Graduate teaching assistants' epistemological and metacognitive development

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Research in general chemistry laboratory instruction has rarely focused on the impact of the learning environment on the graduate teaching assistants (GTAs). We decided to investigate the effect that facilitating a well established cooperative problem-based chemistry laboratory has on GTAs' epistemological and metacognitive development, and how this may translate into their scientific professional growth. Thirteen new GTAs underwent a day and a half teaching training complemented by weekly staff meetings. They were interviewed after their first semester as GTAs, and the data collected were analyzed utilizing a phenomenological approach. Three dimensions that describe the experience lived by the participants emerged from the analysis: affective engagement, metacognitive engagement, and epistemological reflection. The last two offer a rich description of how the laboratory context promotes GTAs' metacognitive and epistemological development, whereas the former provides understanding about the motivation driving their intellectual engagement. Considering the role of metacognition in research, and that personal epistemology is strongly tied to identity development, and that it shapes expectations and ways of learning, it is our contention that appropriate teaching experiences may contribute to better prepare graduate students for their journey in becoming scientists and to embark on successful research.

Keywords: chemistry laboratory instruction, cooperative learning, problem solving, learning theories, epistemological development, metacognitive development

Introduction

The unique learning experiences available to students in the undergraduate chemistry laboratory have prompted a wide range of investigations. While there is disagreement about the effectiveness of the laboratory as a learning environment, the idea that appropriately designed chemistry laboratory instruction can play a significant role in students' achievement of scientific literacy seems to be prevalent among chemistry educators (Hofstein and Mamlok-Naaman, 2007). Consistent with this premise, most of the research has focused on the implementation of different instructional approaches, and students' gains and perceptions (Domin, 1999; Hofstein and Lunetta, 2004; Carillo *et al*., 2005; Cooper, 2009). Interest in teaching assistants has revolved around training for given instructional paradigms (Birk and Kurtz, 1996; Nurrenbern *et al*., 1999; Kurdziel *et al*., 2003; Bond-Robinson and Bernard Rodriques, 2006), and their perceived expectations (French and Russell, 2002; Herrington and Nakhleh, 2003).

Despite the fact that chemistry departments at large, research-oriented, higher education institutions have long relied on their graduate students to serve as laboratory teaching assistants (GTAs), little attention has been paid to the potential impact that *teaching* can have on the GTAs themselves. Even though being a GTA may be presented as a way of gaining valuable teaching experience, more often than not these positions are primarily considered a secure source of financial support, and graduate students and research advisers alike often perceive it as *time away from the research lab*.

French and Russell (2002) posed an intriguing question: *"can teaching inquiry-based labs complement other activities through which GTAs learn to conduct research?"* (p. 1037). Based on the premise that people learn more effectively when they teach, these authors maintained that facilitating development of inquiry skills would in turn favour GTAs' own research skills. By using pre and post semester questionnaires French and Russell demonstrated that the perception of GTAs participating in an inquiry-based introductory biology course was that their instruction involvement had indeed contributed to their ability to do research. In contrast, most of the GTA gains reported in the sparse chemistry-related literature seem to fall within the dimensions proposed by Seymour (2005): gains in knowledge and understanding, gains related to teaching (teaching skills, effective communication, and enjoyment), and gains in appreciation of personal and career paths. In other words, studies have been mostly limited to intellectual gains related to content mastery, teaching ability (most likely understood as ability to deliver information), and GTAs' satisfaction, and have not necessarily resulted from a thorough analysis of the learning environment, but from survey type instruments.

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We believe that a better understanding of potential benefits accessible for GTAs in non-traditional learning environments may place innovative instruction in a new light of appreciation. According to Bond-Robinson and Bernard Rodriques *"teaching requires strategic interactions and problem solving based on understanding the situation, the discipline, and the population of students that one is teaching"* (2006, p. 305). If laboratory instruction offers GTAs an intellectually stimulating environment that transcends meaningless repetition of procedures and engages them in research-like thinking, they may become more enthusiastic and appreciative of the benefits that such an experience may entail. As part of a larger research project, we are investigating the effect that facilitating a well established cooperative problem-based chemistry laboratory has on GTAs' epistemological and metacognitive developments, and how this may translate into their scientific professional growth.

Epistemological development

Epistemological beliefs refer to individual's assumptions about the origin, nature, limits and certainty of knowledge (Baxter Magolda, 2004; Schraw *et al*., 2006) and have been associated with problem solving and self-regulated learning (Neber and Schommer-Aikins, 2002; Schraw *et al*., 2006). Hunter and collaborators have underscored the connections between epistemological development and 'becoming a scientist' (Hunter *et al*., 2007), a stance supported by Baxter Magolda's assertion of personal epistemology being *"intertwined with other dimensions of development, namely, identity and relationships"* (2001, p. 31). Evidence suggests that epistemological assumptions influence expectations about learning (Baxter Magolda, 2004) and may be determinant in how learners deal with conceptual conflicts when presented with formal concepts that contradict their own knowledge (Hewson and Hewson, 1984; Baxter Magolda, 2004). In Tsai's view naïve personal epistemologies may lead chemistry students to learn *"by rote and in isolation without a coherent understanding"* (2001, p. 970). Others maintain that more sophisticated personal epistemologies are associated with higher achievement, better problem solving and production of higher quality solutions (Schraw *et al*., 2006).

In our study we subscribe to Baxter Magolda's Epistemological Reflection Model (ERM) that proposes four stages in the intellectual development (2004). *Absolute knowing* refers to the stance in which knowledge is considered certain and located in an external authority. Individuals in this stage see themselves as receptors of knowledge that is to be regurgitated when prompted. Individuals at the *transitional knowing* level view some knowledge as uncertain, authorities are not all-knowing and value is placed on applicability of knowledge. *Independent knowing* is characterized by viewing most knowledge as uncertain and appreciating independent thinking and sharing of different views. Finally, *contextual knowing* is characterized by the belief that knowledge exists in and is shaped by a context, and that it requires supporting evidence. Findings have shown that college education has positive effects on the development of epistemological beliefs (Neber and Schommer-Aikins, 2002; Pizzolato, 2006); however, a vast majority of college graduates do not progress beyond the transitional level and reaching the independent knowing stage may take several years of post college life (Baxter Magolda, 2004). It has been suggested that the *"lack of challenges where students are encouraged to solve problems independently rather than depend on institutional authorities or parents to solve their problems for them"* (Pizzolato, 2006, p. 228) may be a primary factor in the hindrance of such development. Fortunately, research provides evidence that instruction can be effectively reformed to create an opportunity for epistemological sophistication. As part of the 'Learning How to Learn Science: Physics for BioScience Majors' project, Redish and Hammer (2009) have reported strategies conducive to epistemological and metacognitive gains in college students. In that large-scale project, the adopted reforms intended to make explicit the instruction about scientific reasoning processes and how to think about science, thereby promoting epistemological reflection.

Metacognitive development

Metacognition refers to individuals' ability to reflect about their own cognitive activity and its outcomes. Two metacognition components are widely accepted: knowledge of cognition (declarative, procedural and conditional) and regulation of cognition. The regulatory component consists of the array of actions and activities in which individuals engage when performing a task, and are commonly grouped into *planning, monitoring and evaluating*. Several authors have addressed the relevance of metacognition in chemistry learning and problem solving (Francisco *et al*., 1998; Rickey and Stacy, 2000; Tsai, 2001; Schraw *et al*., 2005; Kaberman and Dori, 2009), and recent work has reported its assessment in chemistry (Cooper *et al*., 2008; Kipnis and Hofstein, 2008; Cooper and Sandi-Urena, 2009; Sandi-Urena *et al*., 2010; Sandi-Urena *et al*., Submitted). It is commonly argued that metacognition can be improved through appropriate instruction (Schraw *et al*., 2005; Schraw *et al*., 2006; Kipnis and Hofstein, 2008) at the same time that quality of learning can be improved when mediated by metacognition-prompting environments (Davidowitz and Rollnick, 2003; Larkin, 2006; Sandi-Urena *et al*., Submitted). Referring specifically to laboratory instruction, Hofstein and Lunetta (2004) maintained that students' learning may be enhanced by creating more opportunities for them to develop and use metacognitive skills during active laboratory engagement. Evidence seems to support this claim (Rickey and Stacy, 2000; Mattox *et al*., 2006; Tien *et al*., 2007; Sandi-Urena *et al*., Submitted).

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 objective is to investigate the learning environment generated by utilizing cooperative problem-based general chemistry laboratory projects. The learning environment has been substantially described in the literature (Cooper, 2009; Sandi-Urena *et al*., Submitted); it has been in place at this institution for over 15 years, and each semester serves around 1300 students. The initial stage of the larger research program comprised a mixed methods sequential explanatory design (Creswell and Plano Clark, 2007) with the objective of studying the impact of the laboratory instruction on students' metacognition use and awareness and problem solving abilities (Sandi-Urena *et al*., Submitted). The quantitative findings obtained supported statistically significant gains in these parameters, while the analysis of the qualitative data produced a frame for explaining such gains: meaningful and purposeful social interaction, and reflective prompting act as promoters of metacognition (Sandi-Urena *et al*., Submitted).

At this point we realized that the nature of the cooperative problem-based instruction positioned the GTAs as active participants in the learning environment, thereby creating the potential for similar GTA gains. Therefore, we decided to scrutinize the laboratory experience as lived by the GTAs, that is, through their participant-observer lens. We believe their informed perspective would be difficult to match by using direct observation for two reasons: the length of time they played the role of *observers* and the intensity of their engagement as *participants*. As a methodological framework, phenomenology seeks to describe *"the essence of human experiences about a phenomenon as described by participants"* (Creswell, 2009, p. 13) and is founded on the premise that is it through this description that understanding of the meaning of the phenomenon can be achieved (van Manen, 1990). It is relevant to emphasize that this meaning is accessed through the description of the phenomenon and not derived from the participants' evaluations about the experience. Casey (2007) suggested the use of a phenomenological approach as research tool to investigate the academic laboratory experience; however, to the best of our knowledge this has not been attempted in tertiary chemistry education. The foundations of our methodological proposal rested on the premise that by distilling the essence and constructing a description of the cooperative problem-based general chemistry laboratory as lived by the GTAs, we might access information about their own opportunities to develop metacognition use and epistemological sophistication.

All thirteen first year graduate students with no student experience in cooperative general chemistry laboratory were recruited. Five of them were females, five were non US-born; in total, they came from five countries, the age range spanned from early 20's to early 40's, five had master's degrees and had previously held a traditional lab GTA position. All incoming GTAs attended a day and a half departmental new GTA orientation before starting their assignments. Several activities were incorporated into these sessions to acquaint GTAs with cooperative problem-based learning and the general workings of the General Chemistry Laboratory Program. However, training was not exclusive, since other aspects such as departmental policies and procedures had to be introduced. Continuous support and coaching was provided in the form of weekly staff meetings led by the GTA faculty coordinator. These meetings were mandatory and included twelve GTAs who had previous experience; the meetings provided not only a formal venue for the discussion of logistics and contents of the projects, but also served to spark reflection about factors intrinsic to the learning environment and strategies to successfully function within the cooperative learning paradigm. These reflections are believed to have helped incoming GTAs with the development of their teaching skills, and were commonly informed by contributions from experienced GTAs. Each new GTA taught three lab sections, each with an enrolment between 20 and 24 students.

Data collection used a semi-structured interview protocol divided into three main parts. Initially, participants were probed to describe their own experience as general chemistry students and any previous experience as GTAs. Next, they were prompted to describe the laboratory they were teaching which included their perception of students' experience and their own experience as a GTA. Finally, after being informed that previous research had shown that students in this learning environment improved their problem solving skills, they were invited to formulate plausible explanations based on their experience and to share any ideas they might have about how students might best learn in a general chemistry lab. Interviews were conducted at the end of their first GTA semester assignment. Participants met with one of the co-authors who is a trained interviewer but held no position within the department at the time of data gathering. Two authors discussed the interview protocol and objectives immediately after each of the first five interviews to assure coherence and adherence to the protocol and research goals. Interviews typically lasted for one hour, were audio taped, transcribed and analyzed using a phenomenological approach.

Outcome space and interpretation

Our data analysis and interpretation strategy was derived from the methodology proposed by Moustakas (1994). The main steps followed were: (a) analysis of the transcribed interviews to identify significant statements; (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. Understandably, this inductive process is non-linear and iterative. Two authors completed the analysis, the third serving as auditor. The resulting outcome space is shown in Fig. 1. Three core dimensions—the affective engagement, the metacognitive engagement and the epistemological reflection—revolve around a central interconnecting factor—the learning environment—which we describe as a 'cognitive and affective imbalance experience'.

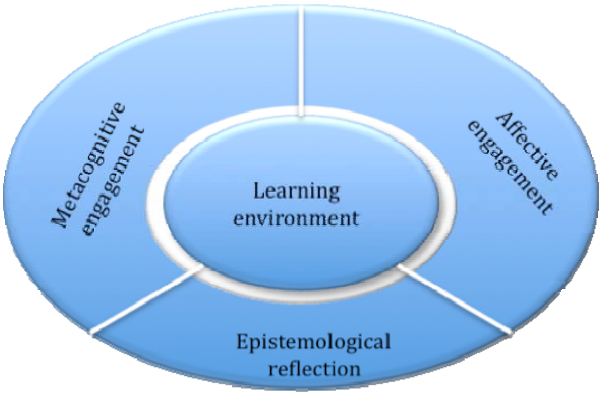

Fig. 1 Outcome space: core dimensions and interconnecting factor.

Despite the training gained from the GTA induction, the participants experienced uncertainty and some degree of confusion when they first faced the learning environment. Anxiety and feelings of unpreparedness are not uncommon even after longer periods of training (Birk and Kurtz, 1996). The setting was unfamiliar; the GTAs had an idea of where they stood and they had understanding of their goals, but bridging of these two was not necessarily clear. In Wheatley's view this "*not knowing what to do*" constitutes a *real problem* (1984). This observation is consistent with reports about GTAs whose initial understanding of not giving *"answers to students during an inquiry-based activity"* (Kurdziel *et al*., 2003, p. 1208) was clear, but who were also unsure as to how to approach the students and what to do to promote learning. In responding to the demands of the challenge, GTAs in our study activated their problem solving and implemented a series of skills deemed necessary in an inquiry-based environment and that, we believe, defined their experience. We propose that in their unity, the three dimensions describe the learning environment as lived by first year GTAs. These dimensions are tightly interrelated and, certainly stemming from the complexity of the environment under scrutiny, there may be multiple intersections. Two dimensions, the metacognitive engagement and the epistemological reflection, informed us directly about gains in intellectual skills. Meanwhile, the affective engagement dimension contributes in sense making and brings unity and cohesion to the model. Fig. 2 shows themes that are representative of the process of categorization leading to the core dimensions.

Exemplar supporting statements from participant interviews are shown in Table 1; they support the construction of the outcome space and the interpretation of the lived experience. It is important to note here that it is not the face value or accuracy of the statements that is relevant but rather their implications. For example, the significance of the judgment *"I think the presentation of cooperative chemistry in general has been flawed"* (NG3, Table 1) goes beyond its discrediting the effectiveness of the learning environment. In context, this particular statement reveals a profound affective engagement and suggests serious reflection about and involvement with the learning environment. In the following sections, we describe the three dimensions in further detail.

Affective engagement

Here participants reveal the relevance they placed on the role that the affective dimension plays on learning and teaching. For instance, using their own words, GTAs

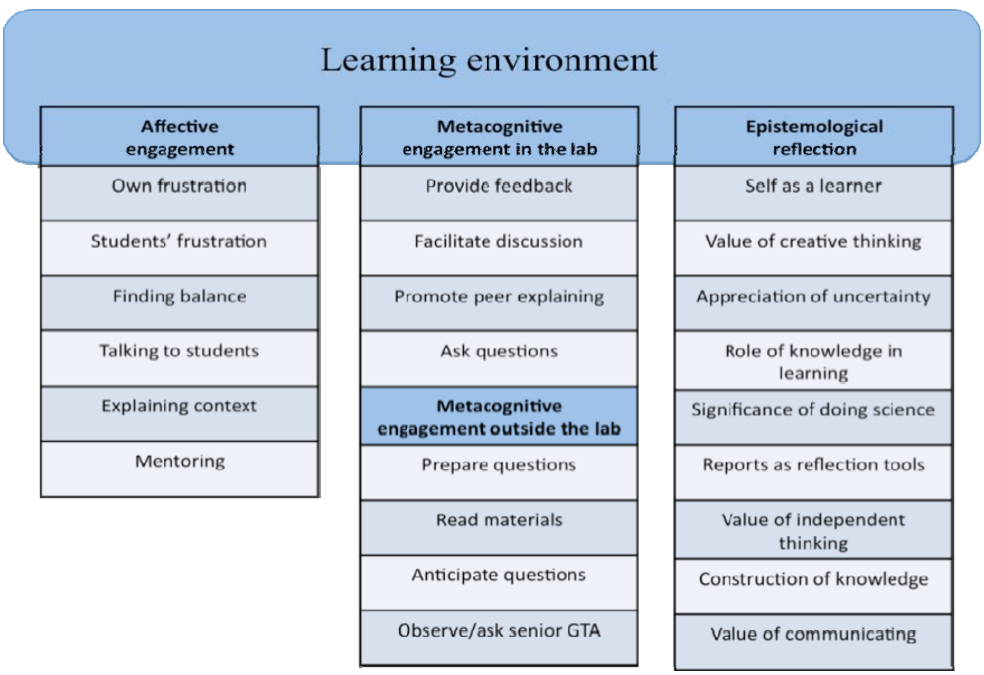

Fig. 2 Outcome space: core dimensions and themes.

Table 1 Exemplar statements supporting the outcome space and its interpretation

GTA Identifier	Supporting statement
	Affective engagement
FB1	"I would say for the first semester to learn that much, I think it should be a good experience, like good learning experience. I don't know how they feel about the lab but I think it was tough […] was like being moved from very cool water to, dumped into very hot water."
LE2	"You know, making sure that when someone is stressing out… 'Sit down, stop, what are you stressed out about?' If you are stressed out you don't learn anything."
NG3	"You know, I think the presentation of cooperative chemistry in general has been flawed." "The cooperative chemistry lab, the way it is taught […] is a more frustrating experience for students in general, now before, before I go on, I am not going to say that this is necessarily a bad thing."
UL4	"So I told the […] the outcome is not the main focus but instead the process, their learning processes, that's important [laughter]." "…I, you know, I need to tell them every time that it is a group time to discuss things and all that."
UL5	"…we were talking science with his group and we really get into a lot of fun talk with them, you know, once everybody's done."
NA6	"Frustrated. Because it is not what they expected as a general chemistry lab. I mean, many of them… most high schools nowadays don't even teach the lab. […] students that had it were shocked when they were asked to formulate their own procedure."
NA7	"Going into the teaching experience I was a little nervous because I had never done it before."
BW8	"I understood some of the frustration maybe they feel, because they are new and they are a little afraid of the lab, coming to this big hall with all these people and all these chemicals around… it is a little scary. Once we went through the weeks they got more confident."
	Metacognitive engagement
GTA Identifier	Supporting statement
XT9	"I don't know if I am more reflective, but sometimes I have to help the students trouble shooting so I have a little more experience solving problems 'cause, you know, before I always had someone that I went to when I was having problems and it'd be like how do you do this, you know."
UL10	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."
NA11	The biggest frustration came with my first lab of each week because that's when you need to work out the bugs really fast, […] However, after my labs I could converse with other TA's and we would figure out what the problems were and we could take care of for the next lab."
NA12	I think coming out of the labs I have a better idea of how to think through the problems that they might have and adjust my teaching methods to their individual needs because not all of them are the same."
BW13	"…the students are more active…they have to think a lot, that is something that I didn't have during the experiments [as a student], I didn't 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 [cooperative labs] they have to actually go through the experiment to actually be able to answer the questions."
UL14	"…you don't 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…"
XT15	"Before, I was just, you know, I would have assumed everything was going to be the step by step thing and that that was probably the greatest thing but, as the lab here, I don't know if they should be given, I think sometimes they need to be given more guidance […] so I mean I think at times here they are expected to do so much.…"
	Epistemological reflection
GTA Identifier	Supporting statement
BW16	"…they have more ideas, maybe someone can come with something they didn't 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 didn't happen, so why didn't it happen, that kind of reasoning should help them, I think."
FB17	"You know, cooperative lab is, it's 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…" "Or somebody can ask you a question and through discussion, you know, that maybe will trigger your thinking, 'oh, I didn't think about this', you know, so I think in such way it has kind of helped students in their reflective thinking." "Well, problem solving skills is the best way and that is probably the best objective that probably is going to have for such a collection of students, so that is what science is about, being critical, ask questions to solve a problem."
BW18	"I am enjoying the lab, so I don't see like teaching as a bad thing or boring […] actually see them in the lab going 'oh, maybe the reaction is like this', thinking about something that is not their major area, they get it, understand some things, and they come to me and say '[GTA's name], I feel like a real scientist'".
LE19	"So I engaged them in a way that no result does not necessarily mean bad. It doesn't mean you did something wrong..."
UL20	"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, so that was, I think that was very important and some of them didn't seem so frustrated anymore, they seemed like they were excited about this stuff."
UL21	"I think I may start kind of looking at things in a more critical way, too. I think because you are trying to reinforce something… […] But since I really tried to come up with a creative way of teaching it, in general, I think it makes me think about it more critically, about other stuff, too, even though they are not related."
NA22	"I don't know what it is but it is the general fear that they have to be accurate. That chemistry is an exact science and it's 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 except for…"
NG23	"If you look at cooperative chemistry you basically are trying to mimic, I'd say when I sit down with my professor and say 'how can we solve this problem'."
UL24	"You know, they have this freedom, first of all, so…and I had that in my mind, I set that in my mind that there is no right or there's no one way of doing this experiment."

described students' 'chemistry lab anxiety' and how this may impact their experience. They sympathized with students' feelings provoked by walking in *"this big hall with all these people and all these chemicals around"* (BW8, Table 1) and are understanding of how this may constitute a source of frustration. Additionally, it was GTAs perception that students' expectations differed substantially from what they encountered the first day of lab; GTAs identified this shocking realization as one of the main sources of student frustration (NA6, Table 1). Consistently, GTAs self-image was not limited to 'knowledge providers' or 'managers'; they saw themselves as mentors: invariably they referred to their 'talking' to students to help them understand the workings of the lab and to their 'explaining' the context of the course. This was best evidenced by a GTA who seems to have monitored students' stress level to intervene because *"if you are stressed out you don't learn anything"* (LE2, Table 1). Likewise, when students showed concern about not producing what they considered the expected outcomes, GTAs offered reassurance that *"the outcome is not the main focus but instead the process, their learning processes, that's important"* (UL4, Table 1). This kind of dialogical interaction may promote meaningful learning by creating a channel to identify links between the conceptual frameworks held by students and instructors (Kinchin, 2003).

Providing learning motivation and encouragement was taken on as one of their duties; it was regarded as a way to help students cope with frustration and required to accomplish the goals set. This GTA engagement helped us in deciphering how students gained the remarkable and accurate understanding of the laboratory format and workings that we had found in previous studies (Sandi-Urena *et al.*, Submitted). It also explained one of the mechanisms operating in helping the students overcome their own initial affective imbalance. Furthermore, this dimension served as basis to understand the motivation that GTAs had to implement the actions that we describe in reference to their metacognitive engagement. In terms of their own frustration, GTAs reported two main sources: the inherent demands from the lab environment and their apparent lack of the required support and tools to handle the lab and accomplish their instructional goals. A feeling of unfairness is apparent; they are being asked to do something that is too demanding even in the affective domain: *"as a TA I've got three classes, I've got homework to do, I've got papers to grade and I've got 55 students to watch over. And three labs a week that take up nine hours [...] There isn't much time for the students to have contact with me..."*.

GTAs are aware that there may be a benefit for students, but it seems to come at a high cost for them; GTAs convey that traditional labs are 'easy' to teach, their rigidity and predictability make them easier for the instructor. In the words of a GTA with prior teaching experience at a traditional laboratory program *"those labs were not difficult to teach because whatever has to be done was written up so you watch and make sure that what the student is doing is right as written in the manual and that is easy to do."* In this dimension GTAs shared their view of the lab format itself and the apparent discrepancy between the 'theory' of cooperative learning and its 'reality' (NG3, Table 1). Their emotional stance towards the format is in most cases explicit and ranges from excitement to complete discontent. However, across the board, participants see the implementation of the format as their responsibility. Some GTAs longed for things like giving quizzes, using short lectures preceding lab work, giving students the 'fundamental knowledge', and making the lab more 'efficient' in teaching concepts, all indicative of a learning environment more familiar to them and in which they are presumably more comfortable. In general, GTAs' frustration diminished as they became more acquainted with the instructional methodology, and possibly, as consequence of the continuous support provided by the GTA faculty coordinator and senior GTAs during the weekly staff meetings. Those who 'clicked' with the lab format seemed to have ended the experience with only some residual frustration from having had too much difficulty at the beginning.

Metacognitive engagement

Cooperative problem-based teaching immersed participants in a *problem situation*. As expressed by one GTA, despite the training efforts, they were *"thrown to the wolves in their own ways"*. Navigation of the problem space and committed reflection informed their development of strategies to succeed in accomplishing their goals and fulfilling their responsibilities. The comment from NA12 (Table 1) is an exemplar of this thinking about their own thinking, and how their monitoring led to evaluation and subsequent adjustment of their task performance. Often this engagement was supported by interactions with other GTAs to '*figure out*' and '*take care*' of problems arisen during instruction (NA11, Table 1). While doing so, they continued to be actively engaged in very critical reflection of the learning environment and everything that was going on around them. We find this deeply connected to GTAs' comparison of their students' lab experience with their own as a general chemistry lab student (BW13, Table 1).

At the time of the interview, participants had a clear understanding of what was expected from them; however, by no means does this imply that they blindly agreed with those expectations (XT15, Table 1). Two components to this dimension emerged that are clearly distinguishable in terms of time and space: engagement *outside the lab* and engagement *in the lab* (Fig' 2). Some of the strategies taking place outside the lab, and without direct student contact, were: planning how to facilitate the lab (*e.g.* UL10, Table 1), reading the GTA lab manual, studying contents, thinking of eventual questions, foreseeing problems, discussing with other GTAs (*e.g.* NA11, Table 1), attending weekly staff meetings, consulting with the instructor, reflecting about the lab, etc. This component underscores GTA's metacognitive reflection, and is characterized by constantly planning, monitoring and evaluating their performance in conducting the task of interest. Participants themselves saw this aspect as something deeply entrenched in the nature of the lab. Strategies utilized during the lab sessions relied on intense social interaction. GTAs purposefully walked through the lab asking students questions, promoting team-work and discussions, guiding students to think through, and encouraging students to figuring out (*e.g*. UL14, Table 1). Communication and interaction took the form of one-on-one conversations or conversations with small groups. During the lab instruction, GTAs engaged in a vast array of skills, including modelling, to engage their students in implementing metacognitive behaviour they deemed necessary for student success (*e.g*. XT9, Table 1).

Epistemological reflection

Sudden introduction to a new and unfamiliar learning environment triggered an epistemological conflict: GTAs had to ponder about their role and function in instruction, and had to decipher the meaning of knowledge and learning in the new environment and to contrast it with their previous notions. Challenges within this non-traditional instructional perspective generated an opportunity for participants to confront their deeply held beliefs about teaching and learning. Kinchin *et al*. (2009) reported such type of epistemological conflict in postgraduate students in the United Kingdom. In their study, postgraduate teaching assistants were simultaneously conducting disciplinary research and engaged in teaching as part of a postgraduate teaching certification. Kinchin and collaborators pointed out that *"reflection upon this* [epistemological] *conflict may be a prerequisite to developing towards a more sophisticated philosophical stance"* (p. 50).

We have chosen statements BW16 through UL24, Table 1, to illustrate participants' agreement with aspects associated with Baxter Magolda's independent and contextual knowing stages: the value of creative thinking, figuring out things, discussion as a means of reaching understanding and constructing knowledge, disbelief of absolute knowledge and acceptance of uncertainty in science, disagreement with the right-and-wrong dualism. Furthermore, they described students' work in their labs as 'doing science' and 'talking science'; they ascertained the relevance of prior knowledge and background on learning, and reflected about themselves as learners. In terms of the Epistemological Reflection Model, the lab offered a context where individuals were exposed to *"the complexity of the world around them"* which *"helps them encounter new assumptions"* thereby promoting their epistemological development (Baxter Magolda, 2004, p. 41). Participants' epistemological beliefs guided the choice of activities they promoted to create the learning environment that they thought would lead their students to success. Although one GTA (FB16, Table 1) was particularly concise in articulating several statements reflecting independent and contextual epistemological views, one way or another, evidence of the above assertions was prevalent in all interviews. By engaging in explaining the nature of the lab to their students, GTAs had to talk and share their views about learning and their epistemological world-views, which inevitably had to be preceded by (conscious or unconscious) epistemological reflection. While the metacognitive engagement dimension is characterized by GTAs regulatory actions, the epistemological reflection dimension is characterized by their pondering about the nature of knowledge and learning. Evidently, these dimensions influence one another, but are different in nature. In some instances participants' evoked views were reminiscent of a transitional way of knowing that confirmed the conflictive character of this epistemological reflection.

Examples of such views include the need to pass on fundamental knowledge to their students, or spend more time on direct instruction thus making the lab more 'efficient' in teaching concepts. Interestingly, despite stating that cooperative labs mimic research (NG22, Table 1) one participant also advocated for lecturing before lab work as means to teaching fundamental concepts and criticized those who are "*so heavily against*" traditional lab environments arguing that "*Schrödinger did the same stuff that I did [as a student)], you know, and […] he turned out OK. He came up with some pretty good ideas.*" As mentioned above, in some instances participants longed for the less challenging GTA and content-centred lab environment, a desire that could stem from a survival instinct to fall back into something easier to teach and less time consuming. In another account, a GTA with prior experience described traditional laboratories by saying that they *"were actually, really… were easy to do labs […] really easy to handle, uh, you go to the lab and watch the students, what they are doing, uh, actually, you supervise them […] help them to do things correctly, handle maybe equipment, you know, uh, procedure, correct them in procedure."* In contrast with the cooperative problem-based experience, this GTA added that for those traditional labs he did not have nor needed training, and that the only meetings called for were *"to agree on what kind of key to use in grading or a grading rubric"*.

Implications

Many would maintain that teaching is the ultimate learning. There is little doubt that reviewing of materials, time on task, preparing for and answering questions, and other instructional activities may have an impact on dedicated instructors' mastery of content. However, does this learning by teaching premise transfer to development of skills? Beyond the naïve assumption that skills can be learnt when taught (Olympic medallists' trainers are not necessarily Olympic medallists themselves), we were interested in determining if engagement in cooperative problem-based projects that required the GTAs to practice higher order skills might have an effect on their epistemological views and metacognition use (can a swimming coach improve her own swimming by *practising* with her pupils?).

The learning environment instantiated in this study grants an opportunity for GTAs to increase their level of epistemological sophistication. This epistemological development is deeply associated with the level of active and reflective engagement with learning and teaching (Kinchin *et al*., 2009) that the GTAs are required to partake in response to the characteristics of the environment. We put forward that this engagement is triggered by the epistemological conflict initially experienced. If GTAs' views about teaching and learning are initially determined by their own experiences as students (Kurdziel *et al*., 2003), placing them in a very dissimilar learning environment might reasonably prompt them to reflect and eventually modify or ratify their views. The evidence we have gathered firmly shows that the learning environment promotes epistemological reflection preceded by a conflict in the ways of knowing, that is, understanding of knowledge and learning. Additionally, our findings agree with those reported by Sanger (2008). This author used written reflections to compare pre-service teachers who had taken several inquiry-based courses with a similar group exposed to several traditional lecture based courses, and demonstrated that the former had *"developed more mature views regarding the nature of science"* (p. 301). Based on her extensive research, Baxter Magolda (2004) maintained that more developed ways of knowing are only reached after years in graduate school or employment. It is not the explicit objective of the lab format to accelerate GTAs' epistemological transformation, but it is evident that the context challenges them and requires such reflection. GTA's framing of their experience—that is their forming a sense of *"what is it that's going on here?"* (Scherr and Hammer, 2009, p. 149)—seems to be consistent with more sophisticated epistemological world-views.

The second aspect of our interest in this study dealt with GTAs' metacognitive development. Previous studies have linked metacognition with expert behaviour; Schraw and collaborators, for instance, highlighted effective planning—in particular global planning—as a key aspect that differentiates experts from novices (Schraw *et al*., 2006). Because metacognition in general is positively linked to aspects such as autonomous learning and problem solving, its role in scientific research is evident. Based on the GTAs descriptions of their experiences in the learning environment employed for this study, we have presented evidence that shows their use of metacognitive strategies. They developed these strategies as a means to perform in a problem situation that mimics aspects of their future research tasks.

Generally, graduate students participate in instruction even before they begin their experimental research. Considering the role of metacognition in research, and that personal epistemology is strongly tied to identity development (Baxter Magolda, 2001), and that it shapes expectations and ways of learning, it is our contention that appropriate teaching experiences may contribute to better prepare graduate students for their journey in becoming scientists and to embark on successful research. By supporting appropriate teaching environments, graduate programs may thereby support earlier development of scientific skills in their students. Despite being rather different in approach and depth, the implications of our findings resonate very well with French and Russell's (2002, p. 1041) assertion: *"That GTAs may be gaining valuable scientific training while teaching inquiry-based laboratories provides further support for a push to change the way in which laboratories are taught."* At this point an even more intriguing question arises: Can someone who does not know how to swim become a swimming coach?

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