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Reform in a general chemistry laboratory: how do students experience change in the instructional approach?

I. Chopra,†[a] J. O'Connor,†[a] R. Pancho,†[a] M. Chrzanowski†[b] and S. Sandi-Urena*[c]

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This qualitative study investigated the experience of a cohort of students exposed consecutively to two substantially different environments in their General Chemistry Laboratory programme. To this end, the first semester in a traditional expository programme was followed by a semester in a cooperative, problem-based, multi-week format. The focus on the experience of a change in the laboratory format is complementary understanding to that from participants exposed to a single format. This work used a phenomenological approach for the reduction, analysis, and interpretation of data gathered from semi-structured student interviews. Through deep analysis, five researchers distilled an outcome space with three fundamental features: (1) ten vectors of change that served as lens to analyse the phenomenon; (2) participants' ability to accurately characterise and differentiate the two instructional environments; and (3) an overarching descriptor that argues that a transition from mindless behaviour to mindful engagement subsumed the experience of a change in the laboratory environment. This outcome space is independent of participants' instructional style preferences. Findings from this work inform the design of laboratory experiences furthering the potential realisation of experimental education at the same time when they extend understanding of learning in the chemistry laboratory.

Introduction

The discrepancy between the professed centrality of the academic laboratory in chemistry education and the lack of a solid body of research evidence to support its role in learning chemistry has been a topic of reflection for numerous authors (Hofstein and Lunetta, 2004; Sandi-Urena *et al.*, 2011; Galloway and Bretz, 2015). Raised awareness of this gap may have driven a recent upswing in studies in tertiary level chemistry education. Nonetheless, a quick review of 69 articles‡ published between 2006 and 2015 reveals a field atomised in its topics of research where a vast majority of authors have published only one article. A few small collections of work have enriched the field with new focuses and methodological perspectives. Exemplars of this work have addressed: (A) the integration of cognitive and affective dimensions of learning in the laboratory by examining students' expectations and experiences in General and Organic Chemistry laboratories (Galloway and Bretz, 2015a, 2015b, 2015c, 2015d), (B) the nature of faculty perspectives regarding goals, strategies, and assessment in the laboratory (Bruck *et al.*, 2010; Bretz *et al.*, 2013; Bruck and Towns, 2013) and students' perceptions of the intended lab goals (DeKorver and Towns, 2015), (C) learning in a cooperative project-based environment (Sandi-Urena *et al.*, 2011a; Sandi-Urena *et al.*, 2012) and the experiences and benefits of teaching assistants in diverse instructional environments as well as their self-image development (Sandi-Urena *et al.*, 2011b; Sandi-Urena and Gatlin, 2012, 2013), (D) quality of oral and written argumentation as derived from participation in an Argument-Driven-Inquiry instructional model (Walker *et al.*, 2011; Sampson and Walker, 2012; Walker and Sampson, 2013a, 2013b; Grooms *et al.*, 2014), and (E) several instantiations of the Science Writing Heuristic (SWH) where students are prompted to use the structure of a scientific claim in their written reports (Greenbowe *et al.*, 2007; Schroeder and Greenbowe, 2008; Hand and Choi, 2010). In some ways, these research endeavours respond to recent (Hofstein and Lunetta, 2004) and past (Hofstein and Lunetta, 1982; Hodson, 1993) calls for studies "to confirm or reject convincingly many of the statements that have been made about the importance and effects of laboratory teaching" (Hofstein and Lunetta, 1982, p. 212).

[a] *Department of Chemistry, University of South Florida, 4202 E. Fowler Ave., Tampa, Florida 33620, USA*
[b] *Department of Chemistry, Case Western Reserve University, 10900 Euclid Ave., Cleveland, Ohio 44106, USA*
[c] *School of Chemistry, University of Costa Rica, San Jose 2060, Costa Rica. E-mail: guillermo.sandiurena@ucr.ac.cr*

† Authorship is equally shared amongst these four co-authors.

‡ Articles on research in learning in tertiary level chemistry laboratory, written in English language, and published in major Science and Chemistry Education Journals (unpublished work).

In 2002, Nakhleh and collaborators firmly stated that: "The goal of research is to thoroughly understand what occurs in the laboratory and then work on revising curriculum and pedagogy" (p. 78). Their proposition focuses on gathering a better understanding of learning in experimental courses as a phenomenon before embarking in curricular modifications, contrary to what seems to be the common approach—making instructional modifications partly based on intuition to then test their effectiveness. Moreover, to reach that thorough understanding researchers need to realise that "the effect or value of the laboratory experience might not be measurable in a quantitative sense" (Nakhleh *et al.*, 2002, p. 78). From this perspective, Nakhleh and collaborators advanced a shift in focus as well as a fresh look at methodological approaches in the field of chemical education research pertaining to the laboratory. In our research programme we use phenomenology (Moustakas, 1994; Patton, 2002) to investigate learning experiences in academic laboratory environments for students and instructors. As a methodological framework, phenomenology intends to elucidate "the essence of human experiences about a phenomenon as described by participants" (Creswell, 2009, p. 13) and is founded on the premise that through this description understanding of the meaning of the phenomenon can be achieved (van Manen, 1990). The existence of an essence to shared experiences is defining for phenomenology the same way the assumption of culture is for ethnography. Patton characterises essence as "core meanings mutually understood through a phenomenon commonly experienced" (1990, p. 106). In van Manen's words "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" (1990, p. 10).

Phenomenological methods intend to bring to light the internal and invariant structure of the phenomenon not in its empirical individuality but in its essence (Patton, 2002). It is relevant to emphasise that this essence is accessed through rigorous and systematic analysis of the description of the lived phenomenon and not extracted from participants' evaluations about the experience. The foundations of our methodological proposal rest on the premise that by distilling the essence and meaning and constructing a thick description of the phenomenon as lived by the participants, we can access understanding about the learning experience and learning environment. In 2007, Casey made a similar case for phenomenology as a methodological research tool to specifically investigate the academic chemistry laboratory experience. However, it was not implemented in tertiary chemistry education until recently (Sandi-Urena *et al.*, 2011a; Sandi-Urena and Gatlin, 2012). With this project, we aim to further introduce the value of phenomenology as a means to address Nakhleh and Collaborators' (2002) call for better understanding of learning in the laboratory through qualitative approaches.

Research question

This study was initiated within the CHEmical Education Research-Undergraduate Programme at the University of South Florida (CHEER-UP@USF!) and is embedded in a larger multi-method research programme that focuses on enhancing our understanding of learning in the tertiary-education chemistry laboratory. The defining characteristics and previous outcomes of this programme have been reported elsewhere (Sandi-Urena *et al.*, 2011a, 2012). The research reported herein complements our prior work, and it addressed the following research question: how do students experience change from an expository and verification-based laboratory programme in General Chemistry 1 to a General Chemistry 2 Laboratory that is cooperative and problem-based?

In general, the little research evidence on the college chemistry laboratory gathered in the past has focused on singular, short curricular modifications rather than looking to understand broader aspects of learning, and has drawn data from student cohorts exposed to only one instructional approach. A particularly significant exception was Domin's report in this Journal (2007). Through mixed-methods Domin gathered evidence from students who had experienced a semester of problem-based laboratories followed by a verification-based semester. This work sheds light on when conceptual understanding takes place in these different environments.

In 1994, Chang and Lederman paid attention to the complexity of the laboratory learning environment and reckoned simplistic the assumption that altering a single variable would produce significant outcomes. Our past studies have compared students and instructors across institutions and laboratory formats while focusing on the holistic experience of learning in a given laboratory environment. This study takes advantage of the rare opportunity of examining two distinctively different learning environments through the lenses of the same students. Our stance is that through the thick description of the experience of change we will gain access to better understanding the contrasts and similarities between these two learning environments and their individual gains, benefits, and shortcomings.

Methods

Context and participants

This study took place at a large, urban, public, research-intensive university in the United States of America. At the time of this study, the institution served over 39 000 students (78% undergraduate). Diverse ethnic minority students made up 39% of the undergraduate student body, 55% identified as female, and 77% were full time students. A typical distribution of majors in General Chemistry is as follows: Pre-professional (pre-Medicine, pre-Pharmacy, and Health Sciences), 61%; Chemistry, 6%; other sciences (Physics, Biology, Geology, *etc.*) or Math, 23%; and Engineering, 8%. The remaining students were non-science/non-engineering majors or post-baccalaureate. The General Chemistry Laboratory Programme served approximately 1600 students per semester and employed chemistry graduate students as teaching assistants (GTAs). Enrolment in General Chemistry Laboratory sections was capped at 24.

The study was implemented while the laboratory programme was undergoing a major change in its format. Before this reform,

according to the course syllabus, the General Chemistry Laboratory was a "course in laboratory methods and techniques" that was concerned with teaching "how to analyse information working in a group or alone, how to organise data and methods of problem solving". In addition, it was intended to facilitate "understanding of the lecture material and support the concepts taught in the lecture course." The laboratory was subservient to lecture and intended to offer weekly verification experiences closely aligned with lecture topics. It utilised mini-lectures at the beginning of the lab meetings, a time for the GTA to go over safety precautions and explain and answer questions regarding procedures, and calculations. First-time GTAs were required to perform each experiment themselves the week before they were assigned to teach it. The rationale was that this would prepare them to respond questions and anticipate and resolve students' procedural problems. An institutionally customised laboratory manual, sole source to be used for the preparation of pre-laboratory reports, stated the goals and procedures. In addition, assessment included weekly post-laboratory reports that followed a detailed template, weekly quizzes, and a practical at the end of the semester. Students worked in pairs except when limitations deriving from apparatuses, equipment, and chemicals required larger groups. In Domin's taxonomy of laboratory instructional styles, this programme was expository (1999).

The Department of Chemistry at the research site created a new programme in tune with educational research findings. The Department provided support to assemble a team of two chemistry education graduate researchers, knowledgeable in instructional design and educational research, to collaborate with the course instructor in achieving this goal. The corresponding author is the only co-author who was involved in this process. His role was that of an expert adviser and not as a standing member of the laboratory re-design team. In addition to the educational research literature, the new programme drew from successful reform experiences (Cooper, 1994; Sandi-Urena *et al.*, 2012). It used a cooperative, project-based, multi-week approach whose general features and applications to General Chemistry have been thoroughly described in this Journal (Sandi-Urena *et al.*, 2011). The broad objective of each laboratory project was framed for the students in a context that intended to make it relevant. Likewise, each project had a research connection where a brief text and a visual linked the topic with chemistry research performed in the Department. Teams of four students planned and devised their own experiments. There were no lab mini-lectures and no quizzes or practical examinations. Students wrote two full individual project reports that went through a double-blinded peer-review process before their final submission. In addition, there were team oral presentations: one talk and one poster. During the semester, students completed peer and self-assessment rubrics. The course description stated that it aimed "to offer an introduction to the science of chemistry from the point of view of practicing chemists. Its core idea is to facilitate students' understanding of the relevance of scientific research in modern society" and to bring students "closer to understanding research as a social endeavour." This programme was consistent with Domin's description of the problem-based laboratory style (1999).

The inclusion criterion to be part of the study was to have completed the General Chemistry 1 Laboratory in the original format, hereafter expository or GC1, and to be enrolled in the re-designed format for the General Chemistry 2 Laboratory, hereafter cooperative or GC2. No member of the research team was engaged in any capacity with laboratory instruction when the data collection took place. The corresponding author was granted temporary access to the course management platform to send a mass email invitation to participate to all students enrolled in the cooperative General Chemistry 2 Laboratory. The invitation, which was IRB approved, described our intention to gather student feedback through interviews to improve the laboratory programme. No monetary compensation or course credit was offered. Confidentiality was guaranteed as was the fact that no instructional staff member would have access to interviews or interviewees' identities. Twenty-one students replied within approximately 24 hours expressing intention to participate. At this time, a second email was sent informing all students enrolled enough responses had arrived and that we might reopen the invitation again if necessary. We followed up with the 21 volunteers and scheduled appointments with 12 of them. Interviews were scheduled at volunteers' convenience during the last two weeks of the semester. The remaining nine volunteers had scheduling conflicts but agreed to be interviewed at a later time if necessary. As explained below, a total of six interviewees were used for this study. Three interviewees were first-year students, one was second-year and two were third-year. In spite of being third-year college students, the latter two had changed majors into STEM fields and were completing their first year in their new STEM major. Five of the participants were majoring in STEM fields; only one of them was not required to take more chemistry classes for their major. The remaining participant started as STEM major but had decided to switch into Education. According to this participant's statements, their overall course performance and the General Chemistry Laboratory sequence played no part in this decision. One participant had taken a Physics lab and another one a Geology lab concurrently with the General Chemistry 1 lab. Two participants had taken a secondary school Advanced Placement Chemistry course that included laboratory work while the rest took the regular Chemistry class. Overall, participants did not have significant experience in an academic science laboratory beyond secondary education.

Data collection

Phenomenological approaches involve "a return to experience in order to obtain comprehensive descriptions that provide the basis for a reflective structural analysis that portrays the essences of the experience" (Moustakas, 1994, p. 13). The nature of data collection is retrospective: creating external instances to reflect about the experience while it is lived would distort the experience and preclude a phenomenological approach. Likewise, phenomenology distinctively uses "descriptions of experiences through first-person accounts in informal or formal conversations or

interviews'' (Moustakas, 1994, p. 21). Semi-structured interviews, in their ability to return students to the lived experiences, were the most suitable source of data collection. During the semi-structured interview, participants were asked broad, open-ended questions related to their learning experience and these questions would build upon the participants' responses. Open-ended questions allowed each interview to be unique to the respective participant and gave him or her the freedom to provide a detailed description of their experience. The interviewer was a chemical education graduate researcher near his graduation date who had developed ample experience conducting interviews over the preceding five years. The corresponding author and the interviewer met and 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 (see Appendix 1 for the interview protocol). There was no evident emergence of new themes after completion of six interviews and the interviewing process was ended. Two participants had emailed to inform us that they could not attend the interview. The other four volunteers were contacted and we agreed to postpone the interviews and hold them at a later time if necessary. Interviews lasted between 45 and 75 minutes, were audio-recorded, transcribed and analysed using a phenomenological approach. Interviewees were assigned pseudonyms; no identifying information was recorded that linked interviews with participants.

Data analysis

Our data analysis and interpretation strategy was derived from the methodology proposed by Moustakas (1994), and is summarised in Fig. 1. The first five steps were: (a) analysis of the transcribed interviews to identify significant statements which is accomplished through extracting statements under the initial assumption that they all have equal value, a step described as horizonalization; (b) coding, that is clustering of significant statements based on their meaning to create invariant constituents (codes); (c) collapse of codes based on thematic similitude to generate 'themes', a process known as code clustering; (d) validation of themes by checking against transcriptions; and (e) synthesis of the codes and themes into a textural description by the narrating process. Understandably, the inductive process of phenomenological reduction is non-linear and iterative. Five researchers completed steps (a)–(e) for the first interview. In our team approach, each researcher performed each task individually and products were discussed during prolonged weekly meetings. Steps (b) and (c) generated a preliminary codebook and list of themes, respectively. Upon the validation of themes, each researcher prepared an individual textural description. The researchers shared and read all five textural descriptions before a meeting in which they were discussed. Research meetings were audio recorded for later reference. Steps (a)–(e) were repeated for three more interviews. This process allowed modification and further improvement of the codebook and theme list. Once each researcher was satisfied with his textural description for the interviews, the research team engaged in (f) the construction of a composite structural description through imaginative variation and (g) synthetic intuitive integration of individual textural descriptions and the composite structural description to condense the meanings and essence of the experience representing the group as a whole. The process of constructing an initial composite structural description entailed researchers working individually first to then discuss and further interpret the results. We decided to represent this description diagrammatically and we refer to it as the outcome space. The outcome space is a single product of the reflection and interpretation of the entire research team. It is noteworthy that, as stated by Moustakas, ''structures underlie textures and are inherent in them'' (1994, p. 79). Therefore, although it is possible to focus on one or the other at different stages of the analysis, this close relationship prompted the emergence of structural features during the discussion of textural descriptions. Far from hindering the systematic approach of the analysis, this intertwining facilitated the natural process of evolving the description from textural to structural.

The additional interviews were analysed using the same steps (a)–(g). No significant modifications to the codebook and list of themes were necessary. However, continued reflection and further analysis allowed the research team to polish these outcomes (*e.g.* selection of labels, crafting of definitions). Likewise, consideration of the textural descriptions for these additional interviews strengthened the construction of the outcome space. Finally, the intuitive integration encompassed all six interviews.

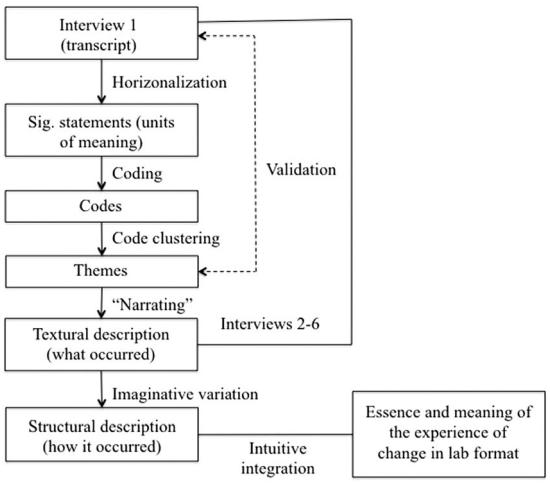

Fig. 1 Phenomenological reduction of textural data.

Results and discussion

Although consistently the general motivations to participate in this study were to somehow contribute to the betterment of the laboratory programme, participants' preferences resulting from the lived experience were dissimilar. This diversity enhanced the opportunities for rich and unique stories of the experience (Laverty, 2003). Alma and Cait were extreme exponents of

this diversity. Towards the beginning of her interview Alma clearly assured that she was not alone in her dislike for the cooperative format to then immediately disqualify the programme:

"A lot of gen chem. 2 students don't like the system, I mean, granted they are used to having everything spelled for them, but, and I, I am not against the whole critical thinking thing, but it was, we were making up work, what we were supposed to do, and why we were supposed to do it, making up stuff is not learning, [laughter], it's just putting information that you think is correct."

Despite her criticism and disapproval, Alma offers a description that is consistent with that of other participants who viewed the cooperative labs more favourably.

On the other hand, Cait was not shy to show her enthusiasm towards the cooperative format in opposition to the expository laboratory:

"Last year [GC1], it was like, read, do this, read, do this, I didn't even know what I was doing to be honest. [...] But, this lab [GC2], I feel like we learn more, 'cause, it's like, they don't tell you what to do, you have to do what you want, it's like your decision, so you have to do your background and from your background information, you do your lab, and I learnt a lot personally. [...] When I get to the lab I am actually doing it myself. [...] So I enjoyed the lab for that."

Yet describing the same aspects of the laboratory programmes, Alma and Cait offer opposing evaluations of their effectiveness. The other participants fell somewhere in between these two extremes except Earl who interpreted the lab formats as a natural progression within a single programme only requiring a more seamless transition. The excerpts above make evident that the characterisation of the instructional formats is independent of the students' affective stance towards them. In previous work in this Journal we drew attention to the coherent interpretation and description of cooperative, project-based learning environments despite diametrically opposed affective stances (Sandi-Urena *et al.*, 2011a). Let us underscore that we are interested in understanding how students experience the change in the lab format and how this may inform understanding of lab learning and lab design over participants' approval or disapproval. Arguing for the superiority of one instructional style over the other is not a goal of this report.

The final codebook comprised 35 codes, most of them with sub-codes (more specific than the code from which they derived).

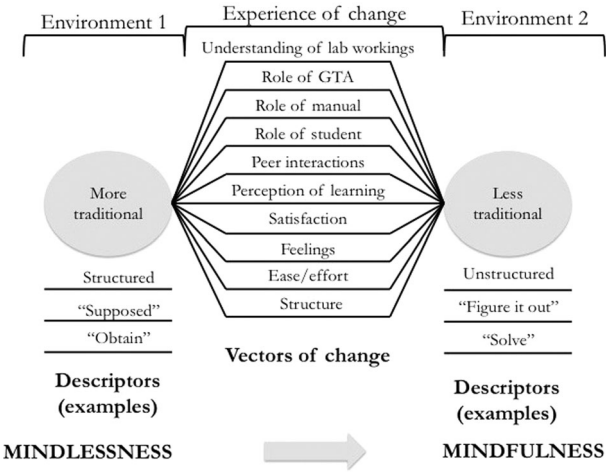

Fig. 2 Phenomenological outcome space.

Thematic clustering led to ten themes that we propose describe aspects of the learning environment along which the participants experienced modification from GC1 to GC2. Therefore, we refer to them as vectors of change (Table 1); these themes were common to the participants independently of their lab format preference.

Through imaginative variation using the individual textural descriptions for the interviews, the vectors of change, and our research team discussions, we obtained the outcome space in Fig. 2. It encompasses three main components: characterisation of the learning environments, vectors of change, and overarching descriptor of the change.

Characterisation of the learning environments

That college students can accurately describe the chemistry laboratory learning environments was first reported over three decades ago (Abraham, 1982). In 1982, Abraham examined how students in three different learning environments (verification, guided-inquiry, and open-inquiry) ranked 25 statements that qualified their experiences. The author concluded "students can identify important differences between inquiry and verification laboratory types, including the emphasis on laboratory skills and scientific processes" (Abraham, 2011, p. 1024). Similarly, in our previous work students immersed in a cooperative, project-based

Table 1 Vectors of change and their descriptions

Vectors of change	Brief description
Easiness/difficulty	Judgement related to effort (in time and dedication) necessary to complete work.
Feelings	Affective disposition towards the lab format.
Peer interactions	Exchanges amongst team members and with others (other teams, other lab sections). Structural (how and why) and teleological (why and what for).
Perception of learning	References to what is learned and how it is learned (products or gains of learning and processes).
Role of manual	Function of the lab manual.
Role of student	Function, responsibilities, expectations of the student.
Role of GTA	Function, responsibilities, expectations of the GTA.
Satisfaction	Overall evaluation, agreement with format, likeness of format.
Structure	Perception of flexibility/rigidity in reference to the lab format components and their interactions.
Understanding of expectations and lab working	Progression in the internalisation of how to function in the GC2 lab.

Table 2 Exemplars of participants' characterisations of the lab formats

Expository lab programme	Cooperative lab programme
Alma: "...last year (*GC1*), my TA since we had the lab manual, kind of went over, briefly, what we were supposed to be doing and from there we kinda just do what we were supposed to."	Alma: "This semester (GC2) she's always willing to help us but she doesn't quite know how is she supposed to answer, [...] especially since the point is kind of make our own experiments."
Bart: "[GC1] it's kinda follow the directions, it helped to, to uh to learn how to use the instruments which is very important, cause I had never been exposed to any of them, so that was very helpful."	Bart: "I think he [GC2 GTA] did it perfectly, he didn't give us too much information and just tell us to do one thing, he let us go our own way [...] almost the perfect medium of, you know, kind-of the Socratic method of asking us questions to make us come to our own conclusions, so I enjoyed it."
Earl: "[In GC1] there is a manual, you are told the exact procedure you are supposed to follow and there is very little...uh, eh, there is very little scientific thinking or critical thinking and analysis in it."	Earl: "I generally understood what you, uh the chemistry department was attempting to do for this semester because obviously you want to create, as a university, students who think scientifically and go along with that method and I see that is what was attempted."

laboratory programme associated characteristics of the designed learning environment with their experience (Sandi-Urena *et al.*, 2011a). These findings complement Abraham's work since the statements here emerged from semi-structured interviews and were not pre-selected by the researchers. The significance of students' ability to characterise the learning environments is twofold. First, it supports student awareness of the different approaches. Although awareness in itself does not guarantee instructional success, oblivion may considerably hinder it. Second, the same students contrasted the two distinct laboratory formats solely based on their experiences. For this process to be meaningful, it is indispensable to gather fidelity evidence to judge the alignment between the enacted and the intended curricula. This need to ascertain fidelity stems from our understanding of the instructor as the single most influential factor affecting learning in the lab (Lazarowitz and Tamir, 1994; Herrington and Nakhleh, 2003); their occasional resistance to reform (Seymour, 2005; Sandi-Urena and Gatlin, 2012) and their tendency to create more traditional instruction under pressure from external factors (Addy and Blanchard, 2010). Table 2 shows exemplary statements discriminating the laboratory formats. Our findings parallel those of Abraham (2011): statements regarding the expository programme are more concerned with skills and techniques whereas those related to the cooperative programme are more so with processes.

Vectors of change

Participants' characterisation of the laboratory formats as a whole produced evidence of the differences they encounter in the transition thereby leading to the vectors of change. Such evidence emerged from the analysis of participants' narratives and was not solicited through direct prompting.

(a) Easiness/difficulty: while the expository style was described as easy and straightforward, interviewees agreed that the cooperative laboratory was hard, sometimes beyond what was deemed necessary. A shared perception was that the demands of the cooperative lab would not be realistic for General Chemistry 1, at least not from day one. They underscored the need to improve the induction into this instructional style to ease the impact of the new expectations: "*the ease into that process of creating your own experiments could be more clearly explained, or how to go, what questions are being asked or what data you are looking to obtain, could have been eased more easily into it*" (Earl).

The difficulty with the cooperative format was linked to having to think too much, having to figure things out, planning outside of lab time, having to monitor and make corrections, change the course of action or repeat laboratory work. The uncertainty of not knowing seemed to be a source of stress. Bart summarised it as follows:

"*Every time I got ready for that lab* [GC2] *I was really stressed out because you had to think so much and you had to, you had to really figure everything out on your own [...] unlike the first one* [GC1]*, where you know, you just follow directions and you didn't really think about it. So it was enjoyable but stressful.*"

This statement presents a view shared by interviewees: easiness was not a determinant factor in developing a positive affective disposition. This finding aligns with student evaluation of instruction research that challenges the often-held assumption that students favour and reward easiness over demanding learning instances (Bleske-Rechek and Michels, 2010; Bergin *et al.*, 2013).

(b) Feelings: in 2011, Sandi-Urena and collaborators suggested that despite the efforts to anticipate and minimize such responses, students whose first college chemistry lab was a cooperative environment experienced an affective and cognitive imbalance likely due to unfamiliarity with the laboratory paradigm. As the laboratory progressed and students gained practical and deep understanding of the workings and goals of the programme, they were able to negotiate meaning and reconcile their initial feelings. Findings from the present study are in alignment with this previous work (Sandi-Urena *et al.*, 2011), which is supported by the remarkable resemblance of students' statements in both cases. They support a similar initial affective and cognitive imbalance that could have been potentiated by their immediately prior experience with the expository lab.

A substantial amount of feelings were expressed in relation with the cooperative format. Initial feelings included confusion and frustration for not knowing what to do and not understanding how the lab worked, and a general sense the unfamiliar setting was overwhelming. At first, Bart "*was a little frightened because, uh, you know, it's a little daunting, that, such an open-ended*

Table 3 Exemplar statements supporting the mindlessness/mindfulness transition

Exemplar statement
Bart: "I am interested in chemistry so in the Chem. 1 Lab, while you could have gone through it mindlessly, I actually was trying to think about some of the chemistry behind it…" "Arguably you could have, not knowing what you were doing, still do the labs [GC1]."
Cait: "Last year [GC1], it was like, read, do this, read, do this, I didn't even know what I was doing to be honest […] But, this lab [GC2], I feel like we learn more, 'cause, it's like, they don't tell you what to do, you have to do what you want, it's like your decision, […] when I get to the lab I am actually doing it myself. […] In chem. 1 […] at a point I was telling my TA 'can we just forget I was here, can I just leave?' because it was pointless to be honest."
Dora: "Instead of having the, like, scientific recipe, ok here is what you are supposed to get at the end [GC1], [in GC2] there is more room for error and also more room, I think, for learning because you get to see, 'well what did I do that made this wrong, right, does it seem, does it match the theory that's behind it', it's a lot more critical thinking."
Faye: "Yes, I was bored in Gen Chem. 1, pretty bored. 'Cause, I mean you had everything out there in front of you, so you just go to lab do what the lab manual says and then you leave, then everything that you just did: out the window. […] But when you are in an experience like that [GC2] you remember it 'cause you have to do most of the work on your own."

format…" Faye was overwhelmed and intimidated "*I went into this year* [GC2] *thinking it was going to be like that* [GC1]*, like maybe ok, we'll have to use our brains a little bit but it will be kind-of laid out there for us, but it wasn't at all what I expected.*"

Initial feelings evolved towards an understanding of the lab environment. For instance, Cait felt accomplished (Table 3) and actually referring to the challenges she declared she "*enjoyed the lab for that.*" Interestingly, the expository lab did not evoke references to feelings other than the impression it was easy (as referred above) and boring.

(c) Peer interactions: the difference in the nature of the interactions was epitomised by Cait's responses when prompted to describe her teamwork. For her, the interaction with lab mates in the expository lab consisted of splitting the chores or sharing data collected independently, which we call group-work as opposed to teamwork.

"*Sometimes, I sat back and just let the group do it* [GC1]*, I didn't learn anything, sometimes, I'm like, I'm tired, I don't wanna do this, you guys do it, they did it, sometimes they said they don't wanna do it, I did it. Did it help? Did it benefit anybody? No.* […] *Last semester* [GC1]*, it was like, ok, you guys do work I'll copy answers later, and I'll just sit down, do nothing.*"

In the cooperative lab, teammates were sounding board for discussion and they practised reciprocal explaining and teaching. Cait provided evidence for positive interdependency; furthermore, they were proactive in engaging others in teamwork despite scheduling obstacles:

"[In GC2] *even though we had different backgrounds, we came together and I really enjoyed that 'cause certain things I didn't know, they taught me and it was like eye opener.* […] *The day before, we* […] *start reading about it* [project] *and doing research and try to understand what we have to do and then the next day, 'cause one of our group members* […] *when he is not working he is in class, so we can't always get in contact with him, so* […] *what we do is we call him and* […] *we try to get him to interact with the group, so when we come in the next day we actually have everything there and we know where to go.*"

Although Earl's team was usually good, he realized others "*had problems doing that, but it can be frustrating, obviously, having to rely on other people, and have your grade or your success depend on that.*" In the expository lab "*… once you were out of class what you did as far as your lab report, if you were doing what you were supposed to do you didn't have to rely on other people.*"

Much against her preferences—apparently because she did not agree that it was their job—Alma's team engaged in interactions consistent with the goals of cooperative work. Describing how they tackled the lab projects, she said: "*Usually outside of class, like all took initiative to do research and then I'll be like, 'ok, I found this sample experiment'.* […] *So I just print it out and bring* [it] *to lab and we all figure it out from there.*" Taking initiative to research, share and evaluate information, modifying procedures, discussing and figuring out collaboratively are all desirable actions in a cooperative lab. However, immediately, Alma reminds us of her objection: "*but then again it's copying somebody else's experiment, we still didn't figure it out on our own.*" Which is to some extent ironic since Alma longed for GC1 where all she had to do was copy the procedure given in the manual. Her team engaged in planning and even collaboration with other teams: "*…most of it was a lot of planning in the lab, talking to the other lab students trying to figure out what they were doing, ha, maybe comparing, ha, trying to figure something out, it's…it's interesting.*" But again, in her view this came as a strategy not to learn but to make up for the laboratory programme shortcomings. Bart's version of the same actions are more positive: "*we had to send out little messengers and we talked to other groups, you know, see what they were doing, how that turned out, you know, pull all of our resources or knowledge and that is really how we were successful in the last labs.*"

Understandably, the demands imposed on students by independent and cooperative work should not reach a break point where students give in to frustration and walk out the lab in defeat. There is a fine line to walk especially in large programmes relying on inexperienced GTAs who may not be acquainted with the instructional style or even the undergraduate experience. Notwithstanding the exceptions, the benefits of "such democratic and negotiated styles of working"—as observed in this implementation of the cooperative lab—have been recognized by many and for long (Hodson, 1993).

(d) Perception of learning: participants' interviews revealed that in both instances, learning opportunities were available.

Learning is not exclusive to one instructional model or another. Intellectually mature students and those who are significantly motivated can and will do their own reflections; they will make connections and enhance their understanding and learning (Fink, 2003, p. 104). Bart made a point in this sense:

"*I am interested in chemistry so in the chem. 1 lab, while you could have gone through it mindlessly, I actually was trying to think about some of the chemistry behind it* [...] *I am not sure if everyone got that from chemistry one because if you went into it not really interested in the science you may not have, you know, thought the same thing, you may just say 'well, what do I need to get an A?' not 'what do I need to do to understand this, what is actually happening.'*"

As instructors we miss an opportunity if we rely solely on students' good disposition instead of building in these instances as integral components of the learning experience. This vector addresses changes in the nature of what was learnt when the instructional model was modified. Learning in the expository lab was driven by mastery of techniques and getting acquainted with how to safely operate in a lab. Bart who felt he learnt in both lab formats condensed his learning in GC1 by saying:

"[In GC1] *I think it was mostly use of the instruments, you know, I've never been in that sort of a lab setting, so I did not know the difference between the precision of every instrument.* [...] *So really, that's probably most of what I learned.*"

Like Bart, Alma also valued techniques. In her view the goals of the lab should be:

"*To learn how to work in a lab setting. To learn how to be cautious of what you are using, to learn how to measure stuff, you know, how to use burettes.* [...] *I learnt a lot my first, the gen chem. one semester because I learnt how to use the burettes, I learnt how to properly use the filters and stuff, um and then, so that's what you should learn in chem. one, knowing how to do things*"

Alma is critical in reference to learning in the cooperative lab: "*I don't feel like I learnt too much in this semester*". For her, learning to do and get things right, completing what she was supposed to do was paramount. She argued that her learning was insufficient because although she learnt:

"*Critical thinking skills* [...] *I am worried about saying that because I don't know if those critical thinking skills are helpful if we still did something wrong and called it right. You know, I still don't know if we did I right.*"

Like all interviewees, Alma associated processing skills (figuring out, critical thinking, planning, evaluating, *etc.*) with the cooperative lab and procedures and correctness with the expository lab, yet she viewed the former as less important than the latter. This is further evidence of how participants relived the experience in the individual lab formats similarly despite their assessment of effectiveness being diametrically opposed. Moreover, the perception of learning elicited from the interviews is consistent with the expressed design of the lab formats as described in the sections above. The expository style aimed at creating a "course in laboratory methods and techniques" whereas in the reformed programme "experimenting is understood as 'trying out' guided by the desire to 'find out' answers to questions."

(e) Role of manual, GTA, and student: these three themes are self-standing yet they are intimately related. The thread that ties them together is the perceived loci of the source of knowledge and the distribution of responsibilities. In the expository format, the GTA is seen as a gatekeeper and provider of instructions and knowledge, and in charge of checking correctness and assigning grades (managerial functions). The GTA does this in tandem with the laboratory manual albeit the manual comes across as the ultimate, absolute, authoritative source of knowledge. Processing was not on the students' court; their responsibilities were procedural. Students had little opportunity to gain ownership of their own work.

"[In] *the old lab format was, you were given a lab manual that told everything you were supposed to do; and very little of it was actual scientific process and method.*" (Earl)

Things were substantially different in the cooperative lab. Cait described how the responsibility shifted towards the students who could not rely on the GTA as a source of procedures and directive answers:

"*Before we leave, he says to everybody 'understand what you are going to do in the next lab'. If you don't he will help you, he will get your mind set on what's, what your next approach is.* [...] *He will tell us like don't forget to review for next week* [...], *'cause it is not his responsibility, it's like ours, in a way.*"

Cait touches upon the sense of ownership elicited by the shift in responsibility. The need to take charge and ownership was common to all participants, who viewed it as necessary to succeed (or survive) in the lab, a trend observed in similar environments (Sandi-Urena *et al.*, 2011a). Notwithstanding, their appreciations differed. Alma understood "*the point is kind of make our own experiments*", however, she could not wrap her head around the idea of doing things this way when "*with the lab manual last semester we didn't have to ask him* [GC1 GTA] *for too much help*". Alma held tight to the belief the lab goals were strictly psychomotor: doing the experiments efficiently.

Dora, who "*really, really, really enjoyed gen. chem. 2 lab*", best illustrated the value of having the freedom to take control of their learning and the chance to try and even fail: "*I can't always follow a textbook lab that tells you how things are supposed to happen.*"

The perception of GTAs not helping enough is not rare in cooperative labs, although students placed blame on the nature of the lab rather than their GTAs. Alma put it this way: "*She* [GTA] *helps out whenever she can but, she tries very hard not to tell us what to do because* [...] *the TAs couldn't really help us too much because I'm assuming the point was for us to kinda figure it out. They helped us whenever they could but there wasn't as much of a discussion at the beginning.*"

Earl clearly differentiated the role of the GTA in the cooperative lab whom he sees as a consultant and not as a provider: "*Um, usually how it'd work was you'd come up with a design and you'd propo...uh you'd explain what you plan on doing to the TA and he'd give you input as far as whether it's good or whether it needs more, or maybe whether you are on the complete wrong direction as to what you need to be doing.*"

Participants' perceptions of the role of the GTAs, the lab manual, and the students in these two separate laboratory

environments mirrored with surprising similarity previous work that examined GTA own perceptions in a traditional laboratory (Sandi-Urena and Gatlin, 2012) and in a cooperative, project-based programme (Sandi-Urena *et al.*, 2011a).

(f) Satisfaction: among the participants, only Alma wholeheartedly disliked the cooperative instructional style, which she found in frontal conflict with her expectations and learning goals: "*I don't feel like I learned too much in this semester.*" She was extremely uncomfortable with losing the certainty experienced in General Chemistry 1 and seeing it replaced by not knowing exactly what to do:

"*With the lab manual they had a specific description of what we were supposed to be doing and the biggest thing is why we were doing it.* [...] *And this semester it was very, very vague, they just told us what we needed to figure out for, like, I don't know, what we were supposed to do there. I just didn't know, we just kind of made it up, I guess.*"

Nonetheless, what prompts Alma's dislike is not frustration due to not understanding her role or the workings of the cooperative lab. The excerpts below show her clear grasping of the expectations, the role of the GTA and the role of the students.

"[In GC2] *what we were supposed to do was given to us, how we were going to get there, we didn't have a clue.*" [...] "*I think it's a problem, because, I mean, granted I understand why she* [GC2 GTA] *doesn't want to tell us what to do, because that defeats the point of us trying to figure out* [...] *we should have a plan when we came in and that made it much more difficult.*"

This evidence does not intend to minimize her affective response. Alma was a very articulate, successful student who did really well in high school chemistry and was doing well on all her college courses, chemistry included. Hers was a thoughtful stance: the new laboratory format clashed with her understanding and expectations of learning, and apparently with her academic goals. Despite her dislike, she was doing well in the cooperative course. By no means was she a disgruntled student seeking some form of revenge or excuse upon the possibility of failure. Her epistemological views are incompatible, although hopefully reconcilable, with what she encounters in this new environment. She wants an authoritative source to let her know what she needs to know so she can do her part: apply herself to learn it right with no ambiguity. Alma was very uncomfortable with not being told what to do and having to "use skills and thought processes that contradicted her conception of knowledge as a transferable object" (Sandi-Urena, *et al.*, 2011a, p. 411). In the past work, we have associated this type of disposition with what Baxter Magolda's framework identifies as an absolute learner (2004). There were no other disqualifying comments in the other interviews. Nonetheless, we acknowledge there was no shortage of students with feelings similar to Alma's. Here is how Dora communicated this reality: "*I know a lot of people didn't like this lab, a lot of people really wanted to go back to the gen. chem. structure, like my group members hated it* [GC2], *they talked about how much they hated it.*"

Other than Alma, the interviewees expressed feelings that ranged from enthusiasm to a rationalised impression the change was an understandable attempt by the institution to do things better. Earl expressed satisfaction by stating that he "*definitely like*[d] *this lab format better than the old ones*" and that "*overall what the main goal of that laboratory was, it was achieved, as far as making the students think more critically and more scientifically.*" Bart showed similar reasoning: "*I kinda prefer this new format because it kinda made you think more, truly.*" Cait "*learnt a lot personally* [...] *I understand, when I get to the lab I am actually doing it myself* [...]. *So I enjoyed the lab for that.*"

(g) Structure: the dichotomy between flexibility and rigidity is implicit in participants' views on components of the lab format mentioned above: peer interactions and roles of the manual, GTA, and student, and satisfaction. For instance, Earl's assertion that in GC1 "*you were given a lab manual that told everything you were supposed to do*" presupposes a tightly controlled learning experience where unpredictability was strategically minimized. Such an experience is void of room for the students to create, decide, or even make mistakes and fail. In going from the expository lab to the cooperative lab, participants experienced a change from "*rigidly structured*" to "*very, very vague.*" Bart found his expository experience structured to the point that "*arguably you could have, not knowing what you were doing, still do the labs.*" The pedagogical implications of this profound statement fuel the controversy surrounding the role of academic chemistry labs. In past research we have gathered similar evaluations of highly structured environments (Sandi-Urena *et al.*, 2011b). With the exception of Alma who longed for the structure, participants appreciated the new freedom despite the challenges that at times made it intrinsically difficult and hard to handle. As suggested above, we know Alma is not alone, after all, a high proportion of first-year students have not reached a formal thinking stage which, added to their prior schooling experiences, may foster resistance to the new less structured environment. The new lab format imposes demands for which many may not be ready affectively or cognitively (Galloway and Bretz, 2015b).

(h) Progressive understanding of lab workings: evidence for evolution in the understanding of how the expository lab worked was absent in the interviews. Participants offered a snapshot-style description of their GC1 lab. The only reference to a reaction towards the expository format was Bart's statement it "*didn't meet my expectations in how easy it was*". The immutable and stationary perception of GC1 contrasted with the evolving and dynamic understanding of the cooperative labs, which drew an initial reaction from all participants. Most of this gradual understanding happened over the first project. This is how Bart saw it:

"*At first I was, um, I don't know, I was a little frightened because, uh, you know, it's a little daunting that such an open-ended format.* [...] *And then, finally we started to get the swing, we decide what we do, um, so, we got used to it eventually...*"

One could argue that this response is only natural given discrepant expectations had been set in place by the preceding expository lab. However, one could counter there is something inherent in the lab styles that makes one expectable—expository—where

the other is dissonant—cooperative. As mentioned above, even as a new experience the expository chemistry lab was assimilated with no conflict. We put forth it somehow fit in and matched the broader understanding of education participants brought in to their college education. Participants' lack of reaction towards and spontaneous acceptance of the expository labs suggest they had been prepared to expect learning environments that posit them in a passive role as receptors of knowledge and executors of instructions. Furthermore, our previous work showed students who entered their first chemistry lab in a cooperative format lived a similar type of dissonant experience (Sandi-Urena *et al.*, 2011a). Likewise, students in this same programme who entered General Chemistry 1 in a cooperative format reported an analogous conflict (unpublished data).

Overarching descriptor of the change

The final stage in our data analysis intends to identify additional structural qualities that shed light on how what happened took place. Per their own account, students experienced a change in laboratory format along the series of vectors described above. We argue a transition from mindless behaviour to mindful engagement subsumes the experience. This feature arose through thorough analysis of the data and analysis of our own weekly discussions of the data. However, once it was pinpointed, evidence to substantiate this feature emerged clearly from participants' statements. Table 3 shows some quotes that illustrate this characterisation.

Although hard to define, we believe the subjective "feel" of mindfulness as a "heightened state of involvement and wakefulness or being in the present" is one to which most can easily relate (Langer and Moldoveanu, 2000, p. 2). In a mindfulness state, individuals are aware of their context, the perspective of their own actions, and the possibilities of diverse perspectives (Langer, 1997). In addition, they are receptive to new information and to process it. Ritchhart and Perkins (2000) have proposed three practices that nurture mindfulness in learning environments: looking closely (active engagement in examining the task, activity, or material with a disposition to find new information), exploring possibilities and perspectives, and introducing ambiguity as conditional instruction in opposition to absolute instruction that presents facts as unquestionable. Independently of participants' lab format preference, the interview excerpts introduced throughout this paper support the characterisation of the cooperative lab as a mindfulness-nurturing environment.

On the other hand, mindlessness can be thought of as automatic behaviour or proceeding on "automatic pilot" without attending to new signals. This resonates with Dora's description of her expository lab experience: "*By the end, after all twelve or so labs, it was like cooking, really cookbook, basically.*" Mindless behaviour in education is promoted by reliance upon distinctions and categories drawn in the past, rules and routines likely to govern behaviour irrespective of the current circumstances, over-structured, fool-proof experiences, perspective-free or absolute instruction, and excessive emphasis on "*learning the basics*" (*e.g.* techniques) and "*paying attention*" (*e.g.* getting things "right") (Langer, 1997; Langer and Moldoveanu, 2000). The evidence presented—including the case of Alma who was its most fervent defendant—portrays the expository lab as one that is considerably less mindfulness stimulating and more prone to favour a disposition towards mindless behaviour.

Evidently, in itself this characterisation does not speak to the effectiveness of the learning environments. Such evaluation can be made only in the light of the correspondence of outcomes with the design of instruction and, in all appearances both experiences were aligned with the goals stated for each programme. However, evidence abounds that supports the positive effect of mindful engagement in learning. In addressing mindfulness as an educational goal, Ritchhart and Perkins affirm "the real educational potential of mindfulness lies [...] in addressing some of the other intractable problems of education such as the flexible transfer of skills and knowledge to new contexts, the development of deep understanding, student motivation and engagement, the ability to think critically and creatively, and the development of more self-directed learners" (2000, p. 29). Ultimately, it is students' prerogative to choose how to relate to their learning environment. For instance, in spite of being able to "*not knowing what you were doing, still do the labs* [GC1]", Bart clarified his intrinsic motivation drove him to approach learning mindfully. On the other hand, one may choose to abstain from being mindfully engaged in an environment that otherwise requires mindfulness. Dora admitted that many of the obstacles she faced in her cooperative lab, derived from her peers' lack of interest and disposition "*a lot of people really wanted to go back to the gen. chem.* [GC1] *structure*". It is unlikely that students who initially reject a learning experience will benefit as much as one would like them to.

Conclusions and implications for teaching

This study investigated the lived experience of participants who completed a cooperative, problem-based General Chemistry 2 Laboratory following one semester of exposure to an expository, verification-based General Chemistry 1 Laboratory. Through inductive data analysis and reduction, we captured the essence of the experience of change in the laboratory learning environment. Participants accurately characterised the two diverse programmes, thereby not only providing further evidence of students' ability to discern and understand their learning environment but also evidence of fidelity for the implementations. Ten fundamental vectors—along which participants experienced significant change—emerged from the data analysis. We put forth the overall experience of change is characterised by a transition from a learning environment that favoured mindless operation to one that nurtured mindful engagement.

Findings suggest an expository lab (or something similar) is the default expectation. In a recent study, Galloway and Bretz (2015b) reported three-fourths of their participants' learning experiences in the laboratory were framed by their expectations. If expectations influence behaviour and shape experiences,

it is important to recognize the vectors along which imbalance may occur. This knowledge will allow instructors to inform and assist students in calibrating their expectations to be more functional in the reformed lab environment. Only "then instructors might have reason to begin to expect the desired effects of innovative and reformed curriculum to appear" (Galloway and Bretz, 2015b).

Furthermore, even if experiences are framed by one's personal expectations, our findings suggest the expectations the learning environments set for students induced rather different behaviours in the same participants. In one case, they perceived themselves and acted as recipients of instructions and knowledge, in the other as inquirers and producers of knowledge. The ability to contrast these divergent behaviours underscores the relevance of examining the learning environments through the lens of the same students.

By identifying and understanding the vectors of change based on students' experiences, this work informs the design of programme reforms. Previous work has suggested there is an adjustment period at the affective level for students who enter their first semester of chemistry lab in a non-traditional environment (Sandi-Urena *et al.*, 2011a). A clash of implicit expectations added to the sense of unfamiliarity with the workings of the lab and general state of confusion may trigger initial resistance in students. Dealing with this process consumes precious time and effort. Using the reported vectors of change, instructors engaged in reform endeavours can incorporate pre-emptive measures to anticipate and minimise negative affective responses. For example, considering the impact the triad Role of manual, Role of GTA, and Role of student has on students' perception of responsibility and ownership, programme designers can decide to include activities that clearly convey related expectations. In the light of experience, this may have to go beyond the assumption that telling the students suffices.

Qualitative inquiry is exploratory and hypothesis generating in nature (Bodner, 2007). As we noted, in participants' perception the expository lab promoted mindless behaviour whereas the cooperative lab created opportunities for mindful engagement. This enlightening finding deepens our understanding of the factors that affect learning experimentally. The evidence presented resonates with Ellen Langer's assertion that "*getting our experience presliced undermines the opportunity to reach mindful awareness*" (1977, p. 23). Interested educators may choose to use the literature pertaining to mindfulness in education to inform their pedagogical decisions and instructional design. A major goal of our research programme is to advance understanding of learning in the chemistry laboratory mindful of students' perspective and using theoretical frameworks, methods, and instruments that can handle and attend to the complexities of such learning environment. A further implication of this study is that it has prompted us to utilise Langer's Mindfulness Theory as lens to analyse laboratory learning environments to draw deeper understanding. Such work is underway and will be reported separately. Literature shows that short-term interventions in which easily manipulable components of a situation are modified (*e.g.* drawing distinctions, receiving alternative forms of instruction, considering different perspectives, or engaging in making more choices) produce greater mindfulness (Ritchhart and Perkins, 2000). The chemistry laboratory is not a short-term intervention but a relatively prolonged experience; therefore, it may stimulate mindfulness as a trait and not just as a response to an isolated stimulus. We believe this study broadens educators' views and understanding of learning in the tertiary chemistry laboratory environment.

Appendix 1. Interview protocol

The interview protocol utilised for this study combines features from the informal conversational interview and the interview guide and can be described as semi-structured. It intends to allow the flexibility to pursue information following the lead of the participants' responses. That is, it gives the interviewer the opportunity to further explore those topics that spontaneously emerge as relevant to the participant during the conversation. At the same time, it keeps the conversation focused along the same fundamental lines of inquiry for all participants. This protocol was developed for this research study drawing from recommendations in Patton (2002) and Seidman (2006). Following the recommendation of the Referees, we copy below the text of the protocol as used by the interviewer.

(1) Introductory aspects [read to interviewee]

We consider of outmost importance for the chemistry program to understand students' experience in our academic and research labs. The best way to accomplish this goal is to listen to the students and give them the chance to tell us about their opinions. We want to learn from you, to be educated by you.

This is not part of your assessment; we are simply listening. The conversations will be audio taped just as a means for us to go back and review what was said and not who said what. This interview is confidential; you will not be identified by name and only the transcriber will listen to this tape. The transcriber is bound to confidentiality, as well. During the conversation, I may take notes, which most probably will be reminders to myself of something I want to inquire about later, or something especially interesting you said. I will not jot down things about you; you are not under observation.

Please feel free to spend as much time as you need or want on any given topic. You do not have to reply to a question if for any reason you do not feel comfortable. We may stop the conversation at any time you wish or need to.

Do not feel like I am being too insistent if I ask some follow up questions to your comments. It is our interest to clearly understand what you mean; we are trying to get to a deeper level of understanding.

Once again, this interview is absolutely confidential and does not have any effect on your assessment.

There are no correct answers; we just want to listen to your comments.

We very much appreciate your taking the time for this conversation.

We will start with some general background information and then we will move on to aspects related to your thoughts about the lab environment.

(2) Background [use these to strengthen rapport with interviewee and set a comfortable environment]

(a) How many years have you been at [institution]?

(b) Where do you come from?

(c) Roughly, what is the size of your high school? Is it rural, urban or suburban?

(d) What kind of science courses did you take in high school? Follow up: what courses in chemistry did you take? What kind of Math courses did you take?

(e) What science classes did you take?

(f) Did they have a lab component? If yes, how would you describe those experiences?

(g) Have you decided on a major yet?

(h) What other courses are you taking now?

(3) General Chemistry Lab experience. [Use prompts and follow-ups as necessary]

(a) Describe experience as Gen. Chem. Student.

You have taken Chemistry 1 lab and Chemistry 2 lab. How would you describe your overall experience as a student in the general chemistry labs? Would you please briefly describe your General Chemistry Labs? Would you describe a typical lab session? Were the procedures and goals given to the students? Was group work used regularly, how large were the groups? How would you describe student–student interactions? How would you describe student–TA interactions? How was it similar or different to the other labs you've taken?

(b) Compare with other lab. experiences and expectations.

How was it similar or different to the other labs you've taken or are taking currently? What were your expectations before entering this laboratory experience?

(c) What was learned?

Would you say your expectations were met? If not, why? Do you believe that the work in the lab had any effect on your overall general chemistry experience, including the lecture course? Follow up why or why not. What would you say you learned or gained from your General Chemistry Labs? Do you think the experiences in the lab course had any impact on the way you think of chemistry problems now?

(4) Conceptions about how students learn

(a) Which do you think should be the main objectives of General Chemistry Labs?

(b) What do you think students should learn from the General Chemistry Lab?

(c) How do you think students would learn best in the General Chemistry Lab?

(5) Wrap up

Is there anything else you would like to discuss that we have not covered? Do you have any other thoughts or comments you would like to share before we end this conversation?

Read to interviewee: Thank you again for your valuable collaboration. Once more, this interview is confidential, it is not part of your assessment, and it will not affect your student status.

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