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Investigating Affective Experiences in the Undergraduate Chemistry Laboratory: Students' Perceptions of Control and Responsibility

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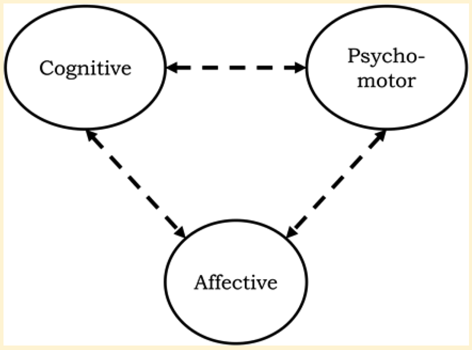
Supporting Information

ABSTRACT: Meaningful learning requires the integration of cognitive and affective learning with the psychomotor, i.e., hands-on learning. The undergraduate chemistry laboratory is an ideal place for meaningful learning to occur. However, accurately characterizing students' affective experiences in the chemistry laboratory can be a very difficult task. While attitudinal surveys offer some insights, an inherent limitation of such fixed-response surveys may prevent students from expressing how their laboratory experiences shape their affective learning. Conducting interviews, however, affords researchers the opportunity to hear students describe learning in their own words. One challenge with interviews is that students may not possess the vocabulary to precisely describe their experiences. Therefore, the purpose of this study was to conduct interviews that encouraged and enabled students to verbalize their feelings about learning in the undergraduate chemistry laboratory. Interviews were conducted with 13 students who were enrolled in either a general chemistry or an organic chemistry laboratory course using a novel interview protocol to elicit descriptions of the students' experiences: a list of affective chemistry laboratory experiences. Findings include that the list of words was able to elicit a wide range of students' descriptions of their affective experiences and that these experiences influence cognitive and psychomotor learning in the undergraduate chemistry laboratory. In particular, the students' descriptions of their affective experiences in the laboratory were grounded in perceptions of control of their learning and the responsibility they felt they had. The implications of this research include identifying experiences that ought to be attended to through changes in pedagogy and curriculum in order for students to experience meaningful learning in their undergraduate chemistry laboratory courses.



KEYWORDS: *Chemical Education Research, Testing/Assessment, Laboratory Instruction, First-Year Undergraduate/General, Second-Year Undergraduate, Organic Chemistry, Hands-On Learning/Manipulatives, Inquiry-Based/Discovery Learning, Learning Theories*

FEATURE: Chemical Education Research

■ INTRODUCTION

Novak's Theory of Education states (ref 1, p 18):

> *Meaningful learning underlies the constructive integration of thinking, feeling, and acting leading to human empowerment for commitment and responsibility.*

This statement points to the importance of three different types of human knowledge in order to construct meaning. Opportunities must be provided to learners across all three domains in order to ensure successful integration and meaningful learning.[1−3] Faculty goals for chemistry laboratories prioritize the cognitive (thinking) and psychomotor (doing) domains.[4−6] From the students' point of view, however, the psychomotor domain is the *raison d'être* for the undergraduate chemistry laboratory, while the cognitive and affective domains are much less visible.[7]

Instructors presume the cognitive insights will readily materialize as students carry out the experiment, collect and analyze data, and fill out a lab report,[4−6] even though students do not always share this perspective.[7] Rarely is the affective domain emphasized by faculty within the context of learning in the undergraduate chemistry laboratory. Theory suggests this would hinder learning because Novak describes affective learning as the "information stored in [the] lower brain centers that results from internal signals and interacts with and plays a role in cognitive learning" (p 59) that then interacts with psychomotor learning.[1]

Nonetheless, students' feelings in the laboratory are just as integral to their learning as the design of the analysis and report questions to elicit cognitive processing. In fact, the National Research Council (NRC) report on Discipline-Based Education Research (DBER) insists that "researchers and instructors should not consider cognitive and affective development apart from each other" (p 158) and that research "on the affective domain should avoid [a dichotomy with the cognitive domain] and recognize the interdependence of affective and cognitive outcomes" (p 161).[8] To better understand how students integrate their thinking and their feeling with their doing in the chemistry laboratory (i.e., engage in meaningful learning),

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we set out to better understand how students describe their affective experiences in the laboratory.

Research on Laboratory Learning

Chemistry is innately a laboratory science. Chemists and educators continually speak to the necessity of laboratory experiences for students.[9−13] The National Science Teachers Association emphasizes that learning in the laboratory can make abstract ideas tangible for students, help develop problem solving skills, and even foster positive attitudes.[14] Yet, there is scant research available to demonstrate the quality and effectiveness of learning in the chemistry laboratory. As noted in the NRC DBER report: "despite its importance in the curriculum, the role of the chemistry laboratory in student learning has gone largely unexamined" (p 132).[8] Hawkes argues that substantial evidence is needed to warrant the "expenditure of time and treasure and student dislike of laboratory teaching."[15] Hilosky et al. echoes Hawkes with a report on the lack of alignment between instructor's expectations for laboratory work and the students' apparent abilities to complete the work.[16] They continue to question why research has not focused on the "impact of laboratory experiences on student learning and attitudes." Although each of these reviews and reports outlines specific suggestions for reform, research has yet to demonstrate the widespread adoption of these suggested reforms, nor examine their efficacy.

Recently, research has been conducted to examine faculty goals for laboratory learning,[4−6] the role of teaching assistants in learning in the undergraduate chemistry laboratory,[17−19] and the effectiveness of inquiry and research-type experiments.[20−22] These projects offer examples of efforts to understand the current state of laboratory learning, yet typify the lack of attention given to affective learning in the undergraduate chemistry laboratory as none of these initiatives provides specific data regarding affective learning. One previous report sought to investigate students' experiences within a cooperative problem based laboratory.[23] With the use of a phenomenological framework, the study found that students experienced an affective response at the beginning of the course brought on by the shock and confusion regarding the lack of familiarity with the innovative laboratory environment. This affective response created a "cognitive imbalance" until the students were able to more fully understand their experience through metacognitive awareness.[23] A second report asked students about their learning in the laboratory using the meaningful learning framework to interpret the findings, but the affective domain was limited to include only connections to the real world.[24]

Affective Learning in Chemistry

Numerous reviews have detailed research on the affective domain in science education in the last 30 years.[25−30] In the context of science education, the affective domain has been defined to include the constructs of attitude, belief, motivation, confidence, anxiety, and values (to name a few).[25] These descriptions have influenced research on affective learning in chemistry. The research reports specific to chemistry that investigate affective learning include development of assessment tools to measure chemistry self-concept[31] and attitudes toward chemistry.[32−36] Additional reports have used these assessment tools to investigate the effectiveness of new pedagogical reforms[37,38] and to demonstrate the necessity of attending to the affective domain in helping students succeed in general chemistry.[36,39−41] Research regarding student affect in the chemistry laboratory, however, has been limited to focusing on how to decrease anxiety[42−45] or increase interest.[46,47] These studies examined sources of anxiety[42−44] and potential ways to decrease that anxiety.[45] The studies on student interest found that students were drawn to experiments with real-life connections[46] and that the students' attitudes toward chemistry influenced the students' attitudes toward the laboratory in general.[47]

In Sevian and Fulmer's review of National Science Foundation (NSF) funded innovations for the undergraduate chemistry laboratory, they found that less than half of the projects indicated affective student outcomes.[48] Course-wide reform with long-term cooperative learning groups,[21,49] short-term reforms implemented once with real-world connections,[50−52] and new technology[52] (to name a few) have been incorporated into introductory general chemistry classes in an effort to improve student learning. In studies evaluating the effectiveness of these reforms, student affect was investigated in a variety of ways, including open-ended questionnaires,[21,51,52] Likert-style attitude surveys,[49,50,52] and student interviews.[21] While these previous studies reported that students enjoyed their lab work, the evaluations did not investigate student learning. Ironically, despite oft-stated goals to improve cognitive learning, these new laboratory experiments or curricula were frequently deemed effective solely on the basis of attitudinal surveys that yielded positive results.

Students' affective experiences in the chemistry laboratory have been narrowly characterized to date. There exists a need to examine affective learning in order to better understand its connection to the cognitive and psychomotor domains, i.e., meaningful learning (or the lack thereof in its absence) from the point of view of the student. Accordingly, the goal of this study was to investigate students' affective responses to experiences in the undergraduate chemistry laboratory by having them describe their thinking (cognitive domain) and feeling while performing experiments (psychomotor domain) in their laboratory course. Figure 1 illustrates the integration of the cognitive, affective, and psychomotor domains. Theory would suggest arrows be drawn going to and from each domain to demonstrate the necessary integration for meaningful learning.[1−3] We designed this particular study to better understand students' affective experiences within the context of conducting laboratory experiments in their undergraduate chemistry laboratory courses.

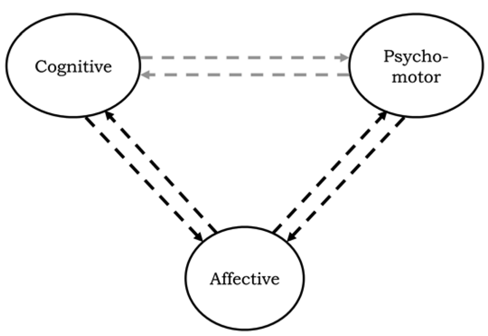

Figure 1. Novak explains how humans make meaning by connecting their cognitive, affective, and psychomotor experiences.[1] This study focuses on how affective experiences relate to cognitive and psychomotor experiences.

■ RESEARCH QUESTIONS

The initial goal of this research was to characterize the integration of affective learning with cognitive and psychomotor

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learning, but given the emergent nature of qualitative research protocols, we soon chose to narrow our focus to examining the nature of the interactions between the affective domain and the cognitive and psychomotor domains. To better understand how students describe their affective experiences in the undergraduate chemistry laboratory, two research questions guided this study:

1. How do students describe their affective experiences in the undergraduate chemistry laboratory?
2. How do students' affective experiences interact with their cognitive and/or psychomotor experiences?

For the purposes of this research, the chemistry laboratory was limited to laboratory courses but did not include undergraduate experiences in a research laboratory.

METHODS

To answer these questions, a qualitative research protocol was developed. By interviewing and asking students to describe their experiences in the chemistry laboratory, we were better able to analyze for common themes, novel experiences, and the range of experiences than had we asked students to respond to a list of predetermined ideas, e.g., by answering a Likert survey. As noted by Kvale and Brinkmann, interviews have the unique ability to create an atmosphere that allows those involved in the interview to be "co-constructors of knowledge."[53] This interview protocol was part of a larger study where students were video recorded while carrying out their laboratory experiments and then interviewed about their experiences. This article focuses solely on the novel first phase of the interview protocol. IRB approval was obtained before interviewing students. All student names below are pseudonyms.

Pilot Study

The interview protocol was pilot tested with 7 student volunteers. The primary goal of the pilot study was to optimize the mechanics of using the video recording equipment in order to best capture students' behaviors while performing their laboratory experiments in the larger study. During this data collection period, an initial interview protocol asked broad questions about the students' goals for learning in their laboratory course and how they thought their learning took place by narrating specific examples from their video. While these interviews did uncover interesting ideas regarding students' beliefs about the purpose of the laboratory and their approaches to learning, the interview protocol was not successful at eliciting specific descriptions of affective experiences. Rather, typical affective remarks included complaints about their lab report grades or inadequate support from course instructors or teaching assistants. The interview protocol did not elicit descriptions from students about their affective experiences *while performing the experiments*. Therefore, the interview guide was modified for the full study to offer students a list of affective adjectives from which they could draw upon in order to catalyze a discussion about their affective experiences.

Participants

Participants in the full study were chosen using stratified purposeful selection from a general chemistry (GC) laboratory course and an organic chemistry (OC) laboratory course for nonchemistry majors at a mid-sized, midwestern university during the fall 2013 semester. The objective of stratified purposeful sampling is to recognize large variations in a sample of respondents rather than to determine the central tendencies among the sample, even though central themes can emerge during analysis.[54] The criterion for this sampling was participants' pretest scores on the Meaningful Learning in the Laboratory Instrument (MLLI).[7] The MLLI is an instrument designed to measure students' cognitive and affective expectations and experiences in the undergraduate chemistry laboratory. Purposeful sampling was chosen to ensure a pool of students who held diverse cognitive and affective expectations for their experiences in the chemistry laboratory.[54] The MLLI was administered during the first week of the semester, and students indicated interest in participating in the study at the end of the survey. Participation in the study was completely voluntary. Scatterplots were constructed of students' affective vs cognitive responses (Figure 2). Quadrants were constructed for the sample as a whole using the median responses (as shown by the solid lines) for both variables in order to select students with varying combinations of high and low expectations in each domain. A relative cutoff at the medians, rather than the theoretical midpoint of 50%, was selected to explore students within this sample. The volunteers who were invited to participate in interviews had diverse MLLI scores and demographic profiles. Of the 82 students who indicated interest in being interviewed, 13 were selected to participate in interviews (denoted with orange triangles in Figure 2).

The 13 students interviewed were 8 women and 5 men, with 8 GC students and 5 OC students. The participants represented a wide range of academic majors, including 8 biology or health sciences majors, 3 engineering majors, and 1 geology major. There were 7 first-year students and 6 second-year students. Table 1 lists the experiment that each student performed during video recording and discussed during the interview.

Laboratory Course Descriptions

The laboratory curricula for both courses were analyzed using the Chemistry Laboratory Inquiry Rubric.[55,56] In comparison to laboratory curricula across the country, the laboratory curricula described here for this study was not atypical from other general and organic chemistry laboratories.[55,56]

In the GC laboratory course, students performed 10 experiments in a 15 week semester. The experiments were a mix of confirmatory and structured inquiry.[55] The topics included stoichiometry, acid/base, oxidation−reduction, thermochemistry, quantitative analysis, and properties of gases. The students worked both individually and in small groups throughout the course, and they were expected to complete the experiments in the allotted 3-h lab time. Each lab room held a maximum of 42 students with 2 teaching assistants per lab room. Students completed individual lab reports to be submitted the following week. The format of the lab reports was a summary data sheet plus one formal lab report during the semester.

In the OC laboratory course, the students completed 9 experiments in the 15 week semester. The majority of the experiments were structured inquiry with some guided inquiry at the end of the semester.[55] The experiments focused on teaching the techniques of extraction, separation, purification, recrystallization, TLC, IR, distillation, and reflux, with many experiments having explicit real world connections. Students performed experiments in pairs and frequently collaborated in larger groups of three pairs. Each lab room held 30 students with one teaching assistant per lab room. Lab work was expected to be completed within the 3 h time block. Lab reports consisted primarily of written responses to laboratory questions

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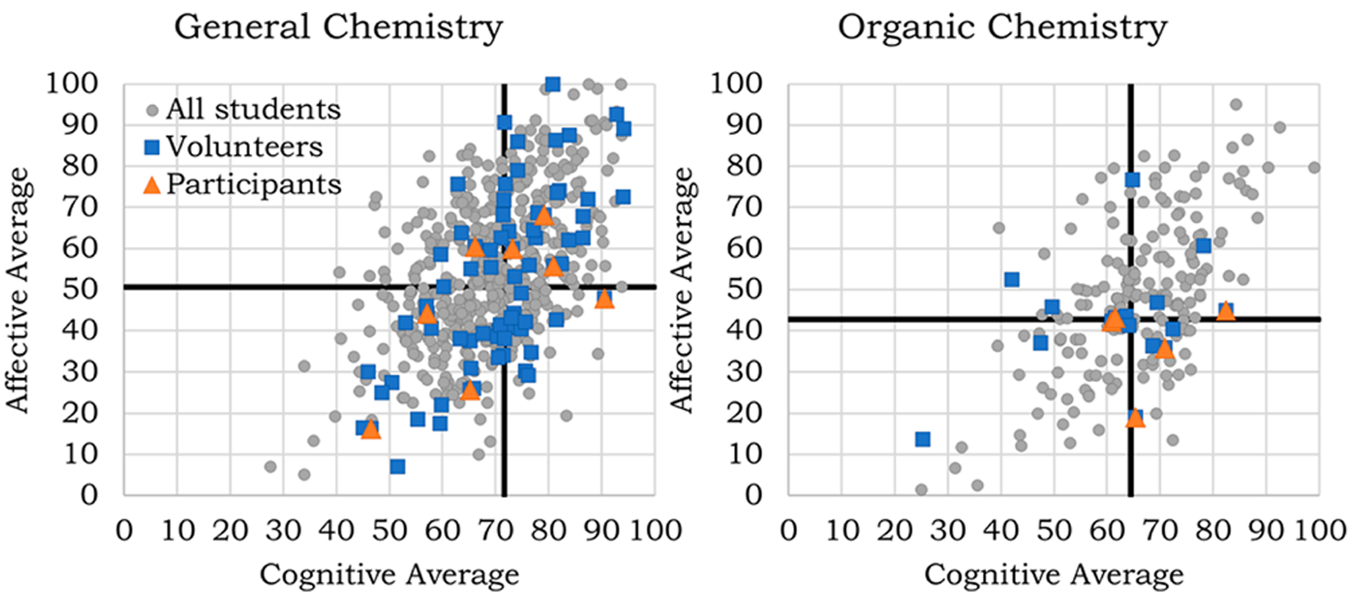

Figure 2. Scatterplots of MLLI pretest affective vs cognitive averages for all students, those who volunteered, and those who participated in the study. The solid lines represent the median cognitive and affective responses for the sample.

Table 1. List of Participating Students' Experiment for Video Observation and Reference for the Interview

Pseudonym	Course	Experiment
Angela	GC	Determination of empirical formula
Pam	GC	Titration using pH electrode
Holly	GC	Activity series of metals
Kevin	GC	Calorimetry
Dwight	GC	Quantification of copper in a penny
Toby	GC	Gas laws
Jo	GC	Gas laws
Meredith	GC	Gas laws
Phyllis	OC	Introduction to TLC
Erin	OC	Introduction to TLC
Jan	OC	Anthocyanins and anthocyanidins
Michael	OC	Distillation of essential oils
Jim	OC	S_N1 Reactions

due within a week, plus two formal reports which were due within 2 weeks.

Full Study Interview Protocol

Students were interviewed within 24 h of being observed and video recorded in their chemistry laboratory course. Semi-structured, individual interviews were conducted using a three-phase protocol for the larger study. This article focuses on the findings from Phase 1 of that protocol. (Results from the video observation and additional analyses of the interviews have been published elsewhere.[57]) The purpose of Phase 1 was to elicit specific descriptions of students' affective experiences in the laboratory. To begin the interview, students were shown a piece of paper listing 18 affective words (Figure 3). Students were told that a student might use some of these words to describe their experiences in an undergraduate chemistry laboratory course. The list of words was compiled from students' descriptions of affective experiences during the pilot study interviews and from items on the MLLI.[7] Half of the words were meant to suggest a positive contribution to meaningful learning, and half likely hinder meaningful learning. The list was not intended to be all encompassing of the affective words that student would use to

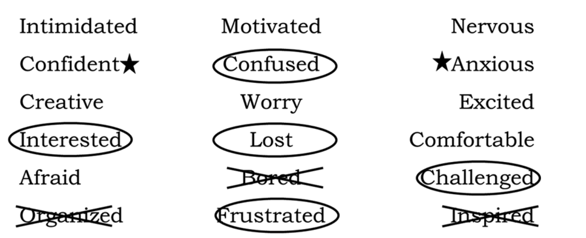

Figure 3. Matrix of affective words as marked by Phyllis (OC). Students were asked to circle words that described their experiences in their chemistry laboratory course in general, place a star by words that described their experiences on the day they were observed, and cross out words that did not describe their experiences.

describe their affective experiences. Instead, the list served as a catalyst for a conversation.

The words were printed on a piece of Livescribe paper, and students were instructed on how to use a Livescribe pen to mark on the paper.[58] Using the Livescribe equipment facilitated synchronization of what the students said with what they wrote during data analysis.[58,59]

Students were asked to complete three tasks with the list of words. First, students were asked to circle any word(s) that described how they typically felt in their chemistry laboratory course. The second task was to place a star next to any word(s) that described how they felt during the laboratory experiment they had just completed right before the interview, i.e., the one in which they were videotaped. The third task was to place an 'X' next to any word(s) that did *not* describe how they usually felt in the chemistry laboratory. After carrying out all three tasks, students were then asked to explain why they marked each circled, starred, and crossed out word, supporting their choices by sharing specific examples from their laboratory experiences. Students were then asked probing questions about how the affective experiences that they shared had influenced their learning in the laboratory (e.g., How do you think that influences how you learn in the lab? Or how did that influence how you went about the rest of the experiment?). Phase 1 of the interview concluded by asking the students why they believed certain affective experiences did *not* occur and whether

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or not they believed these things *should* occur in the undergraduate chemistry laboratory. This phase of the interview lasted from 8 to 15 min.

Qualitative Analysis

The interviews were transcribed verbatim and analyzed both for the frequency with which each word was marked and for the examples students gave. The frequency counts examined how often a word was circled (describing students' experiences), crossed out (not describing students' experiences), or neither (starred for describing the day of being videotaped or not marked by students at all). To answer the research questions, we focused on students' affective experiences in their laboratory course in general; therefore, the starred words were counted with the unmarked words for this frequency analysis.

Students' explanations for choosing specific affective words were analyzed using open coding.[60] Through this process, codes were developed from the data and the descriptions that the students offered. (Sample coding can be found in the Supporting Information.) After open coding, constant comparative analysis was used to refine the codes and examine similarities and differences within the students' descriptions.[60] Codes were compared both across and within students to identify categories of experiences associated with marking each word. The categories were then analyzed through the lens of the Meaningful Learning framework to examine how, if at all, the affective experiences were connected to the cognitive and/or psychomotor domains. These analyses, along with examples from students, are described below.

■ RESULTS AND DISCUSSION

Word Frequency

To begin to explore the answer to the first research question, the frequencies of the words from the interview prompt marked by each student were analyzed. The mean number of words marked by each student was 12, with a minimum of 9 and a maximum of 17. The distribution of words reveals the diversity of these students' affective experiences. Figure 4 displays the

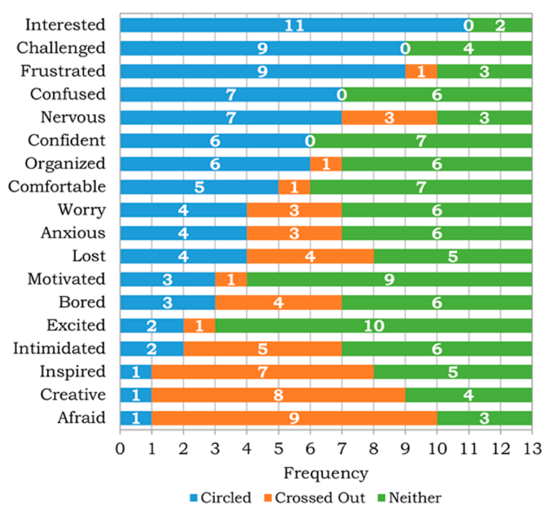

Figure 4. Frequency of words selected to describe students' affective experiences in the undergraduate chemistry laboratory. Students circled words (blue) that describe their experiences and crossed out words (orange) that did not describe their experiences. The words are ordered top to bottom from most circled to least circled.

frequency of each word being circled, crossed out, or neither. To the students, some words have positive connotations while others have negative connotations. Some students discussed the positive connotations of *Challenged*, saying that it motivated them to work hard. However, other students discussed the negative connotations, indicating the challenge was overwhelming for them. For example, Erin said she does not "ever think that a challenge is a bad thing in a chem lab just because every challenge is an opportunity to learn something new that you didn't really know before." But Jan described her experience being challenged as "really hard and [having] lots of anxiety about it" and that "it's challenging to make sure all the stuff is working how it is supposed to." While Erin looked forward to challenges knowing they would help her learn, Jan dreaded challenges and viewed them as a hindrance to her learning.

Blue bars in Figure 3 indicate the number of students (out of 13) who circled that particular word (meaning it described the students' typical experiences in lab). Orange bars represent the number of students who crossed out a word (meaning it did not describe the students' experiences), and green bars indicate the number of students who neither circled nor crossed out that particular word. An average of 6 words were circled by each student (with a minimum of 3 and a maximum of 10), and an average of 4 words were crossed out by each student (with a range of 2–6). These data show that the word list served the students by being useful in offering descriptions of both their positive and negative experiences in the chemistry laboratory.

The most frequently circled word was *Interested*, with 11 of the 13 students choosing it. These students had an intrinsic interest in their laboratory course and chose to say so. Consider how Phyllis (OC) described her interest in lab:

> *Ok, um, well for the interested one, um, I think it was our second experiment we extracted three components from um Excedrin. We extracted aspirin, caffeine, and acetaminophen. And I just thought that was really interesting. I felt like I was kind of like more in like the medical field like last year all we did was titrations. Like we added acids and bases and like what is this? But now the stuff we are doing is actually dealing with medicine and like separating things. I thought it was a little bit more interesting to me.*
>
> (Phyllis)

While *Interested* was most often circled, it was never circled alone. The second most circled words were *Challenged* and *Frustrated*. Whereas students described conflicting connotations of being *Challenged*, they described being *Frustrated* as only hindering their learning experiences. Frustration can sometimes be a catalyst for problem solving, but the students in this study described being *Frustrated* as a road block "when things go wrong or not exactly according to procedure" (Pam, GC) or "when you have to redo a section of an experiment when it doesn't come out the way it's supposed to" (Jo, GC). The next most frequently chosen words were *Confused* and *Nervous,* both of which often indicated a negative experience in the laboratory. Interestingly, all five of the organic chemistry students who were interviewed selected both *Interested* and *Confused*.

Excited and *Motivated* were circled the fewest number of times by students (2 and 3 times, respectively) when describing their laboratory experiences, and each was crossed out only once. The students who marked (circled or crossed out) *Excited* or *Motivated* were in general chemistry. None of the organic chemistry students used either of these words to describe their experiences. While these words were marked least frequently

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by students, their presence on the word list still served as a point of reference for which to begin describing their affective experiences.

Understanding what students are *not* feeling in the laboratory can be just as important as knowing what students *do* report feeling in the laboratory. The words most frequently crossed out where *Afraid*, *Creative*, and *Inspired*. Many students expressed that they felt safe in lab even though, as Jim (OC) said, "We're dealing with some harmful chemicals it was all in the fume hood and we had gloves and goggles on so I wasn't afraid of any chemicals or anything." While it is encouraging that students are not afraid in lab, it is disconcerting that students do not associate creativity and inspiration with the chemistry laboratory. Dwight (GC) and Erin (OC) saw their only creativity in lab as their choice of glassware. Holly (GC) was not "necessarily sure that creative applies to labs" because:

> *You have certain boundaries and you kind of have to stay within them or else your products are not going to be what you want them to be, and like I mean, if you have a beaker and it's the wrong size, I guess that is creative if you have to work around that but it's, you still have a little means and ways to do certain things.*
>
> (Holly)

Similarly, students viewed being *Inspired* as something that fuels a passion for their future career. Erin (OC) talked about being inspired by wildlife and ecology, Dwight (GC) talked about being inspired by medicine, and Angela (GC) talked about being inspired by music and geology. While the skills they were learning in their chemistry laboratory courses could be seen as providing the foundation for their future courses, there was a disconnect for the students between what they were learning and how it applied to their future aspirations.

Curiously, *Bored*, *Lost*, *Worry*, and *Anxious* were marked an equal number of times as either describing a student's experiences or *not* describing a student's experiences in the lab. An example of how students used these words differently can be illustrated by Toby and Pam (both GC). Toby crossed out *Bored*, explaining that "chem lab itself is kinda exciting just 'cause like with what you're doing in it," but Pam had circled *Bored* saying "titrations interest me because I like neutralization reactions but doing the titration can get a little tedious." Toby enjoyed the action of carrying out the experiments, while Pam was more interested in the symbolic manipulation of writing neutralization reaction equations rather than the macroscopic procedures of carrying out the titration. The variety of these words demonstrates how students have different affective experiences in lab.

Students' Choices To Connect Words

The combinations of words used by students provided additional evidence to consider when answering the first research question. When students selected words from the list to describe their affective experiences, they often spoke of connections between/among the words as they chose them. For example, some students paired words together to describe their laboratory experience because the combination of words helped to better tell their story. One example of this is Kevin (GC) who first grouped together *Confident* and *Motivated* because of his "drive to get things done." As Kevin continued, he then paired *Challenged* and *Organized* with *Confident* and *Motivated* because he wants to do well, so he goes into lab with a plan set for how to achieve. Jo (GC) also paired *Organized*, *Confident*, and *Motivated*. She explains that she felt that way "when [she] did [her] procedure... and it was pretty thorough." Having time to fully prepare for lab helped Jo to feel *Organized*, *Confident*, and *Motivated*. Erin (OC) also grouped *Organized* with *Confident* saying, "If I'm not organized, I'm not confident. That's just how I run."

Other students identified connections among words because they felt that the words all meant the same thing. Meredith (GC) and Phyllis (OC) both combined *Nervous*, *Worry*, and *Anxious*. Meredith described this as worrying "about making sure we're doing it right and have enough time and that I'm just doing it right." Similarly, Phyllis worried about "not doing the experiment correctly or... that [she will] get to the report questions at home and [she] won't know what to do." For Meredith and Phyllis, these words described the same feeling they had in lab when they were concerned about doing the experiment correctly.

However, some students purposefully selected contrasting words in order to describe their experiences in the chemistry laboratory. These students circled and crossed out words that were opposites, and in doing so, provided evidence for the validity of the data generated in this study by the interview protocol. For example, when Erin (OC) crossed out *Afraid*, *Bored*, and *Anxious*, she explained that she did not associate those feelings with her chemistry laboratory because of the words she circled (*Organized*, *Confident*, *Interested*, *Comfortable*, and *Challenged*). Erin explained:

> *I prepare for lab so I have no reason to be anxious. If there is something that I miss, I'm sure 10 other people missed it too because I've done so much prep that I feel as if I've done that much prep, if I've missed something, other people have to have missed it. So I'm not ever really super anxious about it.*
>
> (Erin)

Erin also circled *Confused* and *Frustrated*, saying she sometimes experienced these feelings when she did not understand the concepts that were associated with the experiment:

> *Um, confused sometimes. There are things in lab that we haven't gone over in lecture yet and that's a really big point of confusion for me because I study for lecture so and I do read for lab but sometimes it's just there are concepts that aren't, we aren't quite parallel with each other and that's sometimes makes doing lab properly a little bit more difficult. Um, that's where the frustration comes in because I'm like it's not my fault that I don't know this material yet. I tried to understand it before I walked in and that's where some of my frustration comes from.*
>
> (Erin)

Erin's examples illustrate that while a student's choice of words might appear contradictory at first glance, the descriptions of her thinking about lab concepts in fact supported her choice of words. Contrary to Erin, Angela (GC) selected seemingly contradictory words and yet described an experience where she felt both simultaneously. Angela was interested in the work that she was doing in the laboratory, but in order to best recount her experience in the chemistry laboratory, she had to note that she was also worried:

> *Well, kind of, like the topic's interesting but like for me, I haven't had chemistry in four years so I am worried like I don't remember how to use the stuff and I don't and some of the stuff we don't have at our school so I have never seen like some of the stuff and they don't explain it so unless you ask for help.*
>
> (Angela)

From Angela's perspective, *Interested* and *Worry* are inextricably bound. To have a veracious account of what she experienced,

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one must consider how the two words acted in concert. Another example of simultaneously pairing a word perceived as positive (*Comfortable*) with a word perceived as negative (*Boring*) can be seen in a description given by Kevin (GC):

> *Um, comfortable ... I don't know. It was kinda set everything up and then watch, wait. And so that kind of goes with boring too... like it's just, like it's kind of relax and yet boring at the same time.*
>
> (Kevin)

Kevin's boredom seems to stem from the level of comfort he experiences during his lab sessions. His comfort level has led him to outpace the expected work schedule, which appears to have left him with idle time for which he has not found any use.

Discussion of Student Examples

The justifications offered by the students for the words that they chose to describe their experiences provided evidence of how students' affective perceptions influenced their behavior. Students' examples and justifications were analyzed for connections to both the cognitive and psychomotor domains of meaningful learning in order to answer the second research question. Using open coding followed by constant comparative analysis, broad ideas of how students' feelings influenced their thinking and their doing were created.[58] The ideas that emerged were characterized by how students perceived their autonomy in the lab and their perception of the direct influence they have upon their laboratory experiences. This category was called *Control and Responsibility*, with subcategories that distinguished students' experiences of feeling they lacked control versus when they felt in control. These categories yielded unique insight into how students' feelings affected what they think and/or do in their chemistry laboratory courses.

When the student was not the one making choices about what must be done, the experience was classified as *Out of the Student's Control*. Some students discussed experiences where they were aware of their lack of control, such as the imposition of course structure and the assignment of an experimental procedure. In this case, students often considered their responsibility to be to work within the boundaries of the course requirements. For instance, when Dwight talked about feeling *Organized*, he discussed the course requirement to rewrite the procedures in his lab notebook. He explains:

> *Because I have written out the procedures, and even if I haven't them out word for word as with the detail that's in the actual manual, I still, I'm like, I'm forced to get a general understanding of what we're doing in the day. Um yeah, so knowing what we're doing helps me be confident doing it.*
>
> (Dwight)

Though Dwight was not the person responsible for deciding to write the procedure in his lab notebook, the requirement to do so helped Dwight feel organized and ultimately allowed him to confidently move forward with the experiment. As mentioned previously, Erin also spoke of feeling organized as a result of her lab preparation. Her positive laboratory experience depended on this thorough preparation; she characterized her outlook on lab as "doing what they tell you you should do and not just thinking you can do fine on your own." The imposition of course structure including prelab assignments, preparing the lab notebook, and clear procedural directions gave Dwight and Erin the confidence to carry out the procedures, having already thought about what they were to do.

Student recognition that they lacked control over their laboratory experience also came up in discussions regarding the absence of creativity and inspiration in the laboratory. Jim, Jo, Kevin, and Toby each described the procedures as straightforward, as a set series of steps to carry out. Jo explained that she was not inspired because "they're telling you what to do" and she was not creative because "you just follow the procedure really." Kevin described lab as being "very much by the book", while Toby outlined how straightforward the procedure was saying "you do this, and then this, and then this... there's not much room for changing the layout." These students expressed a limited view of creativity as offering the opportunity to make changes in the procedures and/or lab materials, rather an exploration of the hows and whys of the experiment. The realization that the procedure was so straightforward created a boundary in the students' minds where their focus evolved into carrying out the procedure correctly rather than an intellectual pursuit of chemical knowledge.

Contrary to the previous situation, some of the examples students offered to describe their affective experiences detailed situations where they lacked any control to make choices in the laboratory, but the student was not cognizant of this fact. Jan, Angela, Meredith, and Phyllis described incidents where they felt they lacked control while explaining their choice of words including *Afraid*, *Anxious*, *Confused*, *Intimidated*, *Lost*, *Nervous*, and *Worry*. For Angela, she tried her best to carry out the procedure correctly while in the lab room, but said that "the scary thing is that you don't really know if it is right until you crunch the numbers back in your room." Angela spoke of blindly carrying out the experiment without any idea of how to think about the chemistry in real time. In a similar way, Jan felt she lacked control over her laboratory experience without any way to improve it. She explained:

> *I marked the intimidated, afraid, and anxious and all that because um when we were doing the lab, the length of the time that it took to do the reflux of the berry, and the thing took so long that when we got to the end everyone finished at the same time so there was this really big lull which is also why I marked bored. There is this huge lull in the middle where all we could do was set up for the next step but still there was a 45 minute reflux so we still had to wait around and there wasn't much to do in between and that was the same for when we did our chromatography. We also had to wait for those to develop, so there is a lot of waiting in between the steps and we still didn't finish on time which is really frustrating.*
>
> (Jan)

Jan described how she feared not being able to complete the experiment in the allotted time and the frustration that came with long waiting periods. Even earlier in the interview, Jan spoke of the pressure she felt to finish the experiment and the effect it had on her:

> *We don't have enough time, so the whole time we are rushed, and we don't have any time to think about what we are doing. We are just following the lab trying to get data so that we can finish and not lose points.*
>
> (Jan)

As Jan explained her choice of affective words to describe how she felt in lab, it became apparent that she felt like lab was happening *to* her rather than her taking an active role

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in the experiment and her learning. Jan spoke of struggling to keep up and to be able to collect enough data by the end of the lab time, which in turn ultimately inhibited her cognitive processing of the experiment. Phyllis, another OC student, also talked about the pressure of time constraints on her lab learning experience. Here, she explained her choice of words:

> *Um, I feel confused a lot when, like, I don't know, a lot of the experiments, so all of the experiments are like things I haven't done before, like, recrystallization, um the extraction, mostly things I've never done before, so I'll watched the podcasts, like, I kind of read the book, but it's still hard to know what's going on until you actually go through it once. And then lost is kind of the same reason. I've never done it before, so it's kind of hard to get used to, like, how to do things the right way the first time, so I have to do it like 3 times. Um, and frustrated when, well, there's a time constraint and sometimes I feel like we have like two parts to the experiment, and it lasts the whole three hours fifty minutes, sometimes over, and I feel like it's almost too much - especially when a lot of us don't know what is going on. And definitely challenging the lab is, because um, I don't know it's higher level stuff and it's something I've never done before so I have to learn new things and new techniques.*
>
> (Phyllis)

Even though Phyllis would spend time preparing for lab by watching the course podcasts and reading the book, she was not able to grasp the learning outcomes of the experiment or the individual techniques until she carried them out herself. Phyllis viewed her lack of familiarity with the techniques as a hindrance to completing the procedure in a timely way due to needing up to three tries to carry out a technique correctly. Despite her frustration, she pushed through to complete the experiment rather than giving up at the first sign of a mistake. She continued:

> *I mean, I don't expect to do it perfectly just because we are like learning, so I don't worry that much, but I do want to do it properly.*
>
> (Phyllis)

Phyllis displayed perseverance that Jan lacked when faced with obstacles and a lack of control. Pam also brought up situations where she felt out of control and unsure of how things would turn out. Contrary to the previous examples, Pam crossed out *Afraid*, *Anxious*, *Nervous*, and *Worry*. Pam explained that the extent to which she had negative feelings in lab was feeling *Frustrated*. Even then, she said:

> *Um, so I just kind of let things be what they will be, especially like when I can do a lab report and talk about experimental error then I'm like "well this happened and I couldn't do anything about it."*
>
> (Pam)

To a greater extent than Phyllis, Pam showed tenacity to push through when faced with unexpected obstacles and challenges. Pam's acknowledgment that things will go wrong, there will be mistakes, and that the outcome of the experiment is not entirely in her hands gave her the freedom to explain herself and the chemistry she learned in the report. Pam chose to embrace the unknown, rather than fear it.

The third aspect of the *Control and Responsibility* idea was the subcategory *Perception of Being in Control*. This subcategory encompassed students' descriptions of instances when they took responsibility and exerted control in the laboratory. Holly, Jim, Michael, Toby, and Kevin brought up instances of feeling control when they were explaining their choice of circling *Comfortable*, *Confident*, and *Organized*. In their descriptions, the general consensus from these students was that they felt familiar with either the laboratory setting or the experiment itself. In regards to lab in general, Jim said he was "familiar with the lab setting," Michael said that he feels "comfortable when [he] know[s] what's going on," and Kevin said that he went in "knowing more or less what was going on." This familiarity provided prior knowledge for Jim and Michael to feel comfortable and confident in carrying out the experiment but did not always lead to thinking about the underlying concepts. For Kevin, feeling comfortable and confident even allowed him to easily work through any confusion he faced during the experiment. He explained:

> *I didn't mark confused and I kind a thought about it for a little bit, but um I don't know... like any confusion I had I was able to clear up right away.*
>
> (Kevin)

Holly and Toby recounted experiences from high school chemistry that helped them feel comfortable and confident carrying out their experiments.

> *Um, this was actually one of the 3 labs that we did in AP chemistry and I vaguely remembered it, so I was like "oh ok I got this." And it's not that hard to fill up wells and place little things in them and write down what's happening. Like that's not very difficult.*
>
> (Holly)

> *Um I mean, I felt pretty confident about it because I had taken AP physics last year, and we did a lot of you know this type of thermo ... I mean we never really explicitly did an experiment on it, but a lot of the examples are very similar, so like I feel comfortable coming into the lab ... I felt really confident, and then you know comfortable doing it because it wasn't really hard set up and it wasn't really too um much of a challenge just because like the experiments were pretty simple and figuring out how to do them wasn't too hard.*
>
> (Toby)

Holly's and Toby's prior experiences provided a foundation upon which they could build new knowledge. They saw the procedures as simple rather than difficult. Holly and Toby's prior knowledge with the procedures eased any potential anxiety about whether or not they would be able to carry out the experiment. Though for Holly, the familiarity did not remove her desire to carry out the procedure correctly, as she continued:

> *Um I still want to do well, but like, I'm still nervous about messing up ... [and] starting over again would just suck.*
>
> (Holly)

For these students, being comfortable and confident was the result of feeling in control with carrying out their experiments, which in turn improved the conditions for meaningful learning. However, just because the opportunities for meaningful learning existed does not mean that students chose to engage in thinking about concepts.

The previous description of categories that emerged from the qualitative analysis suggests that students have different feelings about their perceived level of control over their laboratory

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experience. Some students appeared to welcome the decisions already made for them by imposition of course structure as a way to initiate their cognitive processing for the experiment and allow for comprehension of the purpose of the steps of the procedures. Holly referred to these choices made for her as "boundaries". Other students interpreted this loss of control as a way to forgo thinking about the underlying chemical concepts and focus solely on the carrying out of the procedures. For them, the perceived boundaries created limitations on their choice to engage cognitively and encouraged a "doing without thinking" mindset. Still, additional students felt overwhelmed by the loss of control, unaware of how to take part in their own learning. When faced with a challenge or obstacle, the students who sensed a lack of control tended to succumb to a desire to just complete the experiment without thinking about any hows and whys—an instance where the perceived boundary inhibited cognition during the experiment. Meanwhile, some students perceived themselves to be in control in the laboratory either from prior knowledge or extensive preparation. The perception of control brought comfort, confidence, and organization along with it. Yet, many students described "rote doing" experiences while in control, rather than building upon the familiarity to explore the chemical concepts behind the experiment. While the perceived absence of boundaries could have catalyzed the pursuit of understanding during the conducting of the experiments, conscious choices were made to ignore the freedom to think about the chemical concepts at work in the experiments. Jim epitomized this mindset when he said:

> *You're standing around a long time so you could probably think about what is actually happening in the reaction.*
>
> (Jim)

He was cognizant of opportunities to think about what he was doing in lab and why, but when asked if he followed through while in lab, he trailed off as if not wanting to admit to this omission of cognitive behavior.

The choice to participate (or not) in learning and make decisions about how to react when faced with certain emotions speaks directly to Ausubel and Novak's meaningful learning theory.[1,3] Ausubel put forth three conditions necessary for meaningful learning: new material must be presented in a meaningful way, the learned must have some relevant prior knowledge, and the learner must make a conscious decision to incorporate the new material in a nonarbitrary way.[3] Thus, students whose affective experiences motivated them toward cognitive processing during laboratory activities could choose to engage in meaningful learning activities. On the other hand, when a student chose to carry out the experiment without thinking ("rote doing"), the student lost the opportunity for meaningful learning. Much as students who attempt to memorize their way through chemistry courses by 'rote thinking', these students report trying to get through their laboratory courses by going through the motions of carrying out the procedure without understanding what they are doing and why.

■ CONCLUSIONS

This exploration of students' affective experiences in the undergraduate chemistry laboratory revealed that students' perceptions of their control over and responsibility for their learning shaped their laboratory experiences. This article described research findings from qualitative interviews structured to elicit specific descriptions of the affective experiences of 13 students in the undergraduate chemistry laboratory. Students were asked to select words from a given list that did, and did not, describe their laboratory experiences and to give examples for why they selected those words. The words that students selected, and the stories they offered in support of their choices, demonstrate the diverse number of ways in which the affective domain is present and active during the undergraduate chemistry laboratory. For instance, even though the majority of students circled *Interested*, it was always circled alongside other affective words indicating the multiple affective dimensions at work during the learning process. Therefore, *Interest* ought not be the only emotion targeted by curriculum development for the undergraduate chemistry laboratory. In this way, the prompt afforded the researchers access to more detailed descriptions of students' affective experiences in the interview setting than the previous interview protocol that had used only open ended questions.

The interviews also revealed that the affective domain manifests in a number, if not seemingly contradictory, of ways during students' learning in the laboratory. For both general and organic chemistry students, the affective experiences that the students described had effects ranging from how and what the students thought (cognitive) to how they behaved (psychomotor) in their laboratory courses. Students who share common experiences can clearly feel differently about them.[1] Even though the students have the same experiences, their different affective responses to those experiences lead them to think and behave differently.[1,2]

This research not only responds to previous calls for studies regarding the importance of affective learning in the undergraduate chemistry laboratory,[8,61] but it also provides evidence for how students' affective experiences influence meaningful learning in the undergraduate chemistry laboratory. While an initial goal of this study was to characterize the influence of the affective domain on the cognitive and psychomotor domains, the findings of this research cannot support a claim that the affective influences the psychomotor and cognitive or vice versa. Rather, these findings do suggest that affective learning cannot be separated from cognitive and psychomotor learning. Thus, the descriptions of the students' experiences led us to examine and characterize the nature of the interactions between the affective domain and the cognitive and psychomotor domains.

Analysis of students' explanations and examples for the words they chose to describe their experiences revealed ideas about how the students perceived autonomy in their laboratory learning and their reactions to that perceived autonomy. Few students welcomed the boundaries imposed upon them as a way to focus their cognitive processing. Rather, students' discussions of their perceived control, or lack thereof, revealed their propensity to carry out the procedures without thinking about the purposes underlying them. For students who viewed the procedure as simple and straightforward to carry out resulting in a loss of autonomy, they overlooked the opportunity to consider the chemistry that afforded such simplicity in order to just adhere strictly to the procedure. For students who felt confident and familiar being in the laboratory, they, too, overlooked such an opportunity. Both of these groups of students made a conscious choice not to actively participate in learning in their laboratory courses. The students who unaware of their loss of autonomy faced an impasse—do they give into carrying out the experiment blindly without thinking or do they consider their options and use their chemistry knowledge to move forward? Their reaction to this impasse could possibly be a defining moment for the potential meaningful learning

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opportunities the student will be able to encounter in the future. The students who chose to give into blindly carrying out the experiment believe that is their only way to success, or at least to get through the experiment. It is possible that these students are not aware of the opportunity available to them to work through their challenges. Or perhaps they believe they are not afforded the chance to actively participate, and that the role to participate in the learning process would be explicitly extended to them if that is what the instructor wanted. Meaningful learning requires the conscious choice of the learner to actively participate in the learning process.[3] The descriptions presented here demonstrate how the variety of affective experiences that the students have in the undergraduate chemistry laboratory often lead to students giving up their active role in learning, either believing it was unnecessary or unavailable to them. Students' beliefs about learning help to explain why, when some students describe similar affective experiences, they chose to respond in different ways. The findings from this study support previous findings that demonstrate the importance of research on affective learning in the undergraduate chemistry laboratory.[61]

Implications for Research

This interview protocol offers researchers an alternative method by which to explore students' affective ideas about learning. Researchers could use this list of affective words, or a similar prompt, to catalyze conversation about students' affective experiences in a variety of laboratory environments, e.g., to explore how students' feelings and actions as a result of those feelings differ in response to changes in laboratory environments (such as different pedagogy or curriculum). Also, while this study used students' MLLI responses as selection criteria to participate in the study, future research could explore the connections between students' MLLI responses and their choice of affective words to describe their experiences in an interview setting.

Analysis of the students' descriptions of their affective experiences revealed their perceptions of their control over their learning and the responsibility they believe they have to participate in learning. Future research could use literature on the "locus of control" to continue to explore students' perceptions of their role in learning in the chemistry laboratory.[62,63]

In addition, this study found that some words have different connotations for different students. The word *Challenged* had positive connotations for some students and negative connotations for other students. When such a word is used on surveys and questionnaires, the ambiguity of interpretations can prove to be difficult for measurement and quantitative analyses. It is important to keep this in mind when performing certain kinds of analysis such as factor analysis that use the item correlations. Otherwise, Angela's selections of *Interested* and *Worry*, and Kevin's selections of *Comfortable* and *Boring* could be interpreted as an instrument that generates random error and unreliable responses. Students' different connotations for these words suggests that students respond differently to the same feeling—some students desire to be *Challenged,* while others fear it.

Implications for Teaching

A better understanding of how individual students attribute different affective words to their experiences in their chemistry laboratory course brings to light the differences between how students and instructors perceive the undergraduate chemistry laboratory. Practicing chemists view the laboratory as a place to explore and exercise creativity to solve novel problems and work toward a solution. For students who shared these views, perhaps the experimental procedures were too straightforward and they felt bound to procedures that hindered their ability to think critically or creatively or to be inspired by their work. In Novak's discussion of meaningful learning, he argues that inspiration can be an outcome of meaningful learning.[1] The fact that words like *Inspired*, *Creative*, and *Excited* were marked as describing students' experiences in lab only once or twice could indicate that meaningful learning was a rare occurrence. Additionally, because *Interested* was never circled alone, but always in conjunction with other words, piquing student interest was not the only affect that students experience in lab. Therefore, piquing interest should not be the only affect that curriculum and pedagogy focus on. The absence of student descriptions of *Excited* and *Motivated* could be an opportunity to focus attention on improving students' affective experiences.

Instructors could easily administer this list of affective words, or something similar, as a short worksheet and ask students to complete the task at the start and/or end of a laboratory experiment or even the semester. In this way, instructors would have a better idea of the variety of affective experiences that their students identify per experiment or per course. As laboratory curricula are often planned far in advance, this data could be used to modify laboratory instruction for the following semester or year. Not every student will be affected in the same way. Targeted designs for laboratory curricula to consider the range of affective perceptions that students bring to the chemistry laboratory is beyond the scope of this work. The findings presented here point to the need for future studies using the framework of "locus of control"[62,63] to investigate and design evidence-based laboratory curriculum.

Additionally, students' orientations toward meaningful or rote learning helped explain why students who expressed similar emotions responded in different ways. Perhaps students who view learning as an exercise in memorization view the laboratory as a place to perform a procedure correctly to obtain one sought after result. Students who tend to shut down when faced with a challenge, or when they feel confused or frustrated, are unaware that these very feelings could be a catalyst for meaningful learning. Students need to be taught to not be fearful of confusion, frustration, or anxiety, but instead to recognize those emotions as part of learning. This mindset could be prevalent when in laboratory environments where students are given choices—they want to pick the one right choice. This mindset is emphasized even more so when students are penalized points for insignificant details mandated by the instructor as a way to motivate students to prepare for lab and read the manual. We are not advocating for decreased student decision making; on the contrary, we are advocating for opportunities for students to critically analyze the possibilities and make choices without fear of penalty. Laboratory work ought to encourage cognitive exploration by asking "why?" without negative consequences.[64] Laboratory work ought to allow for students to make mistakes and repeat procedures without punishment. Undergraduate chemistry laboratory reform ought to start with teaching students metacognitive practices and learning how to learn.[65−67] Then, students could be given the opportunities to see the pitfalls of rote learning and the consequences of ignoring meaningful learning practices.

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Limitations

There are several limitations to this study. First, while each student was interviewed just once, the interviews took place over a period of several weeks during one semester. Some students were interviewed earlier in the semester after having completed only a few experiments. Other students were interviewed later in the semester and could reflect upon a larger number of experiments (and therefore, experiences). In the future, students could be interviewed prior to conducting any experiments (to document their affective expectations) and then multiple times throughout a semester (or even year) of chemistry laboratory to explore how their affective experiences change to facilitate a comparison of *expectations* vs *experiences*. Such data would be exceptionally informative when analyzed in conjunction with students' responses to the Meaningful Learning in the Laboratory Instrument (MLLI) at both the beginning and end of the semester.[7] The MLLI provides a quantitative profile of students' expectations vs experiences in the undergraduate chemistry laboratory.[68−70]

The sample size for this study was 8 general chemistry student and 5 organic chemistry students from one midwestern liberal arts university. The authors of this article do not make any claims that the findings of this qualitative study are generalizable to the teaching laboratory environments of all the readers of this article. The tool used in this study to elicit students' feelings while in lab could be used by researchers and lab instructors to better understand their students' affective experiences at their own universities, perhaps identifying changes in pedagogy or curricula that integrate their feeling with their thinking and doing and, therefore, capitalizing upon the potential of the undergraduate chemistry laboratory for meaningful learning.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.5b00737.

Example coding scheme (PDF, DOCX)

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