Video episodes and action cameras in the undergraduate chemistry laboratory: Eliciting student perceptions of meaningful learning

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Abstract
A series of quantitative studies investigated undergraduate students' perceptions of their cognitive and affective learning in the undergraduate chemistry laboratory. To explore these quantitative findings, a qualitative research protocol was developed to characterize student learning in the undergraduate chemistry laboratory. Students (N=13) were observed and video recorded while performing one of their assigned laboratory experiments. Each student wore an action camera as well as a lapel microphone attached to a voice recorder to capture the experiment from the students' perspective. A tripod camera was also placed unobtrusively in the lab to record the student from a third person perspective. Students were interviewed within 48 hours of their video recording and asked to identify specific learning experiences in their laboratory experiment. The self-selected video episodes were shown to the students, and they were asked to describe what they were doing and why they were doing it. The students' descriptions were analyzed using Novak's theory of meaningful learning to characterize their cognitive and affective experiences. The self-identified learning experiences were dominated by descriptions of psychomotor learning with few students discussing cognitive experiences. The limited connections between cognitive and affective experiences revealed missed opportunities for meaningful learning.

Introduction

The call for research on student learning in the undergraduate chemistry laboratory has reverberated for many years (Hofstein and Lunetta, 1983; Lazarowitz and Tamir, 1994; Nakhleh *et al.*, 2002; Hofstein and Lunetta, 2004; Reid and Shah, 2007; Elliot and Stewart, 2008; Abraham, 2011; National Research Council, 2012; Sevian and Fulmer, 2012). While chemists would agree that the laboratory is a central component of undergraduate education, the process of learning in the undergraduate chemistry laboratory has gone largely unexamined (National Research Council, 2012). The impetus of such research is to give evidence to the value and merit of the undergraduate teaching laboratory. Arguments are frequently made that the laboratory requires too much money, time, and resources for the lack of evidence that students are learning (Hilosky, *et al.*, 1998; Hawkes, 2004). To sustain the claim that the teaching laboratory is a necessity to undergraduate education, evidence must be gathered to demonstrate the unique learning experiences students have in the laboratory. Recent reports on laboratory learning have investigated style of pedagogy (Jalil, 2006), peer-led learning (McCreary *et al.*, 2006), use of simulations (Woodfield *et al.*, 2004; Woodfield *et al.*, 2005; Hawkes and Phelps, 2013), student interaction with laboratory equipment (Malina and Nakhleh, 2003; Miller *et al.*, 2004), student perceptions of their learning (Galloway and Bretz, 2015a; Galloway and Bretz, 2015b; Galloway and Bretz, 2015c; Galloway and Bretz, 2015d), faculty goals for laboratory learning (Bruck et al, 2010; Bretz *et al.*, 2012; Bruck and Towns, 2013), the role of the graduate teaching assistant (Herrington and Nakhleh, 2003; Sandi-Urena *et al.*, 2011; Sandi-Urena and Gatlin, 2013), the effect of reform pedagogy (Tien et al, 2007; Teichert *et al.*, 2008; Domin, 2007; Cooper and Kerns, 2006; Sandi-Urena *et al.*, 2011b; Sandi-Urena *et al.*, 2011c; Sandi-Urena *et al.*, 2012), and research-based laboratory curricula (Weaver *et al.* 2006; Russell and Weaver, 2011; Szteinberg and Weaver, 2013; Winkelmann *et al.*, 2015).

These studies have used quantitative, qualitative, and mixed methods approaches to study student learning in the undergraduate chemistry laboratory. The design of mixed-methods research, while often more complex, can lead to an explanation of a phenomena with "greater depth and breadth" than using one strategy alone (Towns, 2007, p. 147). A mixed-methods strategy uses both qualitative and quantitative techniques within a single study (Creswell, 2003). Within a mixed-methods design, the researcher makes decisions as to the order of the data collection, which strategy receives the higher priority, and at what point the data and findings will be integrated. For example, to investigate faculty goals for laboratory learning, a sequential exploratory design was developed with priority given to the qualitative study that preceded the quantitative study in order to generate data for how to plan the quantitative study (Bruck et al, 2010; Bretz *et al.*, 2012; Bruck and Towns, 2013). Laboratory instructors (N=40) were interviewed and their responses were analyzed using multiple lenses, first to identify the goals by course and demographic of the instructors and then using Novak's theory of meaningful learning to characterize the goals as cognitive, affective, or psychomotor (Bruck *et al.*, 2010; Bretz *et al.*, 2012). Following the qualitative analyses, a survey was developed using the goals that instructors identified in the interviews (Bruck and Towns, 2013).

Another series of studies invoked a sequential explanatory design to study the effectiveness of a new cooperative-based laboratory curriculum where the qualitative study followed the quantitative study as a means to explore and support the quantitative findings (Cooper and Kerns, 2006; Sandi-Urena *et al.*, 2011; Sandi-Urena *et al.*, 2012). First, the Metacognitive Activities Inventory (MCAI) and the Interactive Multimedia Exercises software (IMMEX) were administered to students in traditional and cooperative learning laboratories (Sandi-Urena *et al.*, 2011c; Sandi-Urena *et al.*, 2012). Findings from this part of the study showed that students in the cooperative based laboratory demonstrated increased use of and ability in metacognitive strategies (Sandi-Urena *et al.*, 2012). Then, students in the cooperative based laboratories were interviewed to study the essence of the learning experiences in reformed curriculum (Sandi-Urena *et al.*, 2011b). Evidence from the qualitative study supported the previous quantitative findings by describing the metacognitive processes that students engaged in as they "begin to solve the affective conflict and to try to understand how the lab operates" (Sandi-Urena *et al.*, 2011b). In both of these studies, the combination of the qualitative and quantitative studies allowed for a deeper understanding for the phenomena of interest.

A series of reports have been published on the development and use of the Meaningful Learning in the Laboratory Instrument (MLLI) (Galloway and Bretz, 2015a; Galloway and Bretz, 2015b; Galloway and Bretz, 2015c; Galloway and Bretz, 2015d). Designed using Novak's theory of meaningful learning to measure students' cognitive and affective perceptions towards learning in the laboratory, the MLLI is administered to students at the beginning of the fall semester to measure students' expectations and again at the end of the semester to measure students' experiences (Galloway and Bretz, 2015a). The MLLI has been used to characterize student learning at multiple institutions in both first year university chemistry laboratory courses and second year organic chemistry laboratory courses using a variety of analysis techniques (Galloway and Bretz, 2015a; Galloway and Bretz, 2015b; Galloway and Bretz, 2015c; Galloway and Bretz, 2015d). Major findings from those studies were that students came into their chemistry laboratory courses with high cognitive expectations but their experiences failed to meet those expectations and that students had diverse affective expectations *and* experiences (Galloway and Bretz, 2015a; Galloway and Bretz, 2015b; Galloway and Bretz, 2015c). To be able to give a thick description (Geertz, 1973) of students' perceptions towards their learning, the decision was made to use qualitative research methods to help explain the quantitative findings as part of a sequential explanatory mixed methods design (Creswell, 2003; Towns, 2007). Thus, the goal of the qualitative part of the larger study was to characterize students' cognitive and affective experiences in the undergraduate chemistry laboratory while performing their regular laboratory experiments.

Laboratory work is a unique learning environment in that students physically manipulate equipment with their hands – they are not sitting in a desk taking notes. Thus, research on student learning in the laboratory has the unique opportunity to explore students' behaviors in the laboratory setting. What do the students do and why are they doing it? The study of human behavior involves observation, and with the advent of technology, student behavior cannot only be observed but also video recorded (Yezierski, 2014). In Derry *et al.*'s (2010) review on conducting video research, the value of such data collection is described:

> *"The amount of detail that can be captured in video recordings make them a powerful resource compared to what the human observer can record in real time."* (p. 16)

When a researcher conducts an observation, the field notes recorded by the researcher are the observations that are perceived through their sensory filter (Johnstone, 2006; Sousa, 2011). Thus, details are bound to be overlooked during an observation due to the finite capacity of the human working memory (Johnstone, 2006; Sousa, 2011). Improved video recording technology allows for observations to easily be recorded and watched (and re-watched) so that details are not lost. Video recording as a primary source for research began in the 1950's to study mother-child interactions (Erickson, 2011). The video recording was able to capture both verbal and non-verbal interactions that could easily be missed by a field observer taking notes. Since then, video recording for research purposes has continued into the study of physician-patient interactions, workplace exchanges, study group collaboration, and teacher education (Erickson, 2011). In addition, video recording has long been used as a way to evaluate and improve teaching (Lampert, 1990; Carroll, 2005; Borko *et al.*, 2008; Baecher *et al.*, 2013; Kleinknecht and Schneider, 2013; Cherrington and Loveridge, 2014; Yezierski, 2014). Volet *et al.* (2009) video recorded second-year veterinary science students working on group assignments. Analysis of the video characterized verbal interactions, as well as group dynamics, to explore the extent to which the students participated in high level co-regulatory learning and co-constructing of meaning (Volet *et al.*, 2009). Stieff *et al.* (2013) used video recordings of high school chemistry classrooms to characterize times of confusion, looking for both causes of confusion and ways to address confusion. Class-wide discussions were identified and analyzed for teacher and student dialogue (Stieff *et al.*, 2013). Kulatunga and Lewis (2013) studied the behavior of peer leaders within a reformed first year university chemistry course. Two peer leaders were video recorded while facilitating a class, and the videos were analyzed using multiple discourse analysis frameworks (Kulatunga and Lewis, 2013). In these studies, the video recording demonstrated its utility in capturing of both verbal and nonverbal interactions where audio recording would have only captured verbal interactions.

Video recording has also been used previously in research on laboratory learning. Taylor-Robertson video recorded 22 students in their university biology laboratory course as they performed one of their laboratory experiments (Taylor-Robertson, 1984). The video recording was then used in a subsequent interview with the students to prompt conversation about the students' thoughts, feelings, and actions when they were performing the experiments. Taylor-Robertson categorized the students into three groups based upon the cognitive processing they described in the interviews: think as little as possible, think procedurally, and think meaningfully. A major implication from Taylor-Robertson's work was to design curriculum that required students to think more for themselves rather than allowing them to get by without needing to think about their actions. Unfortunately, no peer-reviewed publications emerged from this research.

In chemistry education research, video recordings (in addition to field observations) have been used to both document student behavior in the undergraduate chemistry laboratory and to evaluate graduate teaching assistants. Similar to the professional development for teachers, graduate teaching assistants were video recorded for formative assessment as part of a training program (Rodriques and Bond-Robinson, 2006; Bond-Robinson and Rodriques, 2006). The video recordings were used for evaluation by the faculty coach (Rodriques and Bond-Robison, 2006) as well as for self-evaluation (Bond-Robinson and Rodriques, 2006). Audio-visual recordings were captured with a video camera mounted on the ceiling of the laboratory room (Rodriques and Bond-Robison, 2006). As the graduate teaching assistants were the subject of investigation, they wore wireless microphones (Rodriques and Bond-Robison, 2006). All audio-visual recordings were wirelessly transmitted through the local area network so that the researchers could observe and adjust the camera angle remotely (Rodriques and Bond-Robinson, 2006; Bond-Robinson and Rodriques, 2006). Malina and Nakhleh (2003) video recorded and interviewed upper division analytical students using a CCD spectrophotometer to understand how the students attributed meaning to the data collection and analysis using the instrument. The videos were analyzed for patterns in the interactions between the students and the instruments, and small groups of students were shown video of other students performing the experiment to elicit conversation about how the instrument works (Malina and Nakhleh, 2003). While many students could talk through how to use the spectrophotometer, they admitted to focusing on completing the experiment quickly and still getting a good grade rather than seeking to understand the theory behind the instrument (Malina and Nakhleh, 2003). Cooper & Kerns (2006) interviewed, surveyed, and video recorded students "using two small unobtrusive cameras placed around the laboratory" to study how students were working with in the context of a redesign, project-based chemistry laboratory course. The cameras were in place for the entirety of the semester to observe how the students evolved through the new curriculum (Cooper and Kerns, 2006). The video recordings captured student interactions and the development of collaborative meaning making as students worked through a series of experimental procedures to identify an unknown compound (Cooper and Kerns, 2006). Teo *et al.* (2014) video recorded two lessons in a study to evaluate flipped teaching in the laboratory. Part of the flipped design involved creating and disseminating videos of how to carry out techniques that the students would use during the experiment. The video recording saw the students referring back to the video instead of seeking personal help from the instructor when they were unsure of how to proceed (Teo *et al.*, 2014). Each of these studies used video recording to capture details of student behavior in the laboratory that might have otherwise been missed by only recording field notes. Additional data sources were also collected and the video recording was supplemental to those sources. Cooper & Kerns (2006) and Teo *et al.* (2014) sought to evaluate a new curriculum; Malina and Nakhleh (2003) investigated students' affordances to a specific piece of laboratory equipment. Malina and Nakhleh (2003) did use video in the interviews, but the students were not reflecting on their own experience but rather explaining the proper technique for the spectrophotometer. While each study stated use of video to record student behavior, little detail was given as to the mechanics of the video collection. With increased technology for video recording, this data collection is a valuable method of researchers seeking to explore student behavior and learning experiences.

Therefore, this study set out to use both interview and video recording methods to study students' learning experiences in the undergraduate chemistry laboratory to seek deeper insight into the quantitative findings from the MLLI studies. The methods from Taylor-Robertson were modeled to be able to both capture students' behavior and learn about their perspectives of what they were doing and why they were doing it.

Theoretical Framework

The learning theory guiding the research design and analysis was Ausubel and Novak's Theory of Meaningful Learning (Ausubel, 1968; Novak, 1993; Novak, 2010; Bretz, 2001). In his study of educational psychology, Ausubel (1968) outlined the necessary conditions for *meaningful learning*: the learner must have relevant prior knowledge, the new knowledge must be presented in a nonarbitrary way, and the learner must then deliberately choose to connect the new knowledge with the prior knowledge in a non-trivial way. Meaningful learning is contrasted against *rote learning* where the learner makes only arbitrary connections between new and old knowledge, i.e. memorization (Ausubel, 1968). Rote learning can also take place when the learner does not have the relevant prior knowledge necessary to make nonarbitrary connections (Ausubel, 1968). Novak furthers Ausubel's theory, stating that the process of meaningful learning is "foundational to both the psychological process of cognitive development of individuals and the epistemological process of new knowledge construction" (Novak, 1993, p. 167). Humans are not born with preconceived ideas about the world, but they create ideas about the world based upon their experiences (Novak, 1993). The process of knowledge creation is "a form of meaningful learning" involving "recognition of new regularities in events or objects, the invention of new concepts or extension of old conceptions, recognition of new relationships (propositions) between concepts, and, in the most creative leaps, major restructuring of conceptual frameworks to see new high order relationships" (p. 183). How a person recognizes patterns, new relationships, or makes new meaning in any way is based upon the "human and value-based character of knowledge and knowledge production" (p. 186). Human knowledge production is made distinct in its "constructive integration of thinking, feeling, and acting" (p. 188). Stated another way: when a person constructs meaning from his/her experiences, s/he engages in cognitive learning (thinking), affective learning (feeling), and psychomotor learning (acting). Each of these systems is unique but interactive as the human brain works to make sense of an experience (Novak, 2010). Research also shows that the brain's memory storage systems are interconnected implying that when a memory is retrieved the cognitive, affective, and psychomotor parts of that memory are retrieved as well (Niedenthal, 2007; Touroutoglou *et al.*, 2015). Thus, when a student learns, the creation of new meaning is based in part on prior thinking, feeling, and doing as well as the new thinking, feeling, and doing. It is not only the new material that influences the learning, but the prior knowledge and experiences as well.

In the undergraduate chemistry laboratory, students conduct experiments by carrying out laboratory procedures – the "doing" of chemistry. While their psychomotor learning is more obvious and visible to the students themselves and the instructor, their cognitive and affective learning systems are also functioning, but unseen. This study was designed to explore students' cognitive and affective learning while performing chemistry laboratory experiments. A qualitative research protocol was designed to seek an in-depth understanding of the students' learning experiences in their undergraduate chemistry laboratory courses.

Research Questions

The overarching research question for the mixed-methods study was: what cognitive and affective experiences do students identify as meaningful in their undergraduate chemistry laboratory course? This article specifically answers the question framing the qualitative interview and video protocols: how do students describe their experiences in the undergraduate chemistry laboratory course?

Methods

A qualitative research protocol was adapted from Taylor-Robertson (1984) and developed to use both interview and video methods. To explore why students do what they do while in the chemistry laboratory, the decision was made to video record students while they performed typical laboratory experiments. Then, within 24-48 hours following the experiment, each student would be interviewed. The video offered the opportunity to not only observe students in the laboratory setting but also to conduct the interview as the students were asked to watch themselves and answer questions about their actions. Descriptions of the sample, laboratory context, pilot study, full study and data analysis are detailed below.

Sample Description and Context

This study took place at a mid-sized university in the midwestern United States during the fall 2013 semester. The courses of interest were first-year university chemistry (GC) and second-year organic chemistry laboratory (OC) for this study science majors other than chemistry.

In GC, students performed 10 experiments in a 15 week semester. These experiments were a mixture of confirmatory and structured inquiry (Bruck *et al.*, 2007; Fay *et al.*, 2007). The topics covered were stoichiometry, acid/base, oxidation-reduction, thermochemistry, quantitative analysis, and properties of gases. Students worked individually or in small groups to collect data in a 3-hour lab period. Lab reports were completed individually and due the week following the experiment. The reports were formatted as a summary worksheet with one formal report during the semester. Each lab room held 42 students working at long benches with 2 teaching assistants (TAs) per room.

In OC, students performed 9 experiments during the 15 week semester which included both structured and guided inquiry format (Bruck *et al.*, 2007; Fay *et al.*, 2007). These experiments focused on teaching the techniques of extraction, separation, purification, recrystallization, TLC, IR, distillation, and reflux with many having explicit real world connections. Students worked in pairs and often collaborated in larger groups during the 3-hour class. Reports consisted of written responses to laboratory questions due the following week, with the exception of two formal reports which students were given 2 weeks to complete. Each lab room held 30 students working at hoods and 1 TA.

Institutional Review Board (IRB) approval was obtained prior to data collection. Students were selected to participate in this study using stratified purposeful sampling (Patton, 2002). The objective of this sampling technique is to capture large variation rather than the central tendencies of the sample, even though the central tendencies can emerge as themes during analysis. The sampling strategy and the sample for this study have been previously described in detail; a short overview is given here (Galloway *et al*., 2015). Volunteers were recruited in conjunction with MLLI data collection (Galloway and Bretz, 2015a). The MLLI is a 30 item assessment tool designed to measure students' cognitive and affective expectations (beginning of the semester) and their experiences (end of the semester). Scatterplots were constructed for students' affective vs. cognitive MLLI responses (Figure 1). Quadrants were constructed using median responses (as shown by the solid lines) rather than 50% in order to select students from the sample with varying combinations of high and low expectations in each domain. The volunteers who were invited to participate in interviews had diverse MLLI scores and characteristics (Table 1). Participation in the study was completely voluntary. Of the 82 students who indicated interest in being interviewed, 13 (16%) participated in the video observation and interview. Students were given pseudonyms to protect their identity.

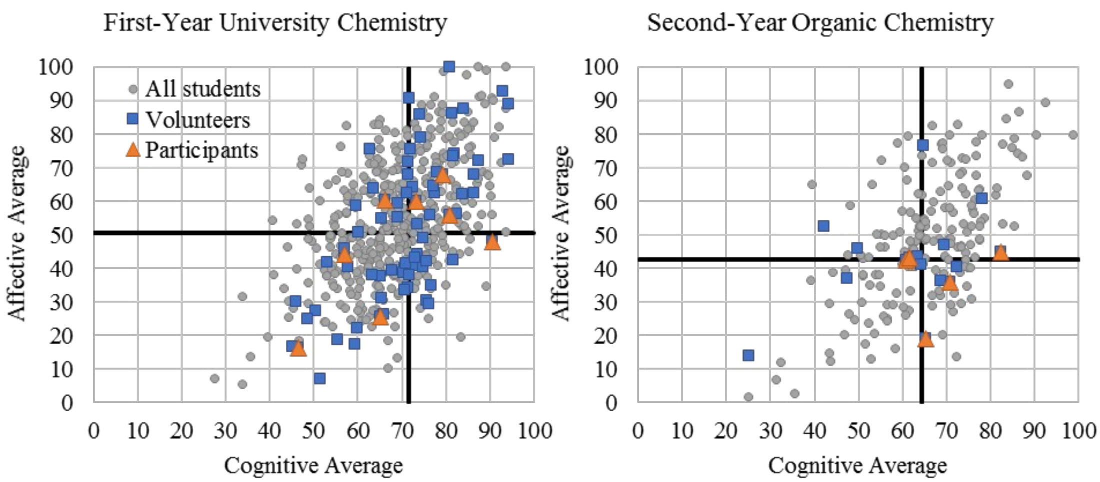

Figure 1. Scatterplots of MLLI pre-test affective vs. cognitive averages for all students, those who volunteered, and those who participated in the study. The solid lines represent the median cognitive and affective responses for the sample. Reprinted with permission from Galloway, K. R.; Malakpa, Z.; Bretz, S. L. (2015). Affective experiences in the undergraduate chemistry laboratory: Students' feelings about control and responsibility. *Journal of Chemical Education*. In Review. Copyright 2015 American Chemical Society.

Table 1. Participating students and their characteristics.

Pseudonym	**Gender**	**Course**	**Experiment**	**Major**	**Year**
Angela	F	GC	Determination of empirical formula	Geology & Music Performance	Second Year
Pam	F	GC	Titration using pH electrode	Biology, pre-medicine	First Year
Holly	F	GC	Activity series of metals	Biology & English Literature	First Year
Kevin	M	GC	Calorimetry	Biology	First Year
Dwight	M	GC	Quantification of Cu in a penny	Biology, pre-medicine	First Year
Toby	M	GC	Gas laws	Mechanical Engineering	First Year

Jo	F	GC	Gas laws	Microbiology, pre-medicine	Second Year
Meredith	F	GC	Gas laws	Microbiology, pre-medicine	First Year
Phyllis	F	OC	Introduction to TLC	Nutrition	Second Year
Erin	F	OC	Introduction to TLC	Zoology & Sustainability	Second Year
Jan	F	OC	Anthocyanins & anthocyanidins	Chemical Engineering, concentration in paper science	First Year
Michael	M	OC	Distillation of essential oils	Undecided, probably biology	Second Year
Jim	M	OC	S_N1 Reactions	Chemical Engineering	Second Year

Data Collection

A pilot study was conducted during the 2013 spring semester in order to determine the mechanics of the video recording. A single camera on a tripod was placed in the laboratory to capture the student's work space, and the participating student wore a lapel microphone attached to a voice recorder that was placed in the student's pocket during the experiment. The first author made observational notes during the experiment. Each student was video recorded and observed for the entirety of the laboratory experiment. While the voice recorder was able to capture the student's conversation, the tripod camera did not capture all that the student did during the lab period. In the GC laboratory rooms, the students work at long work benches. When a participant was on the end of the row, s/he could easily be recorded, but if a participant worked in the middle of the bench, there was no optimal location for the tripod camera to capture the student's behaviors. For the OC lab rooms, the students work at hoods that line the walls of the room or in the middle of the room. Again, there was not always an optimal location for the tripod camera to capture the participant while not interfering with other students. In both courses, when the participants moved away from their work space (to go to the balance, take a melting point, get equipment, etc. as the procedure routinely required the students to do), they were no longer visible through the tripod camera and that section of lab time was not recorded. Thus, in the interview, any self-reflection about these episodes relied heavily on a student's memory rather than prompting from the video.

After the pilot study, the decision was made to add an action camera to the recording equipment. The Looxcie LX2 camera (Looxcie, Inc., 2014) is worn over either the left or right ear. The camera faces out from the student's face chin-level and captures everything the student sees, says, and does from a first-person perspective (Figure 2). In this way, the student's hands and physical manipulation of equipment was included in the video allowing for analysis of how the student carried out the experiment instead of solely relying on the student to recall his/her experiences.

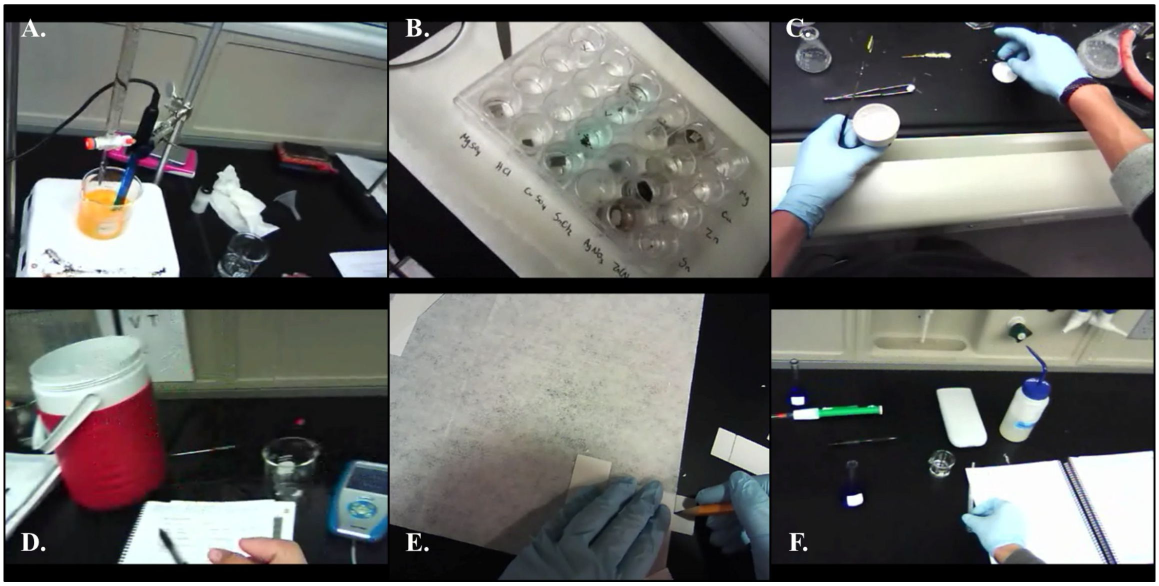

Figure 2. Images of students' points of view captured on the Looxcie action video camera: (A)Pam, (B) Holly, (C) Jim, (D) Meredith, (E) Phyllis, and (F) Dwight.

Students were interviewed within 24-48 hours after their laboratory experiment. This time frame allowed for students to be able to readily recall their laboratory experience while also taking into consideration scheduling conflicts that prevented interviews from being conducted immediately following the laboratory experiment. A semi-structured interview protocol (Box 1) was developed using a multi-phase protocol for the larger qualitative study. Interviews ranged from 45 to 80 minutes and averaged 57 minutes. The first phase of the interview has been described elsewhere (Galloway *et al*., 2015). This paper focuses on the final phase of the interview when the student viewed selected video clips and talked about the experience. For the pilot study, the interviewer selected the video clips to show the student. For the full study, the interviewer sought assistance from the participant to select video clips to watch by asking questions such as times when the student had an "aha" moment, was confused, felt lost, got stuck, was just going through the motions, and/or understood the majority of what was going on during the experiment. The choice to allow the student to select the clips facilitated learning about the experiences the student was drawn to, and therefore deemed important, rather than responding to a list of interview questions crafted by the researcher *a priori*.

Box 1. Sample Interview Questions

- What were the purpose of your actions here?
- What were you thoughts while performing this experiment?
- What were your feelings while performing this experiment?
- What was a particular technique you have learned in the lab?
- What was the intention/reason/purpose for the use of certain techniques for your laboratory experiments?
- What concepts the experiment was covering? How well do you think performing the experiment helped you understand the concepts?
- What other activities, exercises, etc. did you feel like you had to use to try to understand the concepts?

Limitations

The methodological choices made in this study guided the results. Rather than the researcher selecting the video episodes as in DeKorver & Towns (2015), the interview was designed to solicit student identified learning experiences. In this way, the interview was guided by what the student felt was important to learning to explore his/her perspective. This technique may have inadvertently omitted additional episodes that might have been informative, but we chose to study laboratory learning from the students' perspective rather than guiding the interview from the expert perspective.

The students in this study were observed and interviewed at discrete points throughout the semester. Some students participated at the beginning of the semester after conducting only 2 experiments prior to the interview and others were observed on their final experiment of the semester. Those who participated towards the end of the semester could have grown or changed perspectives from students at the beginning of the semester. Longitudinal studies could be conducted following the same students throughout a semester, year, or entire chemistry laboratory sequence to investigate how their perspectives towards learning evolve over time.

Data Analysis

Interviews were transcribed verbatim. The videos were watched multiple times, and running commentaries were created instead of verbatim transcription. Verbatim transcriptions of interviews allowed for analysis of the interview without the sound recording. The running commentaries created a detailed description of what the participating student was doing during the laboratory experiment as a companion to the video recording, not separate from it. Analysis began using open coding; codes were created to give a name to the students' descriptions of their experiences (Saldaña, 2013). After open coding, constant comparative analysis was used to examine the similarities and differences within the students' descriptions as a way to refine the codes (Corbin and Strauss, 2008). Categories of codes were then created in order to identify patterns and themes that characterized the students' experiences (Saldaña, 2013). Analysis of the videos was embedded into the interview analysis because students discussed their experiences while watching the selected video clips. Students' descriptions during the interview were compared with their behavior in the video. The meaningful learning framework was subsequently used as an additional lens to characterize students' experiences. Interview and video analysis was managed using NVivo 10 (NVivo, 2012).

Results & Discussion

Student Selection of Video Episodes

Some students noted multiple instances in response to the questions intended to prompt the selection of video clips, while other students only offered a single experience or sometimes none at all. The students' answers to the question "when was a time when you felt like you were learning something?" were analyzed and categorized using the meaningful learning framework. This analysis led to the creation of four categories of students' self-identified learning experiences: Cognitive, Psychomotor-General, Psychomotor-Specific, and No Learning. No student explicitly talked about affective learning experiences when initially selecting video clips.

Cognitive. Students' responses were categorized as "cognitive" when the student worked towards understanding the chemical ideas during the experiment. Angela (GC), Dwight (GC) and Erin (OC) each described such a cognitive learning experience. For Angela, her "biggest insight" occurred when she "was writing down an observation." Angela was determining an empirical formula and had added the Al to the Cu_xCl_y solution to precipitate out the Cu. During the interview, Angela noted how other students were asking "what's going on?" during this part of the experiment. Angela described her thoughts while writing down her observations:

> *"I was like 'well it looks like the Al is rusting oh wait something is forming around the Al.' And that was like a big thing because we dissolved it later and it made sense why*

> *that was going on. So some people were like 'there's still shiny in here and it needs to go away' and I'm like 'that's Al.'"* (Angela, GC)

Angela realized that the excess Al in solution was not an error and that it dissolved later when she added concentrated HCl. The act of writing down her observations in conjunction with listening to the questions from her peers helped Angela to think through this step of the procedure.

Erin also interacted with her peers, along with her other resources, to make sense of the new information she was learning. Erin conducted a thin layer chromatography (TLC) experiment where the students first explored the polarity of functional groups and solvent mixtures and then were tasked with choosing an adequate solvent to separate a component mixture. She explained:

> *"When we were picking our solvent mixture for part two and looking at the compounds… I kind of explained it to my lab partner, but I was kind of sitting there looking at it and looking at the compounds and then reading through the lab manual again and that was definitely a learning moment for me. It kind of really solidified that for the polar molecules, you know, more nonpolar solvents aren't gonna move up as fast. So that was a really good solidifying moment for me in my learning process."* (Erin, OC)

Erin needed to choose a solvent mixture to separate the components. She used information from the polarity exploration at the beginning of the experiment, talked it out with her partner, referred back to the lab manual, and synthesized her ideas. In addition, Erin exhibited metacognitive skills in reflecting upon this learning experience. During the interview, she talked through the process she took to make the decision instead of just picking a solvent without an explanation. Erin's description shows she worked through the concepts behind the experiment to forge a positive integration of her cognitive and psychomotor experiences.

Dwight's example of learning was also cognitive, but in contrast to Angela and Erin, he spoke of a part of the procedure that he did not understand prior to completing the experiment (determining the amount of Cu in a penny using UV-vis spectroscopy). When asked for a learning experience during this experiment, he said:

> *"Um yeah I know uh let's see at first I didn't let's see I didn't see exactly how the standard solutions were going to work."* (Dwight, GC)

Coming into the experiment, Dwight knew he had to make standard solutions for the calibration curve, but he did not understand how to make the standard solutions to be the necessary concentrations. At the time of this question in the interview, Dwight did not elaborate on whether or how he came to understand how the standard solutions worked, but he did give this example when asked to cite a learning experience, so the inference can be made that he came to understand through doing the experiment. Thus, for Dwight, the physical act of carrying out the experiment helped him understand how to make solutions of a certain concentration.

Psychomotor General. The next student identified learning experiences were two psychomotor categories, both specific and general. The difference between these two categories is student's choice to talk about learning a specific technique, how to use a piece of equipment, etc. versus a broad discussion of the "doing" of chemistry. Kevin (GC) and Holly's (GC) responses both fell within the latter category. Holly carried out the reactivity series of metals experiment, and Kevin performed an experiment to explore the enthalpy of salts in order make hot and cold packs. Both students expressed a familiarity with the materials. Holly had performed a very similar experiment in high school, and Kevin felt the procedure for this lab was "fairly straightforward." Even though neither student identified specific learning moments, they both spoke of learning by doing.

> Kevin, GC: *"Um, hands on so just doing it I guess. Like actually putting into practice what my professor is going on and on about."*
> Holly, GC: *"Um but I don't know, I kind of like things like that because I'm doing instead of just reading like this is the activity series. Like I kind of like that investigative chemistry. Like, do this, and figure out what it is based on your experiment."*

Kevin described how he learned by physically doing the "theoretical things" his professor talked about in class. Holly explained how she enjoyed the experiment even though it was not new to her, she still had something to do and figure out what it meant. These examples were categorized into psychomotor – general because of Kevin and Holly's emphasis on carrying out the experiments and the hands-on experience, but these examples also include an affective component. For Kevin, he was able to make sense of the things his professor talks about in class. By making these connections, he was able to see the relevance of the things he is learning in his chemistry lecture course. In addition, he spoke of his enjoyment of the "hands on" doing of chemistry. For Holly, the style of the experiment appealed to her where she was carrying out an activity to use her observations to explore a phenomena and later make conclusions about the materials. Her situation was similar to Karplus's Learning Cycle of exploration, concept development, and application (Karplus, 1980). Holly was not looking to be told the answer but rather to explore on her own to better understand a chemical process.

Psychomotor Specific. Jo (GC), Toby (GC), Michael (OC), Jan (OC), and Phyllis (OC) spoke of specific techniques, procedural steps, or equipment that they learned to use for their learning experiences. Phyllis named a specific technique that she learned during the experiment:

> *"Um, let's see there was yeah, um, well obviously I learned how to do the chromatography. Didn't know how to do that before."* (Phyllis, OC)

Phyllis mentioned her conducting TLC as a learning experience because it was a new skill that she did not have prior to this experiment. Rather than a specific technique, Jan and Michael described the assembly of different apparatuses as learning experiences:

> Jan, OC: *"I think, like, most like learning 'aha' moment was just, like, making sure, like, realizing that I, like, when the TA came to check when our stuff was set up for the reflux correctly, like he didn't have to change anything, like it was correctly done the first time and I was like 'woo.'"*
> Michael, OC: *"I guess when we were setting up the apparatus I was learning how to put that together. Um I was learning how it worked I guess."*

Jan cited her correct reflux set-up and Michael his steam distillation set-up as learning experiences. While assembling glassware can be considered an important skill for organic chemistry, an understanding of the set-up alone is not the sole learning objective for conducting the experiment. Yet, Jan and Michael identified these instances as their sole learning experience during their observed experiments. In a similar way, Jo and Toby stated their understandings of the procedures, knowing how to carry out each step, as their learning experiences. Both Jo and Toby carried out an experiment to explore the relationships between pressure, volume, and temperature for the gas laws. Jo answered the learning experience identification question by saying:

> *"Um I think it was the temperature one? Pressure temperature? When we had it like there's a small little container hooked up to the pressure meter thing and um then we put it in the water and it like we had to wait for it to stabilize. Um, that one I, like, knew all the steps to it."* (Jo, GC)

Jo's response demonstrated that she believes she learned something in the laboratory because she knew how to carry out all the steps. Note that she did not say she understood the purpose for each step. As with all the students who spoke of psychomotor learning experiences, their focus was on the physical execution of the experiment rather than incorporating any thinking about the underlying chemistry and the hows and whys of each procedural step.

No Learning. The final category of student identified learning experiences was the "no learning" category. Students were labeled "no learning," when they claimed that they did not learn anything at all during the experiment, as was the case with Pam (GC), Meredith (GC), and Jim (OC). Meredith gave a straight "no" without any explanation to the question of whether there was a time where she felt like she was learning during the experiment. Jim and Pam were more hesitant to admit to not learning anything during the experiment and gave explanations for their responses:

> Jim, OC: *"No it was all things that we've done before. … Um setting up the vacuum filtration, like weighing it out. Um pretty much everything was what I had done before. So it was just kind of repetitive."*
> Pam, GC: *"Not really. Because I mean this is stuff number one I know pretty well and number two it's kind of a boring experiment."*

Because nothing in this experiment felt new to Pam and Jim, they did not believe that they learned anything. Like the students in the previous category, they only focused on carrying out the procedures rather than consider the underlying chemical concepts. Meredith, Jim, and Pam spent the allotted time in the lab room performing the experiment, but did not believe they learned anything from being there. The absence of any identifiable learning experiences spoke to their perception that the purpose of the laboratory was a requirement to fulfill rather than a learning environment.

Students' Descriptions of Their Behavior

After the students identified learning experiences and selected video episodes, the interviewer located the chosen clips and watched them with the students. In addition to the selected clips, the interviewer also let the video continue to play as a discussion prompt. Stopping the video every so often, the interviewer asked the students to talk about what they were doing in the clips. This conversation allowed the students to describe their behavior, what they were doing and why, and to discuss the purpose of the step in the procedure as a whole. As each student was participating in performing an experiment in some way (the "doing"/psychomotor part of learning), analysis of these conversations resulted in dividing students' descriptions into cognitive and affective experiences that the students gave while talking about their experiences in the laboratory.

Cognitive Descriptions. The cognitive descriptions that students gave focused on the chemistry content associated with the experiments they did. Erin naturally began talking about her chemistry knowledge when she was asked how she decided for which solvent to use to separate her component mixture:

> *"Ok. This was, ok, so we did it in a 50/50 hexane, and we didn't get very much movement at all of our compounds. Not very much separation. So we were kind of, which was to be expected, you know, they told us you're not going to get very much separation, that's the point so that you figure it out. So we kind of talked, and were like, ok well we know that looking at our compounds, looking at acetaminophen, looking at acetyl salicylic acid and caffeine, they are all highly polar. You know I can tell, it's a carboxylic acid, we have an ester, we have an amide. I know that these are polar molecules. And so if I want more separation, I don't want to make it more nonpolar because if it's more nonpolar it's going to adhere to the polar surface. So that was kind of the logic that we went off of,*

well if we want more separation, we can't make it more nonpolar, therefore we have to do the opposite which is making out solvent more polar. We just switched it. We were like ok if was 80/20 [hexanes/ethyl acetate] before, why don't we just do 20/80." (Erin, OC)

Erin's remarks were unusual in that students rarely talked about their chemistry knowledge without prompting from the interviewer. Once prompted, students would explain the purpose of a technique or why they performed a step in a certain way. For instance, Dwight was asked about how the UV-vis spectrophotometer works and he explained:

"What is does, um, so it sends out light at a certain wavelength and I guess it has a sensor on the other side to see how much got through and then it knows how much it sent out and how much got through so then it can subtract and see how much was absorbed, I think." (Dwight, GC)

Jan, who often described herself as discouraged when carrying out the procedures, was asked if she understood the purpose of the procedures she was carrying out (extracting anthocyanins from berries, hydrolyzing them, and characterizing them with both UV-vis spectroscopy and paper chromatography). Surprisingly confident, she answered:

"Yeah they made sense because when it comes out of the first thing, it had a lot of sediment stuff like the seeds and stuff at the bottom. So we just wanted the liquid because that's where the compounds were dissolved into. So it makes sense that we would do that, and that we would centrifuge it to get all the particles as well to the bottom as possible and then do that again." (Jan, OC)

Jan was able to make sense of and affirm the observation she and her partner made about their solution during the solid-liquid extraction. Similarly, Holly explained how she would create an activity series from her observations:

"I confused myself a lot, but, like, um, if you put Mg, since it reacted with everything, that means that it was, um, a stronger metal, was able to push the other one out of the way or whatever. So when you put the other metals in the Mg, it wouldn't, it's stronger than they are so it's not going to push them out of the way. So you wouldn't expect to see anything. … Yeah. It was kind of the opposite with Cu. Like, nothing reacted, and then, like, in the $CuSO_4$, everything reacted." (Holly, GC)

Holly was able to take ideas and apply them to the observations and data that she collected during her experiment to explore the reactivity of certain metals.

Other students attempted to explain chemical concepts, but found it difficult to generate explanations. Some students reasoned from fragmented understandings when asked the purpose of the techniques they were carrying out, as did Phyllis when asked about the purpose of the filter paper (wick) in the beaker for the TLC:

"I just saw it in the book and I think it's um I saw something in the book for it's kind of purpose but I forget. I don't exactly remember. It helps with like evaporation or something. Or like the running of the water." (Phyllis, OC)

Phyllis thought the filter paper must be useful because she saw it in the scheme in the laboratory notebook. She began correctly talking about evaporation, but failed to articulate correct reasoning. This was particularly surprising given that just minutes earlier in the interview, Phyllis described the solution in the bottom of the beaker:

> *"It is a solution. Basically the 80/20 is like the composition. So it's 80% hexane, 20% ET ethyl acetate. And that is for the solution that goes in the bottom of the beaker for the chromatography."* (Phyllis, OC)

Phyllis had knowledge of what liquid was in the bottom of the beaker; yet, when she discussed what was happening inside the beaker, she could not make the connection between the solution that was poured into the beaker and making sense of the use of the filter paper.

Jan provided another example of fragmented knowledge prompted by the video segments when asked about the purpose of a technique. When asked about the hydrolysis in her experiment and the purpose of the reflux, Jan replied:

> *"Mm. Um, I haven't looked at my lab yet to finish it up for the week but um the only thing like hydrolyze sounds like, hydro which is water, so it sounds like adding water or adding hydrogens to the molecule which I know how like we talked that was in our reading was how it changes when you hydrolyze it like it's supposed to break something off I think and change it into a slightly different compound. So I guess that's going on but I don't know how this does it…And we also noticed like with the condenser, the water was slowly, like, there was water condensing on the outside, too, that was dripping into the solution. I don't know if that was supposed to happen but it was happening for everyone so I figured it was ok. Um I figured like I don't know what I figured. I figured it was important."* (Jan, OC)

First, Jan admitted that she had not yet thought about the purpose of the hydrolysis or the reflux, suggesting that it would come when she worked on the report. Second, she attempted to make sense of hydrolysis by focusing on "hydro-" but overlooking "-lysis" in her explanation. Then, Jan voiced her concern about the reflux while not knowing the purpose of the condenser. Nonetheless, Jan manipulated equipment and collected data all while not understanding the purpose of using certain glassware and even being wary of their ability to function properly.

Jim's fragmented ideas were made clear when he was asked what evidence would confirm his final product was what he intended:

> Jim, OC: *"I mean, ok, I guess I don't know for sure if we did. We didn't like we didn't do the IR spectrum that's next week when it dries but it looked like everybody else's. It looked like it didn't change very much which was good because I think we were only changing like one thing so it didn't like it didn't change it too much."*
> Interviewer: *"Ok."*
> Jim: *"The weight, the masses kind of made sense."*
> Interviewer: *"What would make sense for the mass?"*
> Jim: *"It was going to be a little more um than what we had but it was still like relatively close."*
> Interviewer: *"Um what from the IR from next week will give you uh like assurance that you got the right product?"*
> Jim: *"Well I guess I could take it, if I really want to make sure I could take it and compare it like look up the IR spec online and see if they are the same thing and compare them and see if they're close."*
> Interviewer: *"So compare your IR with the?"*
> Jim: *"The accepted IR spectrum"*

Jim first discussed the mass of the final product in an S_N1 reaction where a chloride is substituted for a hydroxyl group. Jim assumed that he made the right product because the product molar masses were similar and the mass of his product was similar to the mass of his reactant. When pressed for further evidence, such as the absence of a hydroxyl group on the IR spectrum he would take the following week, Jim admitted he would just compare his IR spectrum with one he finds on the internet to see if they are similar, rather than consider how the IR gives a chemist evidence for what functional groups are present in the product. Instead, he sought to affirm his decision by seeking the "accepted IR spectrum" to make sure his looked similar enough to call his product correct.

Lastly, when asked to explain the purpose of the distillation Michael performed, he stumbled around trying to answer before admitting that he stilled need to figure it out. He began saying:

> *"I'm not even quite sure. Like I said, I have to look it up after. But uh, … geez, I guess to, I don't know, to gain more molecules from a substance I don't know."* (Michael, OC)

When asked to explain his thought process, Michael responded by saying:

> *"Oh it's being heated up. You're collecting, I know you're collecting the steam like I get that point but I don't know what it's doing with the stuff that's in there. I understand there's, you're, I don't know if you're purifying, I don't know to be completely honest, I'm not sure."* (Michael, OC)

Like Phyllis earlier, Michael's explanation began with accurate ideas until he admitted to himself that he did not know. Rather than attempt to use his chemical knowledge to craft an explanation, Michael gave up. The solution that Michael provided to this dilemma was to look up the answer later. He carried out the experiment, wrote down the data, and left lab on time. Yet, he had not stopped to think about what he did during lab or why. Michael considered the writing of the lab report as the appropriate time to think through the experiment. Michael was not the only student with this mindset as Angela, Dwight, Holly, Jan, and Pam also clearly indicated they often choose to "figure it out" later (after lab) instead of thinking about the experiment in real time.

Affective Descriptions. Within each student's descriptions of their laboratory experiences, they reported a variety of emotions including worry, frustration, triumph, excitement, enjoyment, and boredom.

As noted previously Kevin and Holly reported that they enjoyed "doing chemistry." Other students also expressed this sentiment, indicating their general enjoyment of being in the laboratory room, including Toby, who, when asked at the end of the interview if there was anything else he would like to say about his experience said:

> *"It's definitely different from what I've [done before] because I haven't had much of an experience so it's just kind of like just neat to do all this stuff … Doing chemistry is pretty cool."* (Toby, GC)

To Toby, the act of carrying out experiments in the laboratory was enjoyable because he recognized that he was learning new procedural skills even though he did not think he was learning any new chemistry knowledge. While few students were as explicit as Kevin, Holly, and Toby about their enjoyment of carrying out the procedures, other students expressed interest about specific aspects of the procedure:

> Phyllis, OC: *"I was like oh that must be an impurity in the aspirin because it's the same R_f as a different one with the same solution. That was kind of interesting."*
> Jim, OC: *"Oh it was fine, I guess if I thought about what was happening, it's a little different because we're replacing the um the hydroxide molecules I think with the chlorine molecules and you're like replacing it in the solid. So it's kind of interesting."*

Dwight, GC: *"And it was cool to see the penny dissolve, all the gas."*

Phyllis was interested in an impurity she thought found in her TLC; Jim found it interesting that the molecules were just switching in solid form (even though the reaction involved a solvent, but Jim did not understand the steps of the reaction). Even though Phyllis' and Jim's interests were connected to fragmented ideas, they did find the way that they understood their results to be interesting. Dwight's feelings came as a result of the color change and gas emission during the dissolving of the penny:

> *"Yeah I don't know if it is here but I know at one point in this lab I was over here and somebody was like 'this is the first exciting lab because they all change colors.'"* (Dwight, GC)

Dwight's remark here was indicative of his experience thus far in the semester and his expectation that perhaps there wouldn't be exciting physical observations. Dwight's observations were different than previous experiments as the color change and gas emission were unexpected which was somewhat enticing for Dwight and his peers.

Students described a range of emotions when they discussed the challenges they faced and whether they were able to overcome those challenges. Pam's and Jan's descriptions of overcoming obstacles included the sense of satisfaction they felt. Pam explained of why she preferred the traditional titration over the modern titration:

> *"I think doing titrations with the indicator is kind of fun because I like getting to that perfect light pink. It makes me feel like I did the titration well. Or with the pH and the lab quest you just don't get that feeling of triumph."* (Pam, GC)

Pam spoke of how rewarding it felt when she attained the "perfect light pink" during the color change at the endpoint of the titration. She acknowledged the work and effort it takes to stop the titration at just the right point at the right color, and thus, she felt rewarded when her hard work pays off. Because the visual effect was not the same for the modern titration, she did not express the same emotion at its endpoint. Jan's feeling of overcoming obstacles came at the end of explaining the difficulty she and her partner had grinding up their berries for the anthocyanin extraction. Every other group had already moved multiple steps ahead while they were still on step one. Jan described the situation saying:

> *"I was getting pretty annoyed. I was… So I was getting really, this is stupid. Because everyone else already had their's ground and were making their samples and by the time we got to the centrifuge everyone had already put theirs in so we had to wait the whole 10 minutes that they centrifuged to do our sample. … I mean it was, it started off pretty bad, it wasn't, like after that it wasn't like hard it was just stressful because we already felt like we were really behind so like we were trying to catch up. And then we felt caught up and then it didn't matter and when our reflux was over, we all had to wait for the same machine anyways so then that was like, we just felt like we were standing around doing nothing."* (Jan, OC)

Jan struggled at the beginning of this experiment and felt this situation created a setback for her for the remainder of the experiment. But, she did express joy at overcoming this challenge:

> Interviewer: *"Did you feel accomplished when you finally got it here?"*
> Jan, OC: *"Yeah. Ahha! I think, I don't know, if by chance when you are watching it later and the camera starts going like this all the time, I'm probably doing my happy dance."*

Like Pam, Jan feels triumphant after working through a challenging situation. In their own ways, both Pam and Jan were challenged, persevered, and celebrated their achievement.

By contrast, both Michael and Meredith described being immobilized by challenges. When Michael watched himself in the video preparing his distillation and waiting to collect product:

> *"If it had pictures then I could set it up without feeling intimidated at all, but I'm not always exactly sure what they're doing like I said before but now I know. I mean it's very simple when it's set up. It's literally, it's steamed, it's heated up, it goes down, reads the temperature…"* (Michael, OC)

Michael felt intimidated by the expensive glassware, unsure how to assemble the pieces and their purpose. After the experiment, he could recite what happened during the distillation, but as he recounted the experience during the interview, he remembered thinking "why do we need to put all that in there?" It should be noted that Michael did have access to pictures for the distillation setup provided in the course's supplemental text. Curiously, Michael wasn't aware that the text provided a picture of the glassware setup.

Meredith began her interview talking about her trouble changing the temperature for the different gas law experiments:

> *"And so we're like trying to get it in and we don't know how far under should it submerge. Um how are we going to change the temperature? And also I think it said where to start, it said just to start at 273 K and so we're like how cold is that? I'm pretty sure that's freezing. Um, I'm, but like we're like how do we get it to be freezing? Like just is just the ice going to measure that or like that was like our problem and like what are going to do about the whole temperature thing?"* (Meredith, GC)

The procedure instructed the students to start with a cold water bath and increase the temperature of the bath by 10K for each measurement, using hot or cold tap water to maintain the temperature. These directions seemed to baffle Meredith. She did not know where to start, and once she picked a starting point, she could not decide where to go from there. Her inability to make the necessary decisions to collect the data created a barrier to her moving forward. This experiment was designed as stations where the students completed 2-3 stations during week one and the remaining station(s) during week two. Meredith and her partners were unable to complete their first station during week one because they could not figure out how to change the water temperature. Meredith described her feelings during this time in lab:

> *"Unsure of what to do. And like setting it up and like well this isn't happening. I mean that's like the learning process but … we followed our procedures of like what it said to do but we were still like that unsure of like well how do you like cause the temperature to change? It says to do this but how do we create that? So that was the biggest frustration that we like spent 45 minutes doing that one like it probably should not have taken that long at all … we could have gotten so much further in the lab which was like just annoying."* (Meredith, GC)

Meredith was frustrated and annoyed by trying to follow the procedures, insinuating that because they made an effort to follow the procedures so closely, that they should not have had so much trouble. Yet, Meredith's perception of working in the laboratory was to follow the procedures exactly and thus was not able to work through how to make decisions on her own about how to carry out this seeming simply procedural step.

Angela also talked about how she felt when she was unsure about what she were doing, but, unlike Meredith, she sought a resolution to deal with her feelings:

> *"Because I just didn't know what to do. Like I didn't know where to find the stuff or I didn't know, like, I didn't know if I was right and I couldn't ask a TA at the moment or something like that so I would just look over and be like 'well you're doing stuff, what do I do?' … I feel terrible. Like I have no idea what's going on. And I'm just like, I feel awkward and I don't know what I'm doing and stuff like that. I don't like feeling that way."* (Angela, GC)

Angela noted that comparing her experiences with others gave her comfort:

> *"Well I am worried about it but I don't think they pay attention too much because they are worried about what they are doing. But then I notice people that are behind, too."* (Angela, GC)

Angela worried about what her peers think of her when she is unsure about what to do next, but then she looks around and realizes that her peers are also worried about themselves, not about her. This realization that her peers were having similar struggles gave her a peace of mind to continue. Angela was not the only one who found comfort in comparing with her peers. Phyllis also talked about her relying on her peers when she tries to make sense of things:

> *"And that is what is confusing to everyone. But yeah. Our table, we do talk a lot because we are all in this big square table together so we all discuss things so it's good. … Because everyone has their little input. Some people remember certain things. And it helps a lot. Remember other things."*(Phyllis, OC)

Phyllis explained that she seeks out other students when she is confused or unsure what to do next. Her peers became a source of encouragement and help. While social interaction is indeed beneficial to the learning process, it is interesting to note that neither Angela nor Phyllis talked about turning to their lab manuals or textbooks when they are in need of guidance. Rather, it appears they looked around for the quickest place to find an answer and move on – a mindset that does not lead to making meaningful connections for conceptual understanding.

Students' Learning Descriptions with Their MLLI Scores

The descriptions above paint a picture of these students' cognitive and affective learning experiences in the undergraduate chemistry laboratory. Some students accurately explained the chemical ideas underlying the experiments they performed; others communicated a fragmented understanding of chemistry. Every student described emotions of one kind or another while performing their lab experiment.

These descriptions were considered in light of results from the quantitative studies (Galloway and Bretz, 2015a; Galloway and Bretz, 2015b; Galloway and Bretz, 2015c; Galloway and Bretz, 2015d). Scatterplots were generated to visualize the interviewees' changes in average MLLI scores from pre- to post-test. (Because Dwight and Holly participated only in the MLLI pre-test, they are not included in the plots.) Figure 3 compares the students' affective averages against their cognitive averages with vectors drawn from pre- to post-test scores to depict changes in the students' responses (Galloway and Bretz, 2015b). A solid line is drawn at $y=x$ as a visual reference for equal affective and cognitive averages.

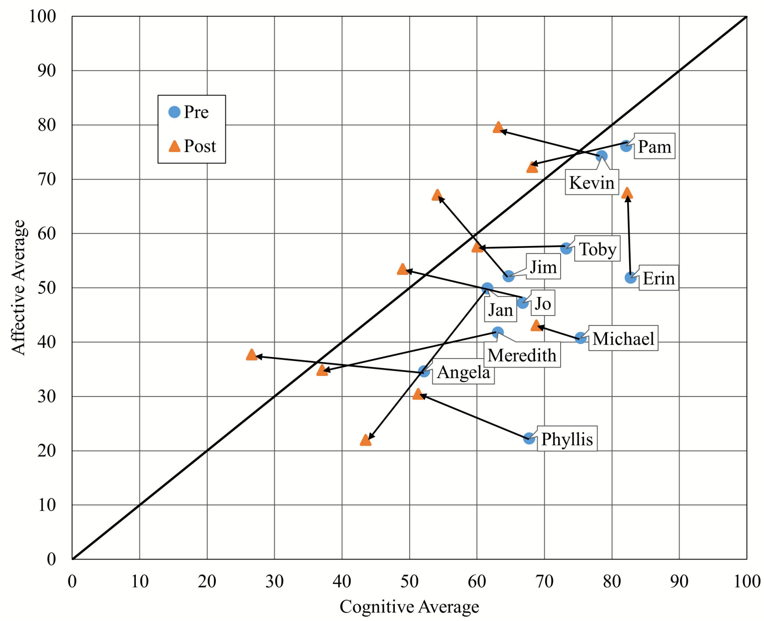

Figure 3. Scatterplot of students' average affective and cognitive MLLI scores with vectors drawn to show changes from pre- to post-test.

All the students' pre scores are below the *y=x* line, indicating higher cognitive expectations than affective expectations. Only Angela, Jo, Jim, Kevin, and Pam had higher affective averages than cognitive at the post-test. Many vectors point to the left, indicating a decrease in cognitive averages, meaning that the students had cognitive expectations that were unfulfilled by their experiences. Erin was the only student who did not respond with lower cognitive scores as her score appeared to remain the same (not that her responses for all of the cognitive items were the same, but overall her cognitive average was the same from pre to post). Erin both demonstrated in the video and spoke openly in her interview about how she integrated her prior chemistry knowledge into conducting the experiment. She spoke of preparing for each experiment until she was confident and organized. She expected challenges because she knew she would learn something through them. She used her resources to make decisions in the laboratory including her textbook and conversations with her lab partner and TA. While not highest responder on either scale, Erin reported high cognitive and affective experiences through her MLLI scores, her descriptions during the interview, and her actions in the video that promoted meaningful learning.

As the most common self-identified learning experience was psychomotor in nature, one reason for the decrease in cognitive responses could be that students paid more attention to what they were doing rather than think about the purpose behind the procedures. The laboratory becomes a place to carry out procedures, not a place to learn how chemistry is conducted and the meaning underlying the actions. Jo, Jan, Meredith, Angela, and Phyllis demonstrated the largest cognitive decreases. These changes are supported by their cognitive descriptions where they talked only about the procedural steps, displayed considerable difficulty explaining the chemical concepts, or shrugged off their misunderstandings saying they would "figure it out later." Despite the overall unfulfilled cognitive expectations, it should be noted that many of these students did have cognitive averages at or above the 50% mark for the post-test, meaning that they agreed that the cognitive experiences listed on the MLLI did occur for them to some extent, just not to the extent that they first expected.

Given that multiple studies (Galloway and Bretz, 2015a; Galloway and Bretz, 2015b; Galloway and Bretz, 2015c; Galloway and Bretz, 2015d) measured affective responses with a large range, it is not surprising that there was more diversity in the changes in affective averages for the interviewees. Some students' experiences exceeded their expectations, some vice versa, and some remained constant. Erin, Jim, Kevin, Jo and Phyllis increased in their affective averages. In their interviews, these students reported enjoying "doing" chemistry, interest in specific techniques, and increased confidence when overcoming challenges. By contrast, Jan had the largest affective decrease (and the largest affective change overall). Jan talked negatively about her experiences in her laboratory course throughout the entire interview and became increasingly frustrated during her video recorded experiment. Despite her interest in chemistry as a subject, her fear of failure was evident in the interview and video where her goal was to get the required data as fast as possible and leave as soon as possible, making meaningful learning highly unlikely.

Interestingly, Jim's cognitive average decreased but his affective responses increased. Jim acknowledged that he could put forth more effort to consider the purpose of the procedures, and think about what was going on at a microscopic level, but that he chose not to. During his video, he can be seen standing around idle while the experiment ran, arguing with his TA over deducted points on a previous lab report, and trying to locate the formula for theoretical and percent yield (instead of trying to think about it on his own). Yet, Jim conducts undergraduate research in a geology lab on campus and reports that he enjoys lab work. The misalignment between Jim's cognitive and affective perceptions of learning hinder him from having a meaningful learning experience.

Conclusions

The goal of this study was to describe students' cognitive and affective learning experiences in the undergraduate chemistry laboratory. A qualitative research protocol was designed using video and interview methods. Students were video recorded with an action camera and a tripod camera conducting one of their regular laboratory experiments. Within 48 hours, students were interviewed and asked to identify learning experiences and discuss their thoughts and feelings while watching their video. The predominant feature of the self-identified learning experiences were the psychomotor aspects – the laboratory gives students the opportunity to use their hands to physically carry out experiments. Few students discussed learning chemical ideas while in the laboratory, and some declared to not learn anything at all. The cognitive processing discussed while watching themselves in the video revealed varying degrees of understanding. The interview was often the first time the students had stopped to think about the whys and the hows of the experiment they had conducted, as they typically delayed such thinking to preparing their report. Though each student completed the experiment within the allotted time, only a few students could explain the purpose of the steps they carried out, and their explanations were laden with inaccurate chemical ideas. Students discussed diverse affective experiences while conducting their experiments. This range of emotions influenced how the students thought and carried out the procedures in the laboratory. The students' MLLI scores were analyzed to explore how the descriptions of their experiences compared to changes in their responses from pre- to post-test.

Findings from students in GC and OC have been discussed simultaneously herein because no single finding was limited to students from only one course. Students in both courses exhibited varying degrees of understanding when attempting to explain the chemistry behind specific steps of the laboratory experiments and discussed a range of emotions they felt while performing experiments. Perhaps it could even be said that the findings were more prominent in OC than GC. With the exception of Erin, the other four OC students all desired to perform the experiment correctly to obtain a perceived, intended result rather than seeking to understand the chemical ideas underlying the experiment. Additional research is needed to understand how students' perceptions of learning evolve as they gain experience in the chemistry laboratory, not only through the first two years of the chemistry sequence, but also through the upper-division courses.

Implications for Teaching

Meaningful learning cannot happen without the integration of thinking, feeling, and doing (Novak, 2010). Thinking and feeling cannot be postponed until after the actions have happened. Whether consciously or not, thinking and feeling occur while doing, but if not focused on the carrying out of the experiment, arbitrary connections are likely to be made rather than nonarbitrary connections made during meaningful learning. Students need to learn the value in thinking about the steps of the procedure, but metacognitive practices are not intuitive (Sandi-Urena *et al.*, 2011c). To initiate student thinking, students need to be asked "why?" and "how?" and "what do you think this means?" (Taylor-Robertson, 1984; Cooper, 2015). There is value in step by step procedures to teach new techniques, but students should not be permitted to blindly continue from one step to the next without purposeful checks on their understanding. Jan felt accomplished when she correctly set up the round bottom flask, condenser, and water tubes for the reflux, but she was concerned to see water dripping from the condenser down into the round bottom flask. She did not understand the purpose of the condenser, nor was she asked to explain why that liquid might be dripping. Asking students to explain as they go is one step to teach the value of thinking about the experiment.

Even though students were primarily focused upon the doing of the experiment, they were not devoid of emotion during their experiments. From enjoyment to frustration to triumph to boredom, students were also not limited to one emotion during their experiments. The presence and diversity of emotions are not in and of themselves hindrances to learning. By characterizing the feeling that the students described in the interview, the goal was to create awareness of the students' learning experiences. Students interact and deal with their emotions differently. When students get stuck and do not know how to push through, or choose to avoid pushing themselves to be challenged, meaningful learning is hindered. Knowing when students feel certain emotions and how they respond can help in the design of future laboratory curriculum. Instructors need to be aware of the influence of the affective domain on learning. If conceptual understanding is a goal for undergraduate chemistry laboratory learning, then the affective domain must also be considered in conjunction with the cognitive and psychomotor domain. Traditional attempts to incorporate the affective domain into teaching have manifested in making chemistry relevant to real life. This research shows that there are many more dimensions to the affective domain that chemistry educators ought to consider in their design of laboratory curriculum, pedagogy, and assessment. Again, the teaching of metacognitive skills could help students to persevere when they encounter confusion, frustration, and mistakes. Teaching students the role of the affective domain and to not be afraid of the challenges of learning could increase the opportunities for meaningful learning in the laboratory.

Implications for Research

This study used video recording methods adapted from Taylor-Robertson (1984) to uniquely capture student behavior in the undergraduate chemistry laboratory and initiate conversation during interviews. While previous studies have used video recording methods in the chemistry teaching laboratory, the study used an action camera to record first-hand experiences from the students' perspectives in addition the typical third-person perspective of the tripod camera. The pilot study utilized only a tripod camera and only a fraction of each student's experience was caught on camera. When each student wore the action camera, all the equipment manipulation , conversations with peers and TA, writing in lab notebook, and movements around the lab room were recorded, giving a more detailed and accurate picture of their experiences. In this study, the video was used specifically during the interviews and to observe the student's cognitive and affective experiences in the laboratory. Because the videos were recorded, secondary analysis could be conducted in the future to study additional aspects of these students' experiences. In future studies, action cameras could be used to explore individual student's experiences in other settings such as note taking and attention in large lecture classes, group collaborations, and undergraduate research experiences. In addition, different theoretical and methodological frameworks could guide the collection of the video recording in new ways such as cognitive apprenticeship, situated learning (Lave and Wenger, 1991), social development theory (Vygotsky, 1978), self-determination theory (Ryan *et al*., 2012), symbolic interactionism (Blumer, 1969; Del Carlo, 2007), or Kolb's experiential learning (Towns, 2001) to name a few. While Looxcie, Inc. (2014) has since exited the consumer business, other action cameras with diverse features are available from variety of different retailers such as GoPro (2015) and Sony (2015).

How students choose to deal with their feelings could reflect the way that they believe best helps them learn. Students like Meredith and Jim who think there is one right answer will only work to achieve that one answer and stop when that answer is reached. Angela, Jan, and Phyllis talked as if the learning process happened to them rather than through them, waiting for things to take place instead of taking charge of their learning experience. Erin and Toby were cognizant of their need to be challenged and frustrated in order to work towards conceptual understanding. Additional research is needed to study the continuum of affective dimensions at work during laboratory learning. Studies on personal identity (Perez *et al*., 2014) and self-concept (Bandura, 1976) could guide the research and analysis of the affective domain.

The findings from this study raised questions that could be investigated in future studies. For instance, how do students' atomic-molecular level interpretations influence their perceptions of their learning? Could it be that students overestimate their conceptual understanding leading to inflated ideas about their abilities to conduct the laboratory experiments? Additionally, the scope of our research included only laboratory experiments conducted in a physical lab space. Future research could investigate students' cognitive and affective perceptions of learning within the context of virtual laboratories or computational laboratories.

Previous research using meaningful learning as an analytical lens categorized biology laboratory students into three groups: think meaningfully, think procedurally, and think as little as possible (Taylor-Robertson, 1984). Grove and Bretz (2012) classified second-year organic chemistry students into meaningful learners, transitional learns, unaware learners, and indifferent learners. The goal of this study was not to classify students, but to give a thick description of their cognitive and affective learning experiences in their chemistry laboratory courses. There may be connections between the students in this study and the classifications previously published. Future research could identify positions intermediate between rote and meaningful learning, as well as explore connections between Taylor-Robertson's (1984) and Grove & Bretz's (2012) categories. Are the students who think procedurally or as little as possible transitional, unaware, or indifferent learners? How might using these categories aid in the design of targeted interventions for laboratory learning? Understanding differences in how students view the learning process would be beneficial to the design of evidence based laboratory curriculum.

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Notes
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