dimensions: Doing, Knowing and Transferring. Overall, from the perspective of the GTAs the experience is consistent with a verification type laboratory (Domin, 1999) where for all practical purposes the students have access in advance to the expected outcomes of the laboratory experience and to the procedures. Furthermore, the experience is centered on contents, procedures and techniques. Our phenomenological approach is aimed at elucidating "the meaning, structure, and essence of the lived experience" (Patton, 2002, p. 482) and it is not pre-occupied with the designed curriculum or achievement of professed goals. Although it is not our immediate intention to use our methodological approach as an assessment tool, identification of an apparent mismatch in this study suggests its suitability for this kind of purpose: in principle, the designed curriculum was meant to be an inquiry-based experience. Roehrig and collaborators (2003) have reported qualitative evidence of instances in chemistry laboratory instruction were a presumed reformed inquiry-based curriculum defaults mostly to an expository style experience for GTAs and students. These authors identified as probable reasons (a) GTAs' prior experiences as students, (b) GTAs' lack of instructional skills to facilitate the learning environment and (c) GTAs' ill-formed conceptions about learning.

We put forth that in our case, the methodological approach moves us closer to understanding the underlying causes of this occurrence. Through the structural analysis of the experience we suggest that the interconnecting factor without which the experience is no longer 'what it is' is precisely the GTA's perceived role. The conjuncture of the GTA experience is very unique and by no means do we intend to equate it to that of professional teachers. However, we may still borrow some of the understanding of teachers' development of professional knowledge for teaching. Teachers develop their understanding and knowledge through experience and reflection and drawing from their coursework (Carter, 1990). In teachers' case, this is a process that evolves over a period of years (including college training) and is supported by skilled mentors and an educational infrastructure. In this study, chemistry graduate students structured their GTA self-image in a very short period of time and with very limited resources from which to draw and typically insufficient support (Stacy, 2000). Their instructional practice in the laboratory did not allow time or adequate opportunities to reflect about their views of themselves as instructors. Constraints in terms of time and resources in face of a daunting task pushed them to operate on pedagogical emergency mode. Instead of risking a conflict or dilemma that might have triggered their reflecting, they tailored their experience to conform to, and thereby strengthen, their GTA self-image. This is reflected in their "*Doing*" to achieve "*Knowing*" of everything to anticipate anything that may create an unexpected situation. "*Transferring*" through detailed lecturing and direct responses of questions seem to serve the same purpose. In summary, the learning environment is shaped to adjust to the GTA self-image and not necessarily to achieve desirable learning outcomes.

In their central role, the GTAs viewed themselves fundamentally as providers of knowledge (procedural and conceptual) and managers (of grading, time and safety) thereby relegating the potential learners to consumers of knowledge and laboratory clerks responsible for performing the experiments. Interestingly, Hofstein and Lunetta (2004) suggested this detrimental behavior, in their review of the laboratory in science education, when they stated that instructors "spend large portions of laboratory time in managerial functions, not in soliciting and probing ideas or in teaching that challenges students' ideas" (p. 44).

The learning environment instantiated in this study grants an opportunity for GTAs to enhance content mastery, communication skills and personal satisfaction, all traditional gains (Seymour, 2005). However, it is important to note that teaching labs is not indispensable for content mastery or technique refinement; both could be accomplished in the graduate research experience. Communication skills could be developed in research group meetings or through teaching lecture classes. Therefore the gains accessible to these GTAs are not exclusive to teaching in a laboratory setting. The experience itself offers few, if any, opportunities for epistemological doubt, a necessary precursor for the adoption of more sophisticated views of knowledge and science (Bendixen, 2002). In fact, the experience may be counterproductive in this regard (Hammer, 1994). The lived experience of these GTAs reflected little to no sign of cognitive or affective challenges compared to those identified in GTAs who participated in a less traditional learning environment, cooperative problem-based laboratories (Sandi-Urena *et al.*, 2011). Perhaps a more cognitively challenging and engaging environment may help GTAs view themselves more as participants in the learning process and less as transfer of knowledge agents and managers of time and safety.

Implications

Calls for laboratory reform are not new; however, the focus of reform efforts is almost always the undergraduate students. Chemistry graduate students typically teach labs before they start their own research, and for most future faculty, laboratory teaching is the only form of teaching experience before securing a faculty position. With these facts in mind and the current findings in light of previously reported benefits of less-traditional laboratory teaching (French & Russell, 2002, Feldon *et al.*, 2011, Sandi-Urena *et al.*, 2011), it would appear a case can be made that reform is in the best interest of undergraduate students and the graduate students who facilitate the labs. These findings may be a step in that direction and may ultimately inform the reform of laboratory instruction and GTA training.

Although GTAs may base their teaching on their own experiences as students, it may be over-simplistic to think that just presenting them alternate instructional approaches will modify this behavior. This study shows that there is something more entrenched that needs to be addressed and that *providing the (pedagogical) knowledge* may not be enough. That is, it may not be sufficient to just tell chemistry graduate students *what* to teach and *how* to teach it. GTA preparation may need to consider a less surface-level approach and aim at holistically preparing the chemistry graduate student for a responsibility that in principle was not what they signed up for when they decided to become scientists. On a larger scale, this view may entail for laboratory instructors and decision makers "rethinking our own views of teaching and learning so that we are better able to serve all the students" and GTAs (Stacy, 2000, p. 77). Additionally, we maintain that this reflecting about the self as instructor is indeed a contributing factor in the journey of becoming a scientist in which students embark when entering their graduate programs. In concluding, we see the role of the GTA as central in the general chemistry laboratory experience but not in the same sense that GTAs in this study viewed themselves. GTAs are essential in that they can promote an environment in which students advance in a trajectory of becoming independent and autonomous learners.

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