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A COMPARISON OF FIRST-SEMESTER ORGANIC CHEMISTRY STUDENTS' EXPERIENCES AND MASTERY OF CURVED-ARROW FORMALISM IN FACE-TO-FACE AND CYBER PEER-LED TEAM LEARNING

For the degree of Doctor of Philosophy

Is approved by the final examining committee:

Pratibha Varma-Nelson Chair	Trevor Anderson
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A COMPARISON OF FIRST-SEMESTER ORGANIC CHEMISTRY STUDENTS' EXPERIENCES AND MASTERY OF CURVED-ARROW FORMALISM IN FACE-TO-FACE AND CYBER PEER-LED TEAM LEARNING

A Dissertation
Submitted to the Faculty
of
Purdue University
by
Sarah Beth Wilson

In Partial Fulfillment of the
Requirements for the Degree
of
Doctor of Philosophy

December 2015
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West Lafayette, Indiana

For my husband and son

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GLOSSARY

Adobe Connect is a web conferencing program that provides the following features for synchronous online collaborations: voice communications; video; chat; simultaneous screen sharing; subgrouping; polling; screen recording; and whiteboard collaboration. Adobe Connect has been used in the cPLTL courses at Indiana University-Purdue University Indianapolis (IUPUI), Purdue University, and Florida International University (Mauser et al., 2011; McDaniel et al., 2013; Smith, Wilson, Banks, Zhu, & Varma-Nelson, 2014).

Cyber Peer-Led Team Learning (cPLTL) is a synchronous online version of Peer-Led Team Learning in which 6-8 students work collaboratively to solve challenging problems that are aligned with the course content (Mauser et al., 2011; McDaniel et al., 2013; Smith et al., 2014).

DFW Rate is a course-level student performance indicator that is calculated from the number students in a course who earned grades of D/F or withdrew from the course divided by the total number of students.

Oncourse, an online course management system invented by Dr. Ali Jafari's and his research team at IUPUI, has been utilized on all eight Indiana University campuses (Jafari, 1999).

Peer Leaders are undergraduate role models & facilitators of group work in PLTL workshops who are recent successful completers of the course with demonstrated communication and leadership skills (Gosser et al., 1996). They "serve as a bridge between students and instructors" (Gafney & Varma-Nelson, 2007, p. 535).

Peer-Led Team Learning (PLTL) is an active learning pedagogy in which 8-10 students collaboratively solve challenging problems aligned with course content under the guidance of a trained peer leader (Eberlein et al., 2008).

Workshops are weekly mandatory PLTL sessions in which students work collaboratively to solve challenging multi-step problems to practice content they are learning in the affiliated course (Eberlein et al., 2008).

Workshop Zero is a pre-semester workshop in which cPLTL students optimize their computer settings and get acquainted with the technology (Mauser et al., 2011).

ABSTRACT

Wilson, Sarah Beth Ph.D., Purdue University, December 2015. A comparison of first-semester organic chemistry students' experiences and mastery of curved-arrow formalism in face-to-face and cyber Peer-Led Team Learning. Major Professor: Pratibha Varma-Nelson.

The cyber Peer-Led Team Learning (cPLTL) workshops are a synchronous online adaptation of the educational intervention PLTL, in which students, under the guidance of undergraduate peer facilitators, collaboratively solve problems in small groups. The purpose of this parallel convergent mixed methods study was to assess the impact of implementing cPLTL in an organic chemistry course on students' workshop experiences, performance, and development of curved-arrow formalism skills. Statistical analyses revealed comparable attendance rates, distribution of course grades, and achievement on American Chemical Society First-semester Organic Chemistry Exams. However, plotting workshop grades by AB, C, and DFW grade groupings revealed that PLTL students earned more successful grades than their cPLTL counterparts (91% vs 77% ABC grades). Utilization of a new curved-arrow formalism analytic framework for coding student interview artifacts revealed that cPLTL students were statistically less likely to successfully draw the product suggested by the curved-arrows than their PLTL classmates. Both PLTL and cPLTL students exhibited a comparable incidence of relational to instrumental learning approaches. Similarly, both PLTL and cPLTL students were more likely to exhibit a common Scheme for Problem-Solving in Organic Chemistry (SPOC) than having dialogue that could be characterized by Toulmin's Argumentation scheme. Lastly, implications for faculty are suggested, including: developing more explicit connections conceptual, mode, and reasoning components of understanding curved-arrow formalism for organic chemistry students; optimizing graphical collaborative learning activities for online learners; and developing online students' sense of community.

CHAPTER 1. INTRODUCTION

1.1 Impetus of the Study

I pursued this study of students’ use of curved-arrow formalism as a means of assessing content mastery due to her dual professional experience as an industrial synthetic organic chemist and organic chemistry instructor. The ability to utilize curved-arrow formalism during the deduction of mechanisms of reactions and the structure of potential side-products is a necessary skill to do organic chemistry. Therefore, focusing students on learning curved-arrow formalism rather than merely memorizing should be one way to encourage novices to develop their problem-solving skills, so their thinking can be more facile in novel situations. Likewise, organic chemistry instructors devoted to incorporating collaborative learning in their classrooms should consider the effectiveness of such pedagogical approaches to an online setting in this age where more hybrid and online courses are being implemented in higher education.

1.2 Statement of the Problem

This work was undertaken because: (1) There has been no study to characterize organic chemistry students’ experiences or course performance in PLTL or cPLTL settings; (2) There has been no study to assess first-semester organic chemistry students’ curved-arrow formalism mastery achieved in Peer-Led Team Learning (PLTL) or cyber Peer-Led Team Learning (cPLTL) settings.

1.3 Research Questions

The guiding research questions for this study were:

- How do organic chemistry students experience the PLTL and cPLTL settings?
- Are organic chemistry students' performance comparable in the PLTL and cPLTL settings?
- Do high- and low-performing students experience the PLTL & cPLTL settings differently?
- Do high- and low-performing students from the PLTL & cPLTL settings use or understand curved-arrow formalism differently?

1.4 Theoretical Frameworks

This study was grounded in two theoretical frameworks: social constructivism and C-R-M model of factors, which influence a student's ability to interpret an external representation. In the following sections, I describe each of these theoretical frameworks and how this study is grounded therein.

1.4.1 Social Constructivism

Social constructivism is a theoretical framework which asserts that people interpret concepts and models in order to make sense of their surroundings and experiences, rather than discover existing knowledge (Bodner & Klobuchar, 2001; Bodner, 1966; Driver, Newton, & Osborne, 2000; Scardamalia & Bereiter, 2006; Walker & Sampson, 2013; Watson, 2001), thus, "knowledge is constructed in the mind of the learner" (Bodner, 1966, p. 874). This knowledge construction process is aided through social interactions (Eberlein et al., 2008) in which students interact with slightly more advanced peers who urge them to develop greater understanding of concepts within their Zone of Proximal Development (ZPD), the range of activities a student can successfully accomplish with appropriate scaffolding (Vygotsky, 1978).

In the first-semester organic chemistry PLTL workshop series, undergraduate peer leaders facilitate students’ collaborative interactions to solve challenging organic chemistry problems. Rather than provide answer keys, peer leaders employ a combination of asking leading questions and orchestrating collaborative learning techniques (CoLTs) among the classmates that partner more advanced students with students whose content mastery with respect to a given concept is just beginning to emerge. Consequently, students develop within their unique ZPDs while simultaneously aiding classmates’ learning. Therefore, students’ development of first-semester organic chemistry content mastery, including curved-arrow formalism and problem-solving to distinguish substitution and elimination reaction conditions, is a social, rather than individual, pursuit.

As I sought to characterize students’ organic chemistry content mastery via both qualitative (interview with probes) and quantitative (standardized national exam) approaches, I took into account the student-student and student-peer leader interactions in both learning environments since each student’s construction of knowledge occurred in a social context.

1.4.2 C-R-M Model

The C-R-M model (Figure 1-1) is a device for faculty and researchers to account for factors and the interaction of factors that play a role in a student's understanding of an external representation (ER) (Anderson et al, 2013; Schönborn & Anderson, 2008, 2009, 2010), including: "students' *reasoning* factor (R factor), students' understanding of *concepts* of relevance to the ER (C factor), and the nature of the *mode* in which the desired phenomenon was represented by the ER (M factor)"(Schönborn & Anderson, 2009). As the Venn diagram indicates, a students' total ability to reason includes their ability to reason with the particular ER (R-M) and his or her conceptual knowledge (R-C). Likewise, the C-M interaction factor refers to the "conceptual knowledge that is communicated through, or represented by, the graphical markings and symbolism used to construct the ER" (Schönborn & Anderson, 2009, p. 208).

The C-R-M model has been applied to biochemistry (Linenberger & Holme, 2014, 2015; Milner, 2014; Saleh, 2015; Towns, Raker, Becker, Harle, & Sutcliffe, 2012; Trujillo, Anderson, & Pelaez, 2015); anatomy and physiology (Cheng & Gilbert, 2014); genetics (Edfors, Wikman, Cederblad, & Linder, 2015); and molecular biology (Rybarczyk, Walton, & Grillo, 2014). Additionally, the C-R-M model has been applied to stereochemistry (Edfors et al., 2015) and animation (Al-Balushi & Al-Hajri, 2014) of organic chemistry concepts, but the C-R-M model has not previously been applied to organic chemistry students' understanding of curved-arrow formalism. In this study, I examined PLTL and cPLTL students' dialogue and artifacts to gauge their understanding of curved-arrow formalism.

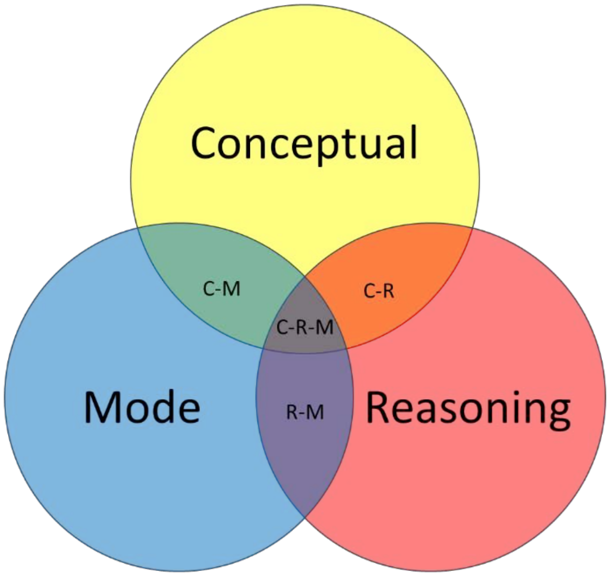


Figure 1-1 Venn diagram representing the three factors and four interaction factors which affect students' understanding of external representations (Anderson et al., 2013; Schönborn & Anderson, 2009, 2010)

1.5 Significance of the Study

Several aspects of this study are significant. For example, this study augments the emerging literature regarding whether social constructivism is as effective in a synchronous online setting as it is in face-to-face learning environments (Smith et al., 2014). Secondly, this study is one of the first in which Revised Bloom's Taxonomy for the Cognitive Domain (Anderson & Krathwohl, 2001) has been used as an analytic framework to classify science student discourse (Christian & Talanquer, 2012a). Thirdly, this study's utilization of both curved-arrow formalism error literature (Grossman, 2003; Grove, Cooper, & Rush, 2012; Scudder, 1992) and grounded theory led to the development of a novel analytic framework for evaluating students' use of curved-arrow formalism. Lastly, the analysis of students' experiences in face-to-face and online PLTL settings through analysis of workshop discourse and interview responses could be leveraged to develop cPLTL/PLTL best practices and training materials.

CHAPTER 2. REVIEW OF THE LITERATURE

2.1 Peer-Led Team Learning (PLTL)

2.1.1 Introduction

In the recommended PLTL model, groups of approximately eight students are facilitated by a trained peer leader to collaboratively solve problems for 90-120 minutes each week (Gosser et al., 1996). The peer leaders are usually recent completers of the course who have demonstrated interest in helping others learn, have exemplary communication skills, and adeptness in the subject matter. Compensation for peer leaders has ranged from modest salaries or college credit to promises of meaningful recommendation letters, depending on the culture of the implementing institution (Gosser, Jr., Kampmeier, & Varma-Nelson, 2010). Additionally, PLTL workshops being an integral part of the course have usually been interpreted as being a requirement of the course and a complement to the lecture, although two research studies have offered limited placement of interested students in PLTL sections in order to create control group sections (Alger & Bahi, 2004; Chan & Bauer, 2015). Special emphasis has been communicated during national dissemination workshops that PLTL is not intended to be implemented as a means to just help females or underrepresented minority students, nor is it a remedial program, although several studies have, in fact, cited PLTL's unique effectiveness for those subsets of the population (Drane, Smith, Light, Pinto, & Swarat, 2005; Horwitz & Rodger, 2009; Lewis, 2011; Preszler, 2009; Quitadamo, Brahler, & Crouch, 2009). I agree with Dr. Varma-Nelson that if PLTL were implemented as an academic intervention for only at-risk students, the program enrollment could decline and the beneficial dynamic of bringing students of varying abilities, backgrounds, and problem-solving skills together would be reduced (P. Varma-Nelson, personal communication, April 28, 2014).

2.1.2 History of PLTL

Beginning in 1991, small, peer-led groups were formed for collaborative problem-solving within a large-enrollment general chemistry course at the City College of New York (Gosser et al., 1996; Gosser, Jr. et al., 2010; Gosser, Jr., 2015; Woodward, Weiner, & Gosser, 1993). Given the initial promising results, the National Science Foundation (NSF) funded the development of these peer-led workshops in general chemistry (NSF-DUE #9150842). Then, a Workshop Chemistry Curriculum Planning Grant (NSF-DUE #9450627) was awarded to Gosser & Weiner. One year later, Gosser, Radel, & Weiner were granted a $1.6M continuing grant by NSF-DUE (#9455920) as part of the Systemic Change Initiative to partner with ten senior and community colleges at the City University of New York as well as the Universities of Pittsburgh and Pennsylvania to continue the development of Workshop Chemistry curriculum for general chemistry courses. Development of the pedagogy was extended to include an organic chemistry course at the University of Rochester and in both an organic and a general, organic, and biochemistry (GOB) courses at St. Xavier University (Gosser, Jr. et al., 2010). Shortly thereafter, Workshop Chemistry was renamed as Peer-Led Team Learning (PLTL).

Early PLTL publications reported improvements in students' course grades and enthusiasm for learning (Gosser et al., 1996; Woodward et al., 1993), which led to interest in disseminating the pedagogy more widely. In 1999, the National Science Foundation funded the PLTL project to disseminate the methodology across STEM disciplines nationally, which included a variety of national dissemination strategies and created the Workshop Project Associate small grants initiative (NSF-DUE #9972457). The PLTL project team was also awarded supplementary funding for dissemination to two-year colleges (NSF-DUE #0004159). Similarly, a grant was funded in 2003 (NSF-DUE #0231349) in order to provide inspiration, instruction, support, and mini-grants to strengthen the PLTL national network across science, technology, engineering, and mathematics (STEM) courses (Gosser, Jr. et al., 2010) as well as economics (White, Rowland, & Pesis-Katz, 2012). Additionally, PLTL dissemination was funded through the Multi-Initiative Dissemination (MID) Project (NSF-DUE #0196527).

While most of the implementations of PLTL were as a complement to the lecture, the PLTL pedagogy was also integrated into the Center for Authentic Science Practice in Education (CASPiE) project, an initiative to develop laboratory modules to provide undergraduates with authentic research experiences, including guidance from peers as they pursue research-based projects (NSF-DUE #0418902) (Weaver et al., 2006). At last estimate, PLTL has been implemented at more than 150 institutions in the United States, from two-year community colleges to large research universities (Gosser, Jr. et al., 2010). Additionally, there has been international interest in implementing PLTL, including Australia (Stewart, Amar, & Bruce, 2007), China (Gosser, Jr. et al., 2010), India, and Turkey. Thus, the original seed funding from NSF catalyzed the formation of a community of STEM faculty that have contributed to the large and continuously growing body of scholarly PLTL literature, including a suite of guidebooks which were written to provide examples of workshop problems for a variety of chemistry courses, recommendations for training peer leaders, and responses to frequently asked questions (Gosser et al., 2001; Gosser, Strozak, & Cracolice, 2006; Kampmeier, Varma-Nelson, Wamser, & Wedegaertner, 2006; Kampmeier, Varma-Nelson, & Wedegaertner, 2001; Roth, Goldstein, & Marcus, 2001; Varma-Nelson & Cracolice, 2001).

The early developers of the PLTL model evaluated the program using a mixed methods design which included course grade comparisons, surveys, interviews, and focus groups of faculty and students. Six “critical components” emerged (Gosser et al., 2001, p 4):

> *Faculty involvement.* The faculty members teaching the course are closely involved with the workshops and the training of workshop leaders.
>
> *Integral to the course.* The workshops are an essential feature of the course.
>
> *Leader Selection and Training.* The workshop leaders are carefully selected, well-trained, and closely supervised, with attention to knowledge of the discipline and teaching/ learning techniques for small groups.
>
> *Appropriate materials.* The workshop materials are challenging, intended to encourage active learning and to work well in collaborative learning groups.
>
> *Appropriate organizational arrangements.* The particulars, including the size of the group, space, time, noise level, etc., are structured to promote group activity and learning.

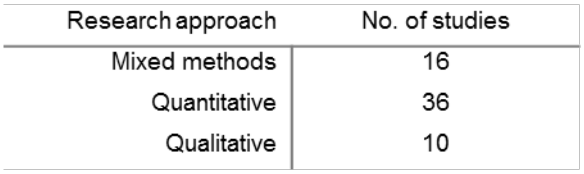
Administrative support. Workshops are supported by the department and the institution as indicated by funding, recognition, and rewards.

Additionally, as a PLTL workshop series coordinator, I also agree with the 120-minute workshop duration and absence of answer keys (Gafney & Varma-Nelson, 2008) recommendations because students must be allotted sufficient time and incentive to debate and discuss concepts.

2.1.3 Sampling

Only peer-reviewed, scholarly work are included in this review of the PLTL literature. My search protocol included: accessing the Scopus, Science Direct, Institute of Electrical and Electronics Engineers (IEEE) Xplore, PsycArticles, PsycINFO 1887-current (EBSCO), Journal Storage (JSTOR), Papers on Engineering Education Repository (PEER), Educational Resources Information Center (ERIC) Proquest, and ERIC (EBSCO) databases; searching individual discipline-based education research (DBER) journals; and performing citation searches in Google Scholar of articles obtained through the other search mechanisms. Qualitative, quantitative, and mixed methods studies were all included in this review (Table 2-1), as long as the articles reported methodology, analysis techniques, and findings. White papers and articles that were anecdotal in nature are excluded from this analysis.

Table 2-1 Types of research approaches identified from 62 peer-reviewed studies



Research approach	No. of studies
Mixed methods	16
Quantitative	36
Qualitative	10

Overall, 62 studies from a variety of STEM education journals were identified for inclusion in this review the PLTL literature, including: *Journal of Chemical Education*; *Journal of Research in Science Teaching*; *Chemistry Education Research and Practice*; *Journal of College Science Teaching*; *The Chemical Educator*; *International Journal of Instructional Research*; *International Journal of Science Education*; *International Journal of Teaching & Learning*; *International Journal of Science and Mathematics Education*; *International Journal of Learning, Teaching, & Education Research*; *Australian Journal of Education in Chemistry*; and others are reported. Conference proceedings from American Society for Engineering Education (ASEE), IEEE, and Special Interest Group on Computer Science Education (SIGCSE) conferences were included in this review because those manuscripts were peer-reviewed.

Key findings from the five themes which emerged from this synthesis of the literature are presented (Figure 2-1), including: (1) program evaluation; (2) PLTL’s effect on reasoning skills & critical thinking; (3) PLTL’s effect on students’ affective domain; (4) peer leader research; and (5) variants of the traditional PLTL model.

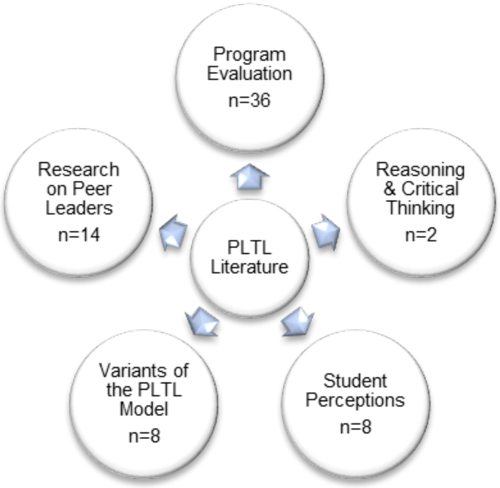


Figure 2-1 Five emergent themes from review of 62 PLTL studies

2.1.4 Program Evaluation

The PLTL literature reveals that PLTL student success measures were evaluated in a variety of undergraduate disciplines, including: general chemistry (Alger & Bahi, 2004; Chan & Bauer, 2015; Drane et al., 2005; Flores et al., 2010; Hockings, DeAngelis, & Frey, 2008; Lewis, 2011, 2014; Lyon & Lagowski, 2008; Mauser et al., 2011; Mitchell, Ippolito, & Lewis, 2012; Shields et al., 2012; Smith et al., 2014); organic chemistry (Lyle & Robinson, 2001; Rein & Brookes, 2015; Tien, Roth, & Kampmeier, 2002; Wamser, 2006); allied health or general/organic/biochemistry (Akinyele, 2010); introductory biology (Drane et al., 2005; Peteroy-Kelly, 2007; Preszler, 2009); anatomy & physiology (Finn & Campisi, 2015); bioinformatics (Shapiro, Ayon, Moberg-Parker, Levis-Fitzgerald, & Sanders, 2013); mathematics (Curran, Carlson, & Celotta, 2013; Flores et al., 2010; Merkel & Brania, 2015; J. Reisel, Jablonski, & Munson, 2013; J. R. Reisel, Jablonski, Munson, & Hosseini, 2012, 2014); computer science (Alo, Beheshti, Fernandez, Gates, & Ranjan, 2007; Biggers, Yilmaz, & Sweat, 2009; Horwitz & Rodger, 2009; Hug, Thiry, & Tedford, 2011; Roach & Villa, 2008; Utschig & Sweat, 2008); engineering (Foroudastan, 2009; Johnson, Robbins, & Loui, 2015; Mottley & Roth, 2013; Pazos, Drane, Light, & Munkeby, 2007); psychology (Murray, 2011); and physics (Drane et al., 2005). Although implementation of PLTL has been reported in a high-school setting (Cracolice & Deming, 2001), no peer-reviewed scholarly articles were available at the time of this review article. Lastly, there is one PLTL program assessment study evaluating a graduate-level nursing course (White et al., 2012).

The most common factor reported as a measure of student success, course grades, were reported by 50% of the program evaluation research studies (Table 2). PLTL students' course grades were statistically higher than non-PLTL students' course grades in fourteen of these studies (Hockings et al., 2008; Horwitz & Rodger, 2009; Lewis, 2011; Lyle & Robinson, 2003; Lyon & Lagowski, 2008; Mitchell et al., 2012; Peteroy-Kelly, 2007; Preszler, 2009; Reisel et al., 2013; Reisel et al., 2012, 2014; Shields et al., 2012; Smith et al., 2014; Tenney & Houck, 2003). Reisel et al. (2013, 2012, 2014) reported significant improvement in average Calculus I course grades and improvement in Algebra course grades, suggesting content-based differences in PLTL's impact on student learning. Both Drane et al. (2005) and Chan & Bauer (Chan & Bauer, 2015) studies reported no significant difference in course grades for PLTL and non-PLTL students, but it should be noted that students' participation in PLTL was optional in both studies. Drane et al. (2005) reported no significant difference in course grades for physics PLTL students, but the group size was larger than recommended 8-10 students per peer leader. Chan & Bauer (2015) likened the "integral to the course" critical component (Gosser et al., 2001) of PLTL implementation and "well-integrated," which they defined as smooth sign-up and communication processes with mandatory attendance for students who elect to participate in PLTL. Therefore, research indicates that when PLTL is implemented according to the model, there is a notable, if not significant, improvement in student performance, as measured by course grades.

Table 2-2 Factors given as indicators of student success

Reference	Mean Course Grade	Pass Rate (% ABC)	DFW Rate	First-semester ACS Exam Scores	Semester Exam Grades	Retention
Akinyele (2010)			✓			
Alger & Bahi (2004)				✓		
Alo et al (2007)		✓				
Biggers et al (2009)		✓				
Chan & Bauer (2015)				✓	✓	
Curran et al (2013)					✓	
Drane (2005)	✓					✓
Finn & Campisi (2015)					✓	
Flores et al (2010)		✓				
Foroudastan (2009)						✓
Hockings, DeAngelis, & Frey (2008)	✓					✓
Hooker (2011)		✓		✓		✓
Horwitz & Rodger (2009)	✓	✓				
Lewis (2011)		✓		✓		✓
Lewis (2014)						✓
Loui et al (2013)					✓	✓
Lyle & Robinson (2003)	✓				✓	
Lyon & Lagowski (2008)	✓				✓	
Mauser et al. (2011)	✓		✓	✓		
Merkel & Brania (2015)		✓				✓
Mitchell, Ippolito & Lewis (2012)	✓	✓		✓		
Mottley & Roth (2013)	✓					
Pazos et al (2007)						✓
Peteroy-Kelly (2007)	✓				✓	
Preszler (2009)		✓	✓			
Rein & Brookes (2015)	✓					
Reisel et al (2012)	✓					
Reisel et al (2013)	✓					
Reisel et al (2014)	✓					
Roach & Villa (2008)						✓
Shields et al (2012)	✓					
Smith et al. (2014)	✓		✓	✓		
Tenney & Houck (2003)	✓	✓				
Tien, Roth, & Kampmeier (2002)	✓	✓				
Wamser (2006)		✓		✓		
White, Rowland, & Pesis-Katz (2012)	✓					

In addition to or in lieu of reporting the comparison of mean course grades for PLTL and non-PLTL students, fifteen studies reported %ABC (also known as pass rate) and/or %DFW rate, which enumerates students who withdrew from the course or earned grades of D or F. Mitchell, Ippolito, and Lewis (2012), Wamser (2006), Tien, Roth, & Kampmeier (2002), Tenney & Houck (2003), Akinyele (2010), Biggers (2009), Horwitz (2009), and Preszler (2009) reported significantly higher pass rates for PLTL students. Although the Alo et al. (2007) study of implementation of PLTL in various Computing Alliance of Hispanic Serving Institutions (CA-HSI) partners did not include statistical analysis of differences in pass rates for PLTL and historical non-PLTL students, they reported a 60% increase in ABC grades for University of Houston Downtown college algebra PLTL students as compared to historical non-PLTL course grades as well as improvement in the pass rates of both computer science I (18%) and computer science III (29%) at the University of Texas at El Paso (UTEP) (Alo et al., 2007). There was no improvement in UTEP's PLTL computer science II pass rates during the same time period. Tenney & Houck (2003) and Mottley & Roth (2013) reported positive correlations between introductory PLTL workshop attendance and course grades. Finn & Campisi (2015) reported statistically significant improvement on a tissues/muscle physiology unit and a partial effect in the terminology/cells unit, and no effect in other anatomy & physiology topics, suggesting again that PLTL may be more effective for certain content or question styles. Hooker (2011) reported that there were a higher percentage of students with ABC grades, but the difference for the small populations did not reach statistical significance. Lastly, Merkel & Brania (2015) reported no significant difference in PLTL and non-PLTL grade distributions, although they suggested that the variability of commitment of peer leaders and shortened duration of workshops may have been factors. Thus, these studies indicate that there is a positive correlation between workshop attendance and increased proportion of students earning A, B, or C grades when facilitated by reliable, peer leaders in full-length PLTL workshops, although further research is required to identify specific STEM content and problem types that are more effective for PLTL workshops. A positive correlation between workshop attendance and course grades was also reported separately by Wedegaertner and Garmon (Gafney & Varma-Nelson, 2008, p 19-20).

Sixty-seven percent of the chemistry program assessment studies measured student success on a nationally normed American Chemical Society (ACS) First-Semester Chemistry Exam. Lewis (2011) reported that PLTL students earned significantly higher ACS exam score percentages than non-PLTL students, despite comparable SAT scores. Alger & Bahi (2004) reported that there was no significant difference in PLTL and non-PLTL students' performance on an ACS exam, but the study included a comparison of two different academic interventions instead of implementing a standard control study design. Chan & Bauer (2015) also reported no significant difference in PLTL and non-PLTL students' ACS exam scores in their randomized, quasi-experimental study. Mitchell et al (2012) reported that PLTL and non-PLTL students in first- and second-semester general chemistry courses earned comparable ACS exam scores. Wamser (2006) reported that PLTL students' ACS exam scores were in the 77th percentile, while the historical non-PLTL students' ACS exam scores were in the 69th percentile.

Chan & Bauer (2015) converted the ACS exam scores to Z scores instead of comparing mean ACS exam scores, a key technique if comparing student performance on multiple versions of an exam, and they found no significant difference between PLTL and non-PLTL students’ ACS exam Z scores. This finding, that studies can simultaneously show significant improvement in students’ course grades, yet achieve comparable ACS exam scores suggests there may be a set of skills that are assessed in the calculation of course grades, but not assessed by ACS exams. For example, Smith et al. (Smith et al., 2014) reported that PLTL general chemistry students discussed the problem-solving process only when they had different answers, while cyber Peer-Led Team Learning (cPLTL) general chemistry students were more likely to have a problem-solving focus during the workshops. Their finding suggests that standardized assessments may not measure important attributes of student development, such as having a problem-solving mindset. In 2010, Holme et al.(2010) reported the development of assessments to measure students’ problem-solving, metacognition, and cognitive development, but utilization of these new instruments has not yet been reported in PLTL literature.

The least commonly reported measurement of program success reported in the literature was retention, defined as completing the course being evaluated (Hockings et al., 2008; Horwitz & Rodger, 2009; Lewis, 2011). The creation of small learning communities in order to increase student retention is often cited as a reason for institutions to implement PLTL (Gosser, Jr. et al., 2010). Six studies reported a statistically significant improvement in the retention rate of PLTL students (Drane et al., 2005; Hockings et al., 2008; Horwitz & Rodger, 2009; Lewis, 2011, 2014; Loui, Robbins, Johnson, & Venkatesan, 2013), while two studies reported no significant difference in retention rate (Merkel & Brania, 2015). A key difference between the Merkel & Brania (2015) study and the studies which report significant differences in retention rate is the duration of the workshop sessions. The calculus I PLTL workshops investigated by Merkel & Brania (2015) ranged in duration from 50- to 75-minutes, while the recommended duration of a PLTL workshop session is 90-120 minutes in order to provide adequate time "for productive cooperative work and the development of problem-solving skills." (Gafney & Varma-Nelson, 2008, p. 12) Although not statistically significant, Hooker (2011) reported a notably higher retention rate of PLTL students than non-PLTL students. Furthermore, the PLTL students provided feedback in the end-of-semester survey that PLTL created interdependent learning communities for the students (Hooker, 2011, p. 224):

> …having a group that the student could relate to did help them stay in class until the end. Several students commented that they felt responsible for helping the other members of their group show up and pass the class. Others commented how they felt as if they belonged and it was important for them to do their best so that they did not let the rest of the group down.

The appropriate definition of retention, students persisting in subsequent courses, was reported in three studies, enrolling in the next course of the curriculum sequence (Loui et al., 2013; Mitchell et al., 2012), or completing a sequence of courses (Lewis, 2014; Pazos et al., 2007). Pazos et al reported that, after adjusting for SAT-math score, gender and ethnicity, engineering students who participated in two or more PLTL workshops during the semester were five times more likely to complete the four-course engineering analysis sequence than students who participated in fewer than two workshops (Pazos et al., 2007). Loui et al (2013) reported a significant interaction between workshop attendance and retention for female PLTL students. Lewis reported a significant impact for general chemistry I PLTL experience and enrollment in general chemistry II and organic chemistry I (Lewis, 2014). Mitchell, Ippolito, & Lewis (2012) reported that there was no significant correlation between participation in first-semester general chemistry (GC1) PLTL and enrollment in second-semester general chemistry (GC2). However, the statistically significant increase in pass rate of GC1 PLTL students compared to GC1 non-PLTL students coupled with the pass rate of GC2 PLTL students being 16% higher than GC2 non-PLTL students led to an important difference in the retention of students in the chemistry course sequence at their large southeastern primarily undergraduate institution.

White, Rowland, and Paesis-Katz (2012) performed PLTL program analysis of their graduate-level nursing course as a qualitative study in which student perceptions were gathered through focus group feedback. The researchers reported that students perceived the PLTL workshops as crucial to their content understanding, problem-solving and critical thinking skills, and diminished course anxiety.

The Lyle & Robinson study (2003) is particularly important, not only in the body of PLTL literature, but also in the current research climate because qualitative studies in the psychological sciences, which would include education literature, have been criticized for lack of reproducibility of results (Open Science Collaboration, 2015). These researchers re-evaluated the PLTL program evaluation data from earlier studies and reaffirmed the statistical significance of the PLTL implementations. Moreover, the similarity of PLTL program evaluation findings across a variety of settings and disciplines suggests the reproducibility of PLTL's effectiveness (Lyle & Robinson, 2003).

2.1.5 Reasoning Skills & Critical Thinking

My review of the PLTL literature revealed that there are two studies in which critical thinking or reasoning skills of PLTL students were specifically investigated. Peteroy-Kelly (2007) suggested that the use of concept mapping was a proxy for conceptual reasoning because Cohen (1987) posited that concept mapping required greater metacognitive reflection than paragraph writing, so concept mapping is an indication of enhanced reasoning skills. She reported PLTL students' statistically significant increase in: (1) semester exam scores; (2) final exam scores; (3) course grades; and (4) post-test use of concept maps to communicate relationships between non-science words. In contrast to the Peteroy-Kelly (2007) study, Quitadamo, Brahler, & Crouch (2009) utilized an instrument, the California Critical Thinking Skills Test (CCTST) (Facione & Association, 1990), rather than observing the occurrence of students' concept mapping as the assessment for critical thinking gains. These researchers reported a significant interaction for critical thinking gains and PLTL involvement, with particularly positive performance and retention gains for females.

2.1.6 Student Perceptions Research

Since the inception of PLTL, the most common means to measure the students' perceptions of the impact of PLTL involvement has been the Student-Assessment of

Learning Gains (SALG) survey, developed by Seymour (2000), or modified versions thereof. Finn & Campisi (2015) reported that over seventy percent of their PLTL students rated their learning gains in PLTL positively. Similarly, Tien, Roth, & Kampmeier (2002) reported that PLTL students were significantly more likely to credit PLTL workshop involvement with increased learning than non-PLTL students' perceived learning gains from recitation. Engineering PLTL students in Loui et al's (2013) study reported gains in their content understanding, while 65% of the introductory biology students in Peteroy-Kelly's (2007) study reported that PLTL participation helped them understand the main concepts (or relationships between concepts) of the course. Computer science PLTL students in the Emerging Scholars Program reported a significantly lower perception than their non-PLTL counterparts that their instructor covered course material too quickly (Horwitz & Rodger, 2009), suggesting that workshop experiences helped the PLTL students construct their mental models of the content more rapidly.

Chan & Bauer's (2015) study reported no significant difference between PLTL and non-PLTL students' scores on the Attitude to Subject of Chemistry (ASCI) (Bauer, 2008), which measures five aspects of student's chemistry-related perceptions, including: interest & utility; anxiety; fear; emotional satisfaction; and intellectual accessibility. Likewise, these researcher reported no significant difference between PLTL and non-PLTL students' scores on the Chemistry Self-Concept Inventory (CSCI) (Bauer, 2005), an instrument which measures the degree to which each student views himself or herself as capable in the field of chemistry, science, or academic settings. The researchers interpreted their findings as evidence that students who "take full advantage" of professor-led review sessions, self-assembled group, tutoring sessions, or PLTL are equally benefitted with respect to chemistry attitude or self-concept (Chan & Bauer, 2015, p. 24).

Black & Deci (2000) administered surveys at the beginning and end of a PLTL Organic Chemistry course to compare students' perceptions of the supportiveness of the learning environment and students' course performance. The surveys were generated as a conglomerate of questions from previously-validated instruments which measured the following constructs: learning climate; perceived confidence; interest/enjoyment; anxiety index; grade orientation; and leader autonomy support. Black & Deci evaluated the survey via principal components factor analysis to affirm that the survey assessed the five intended constructs before administering the instrument to their study population. The researchers proposed that students with an internal locus of control (Murray, 2011), or autonomous sense of self, would perform well in the course due to interest (Black & Deci, 2000). Multiple regression revealed that the students' perception of the supportiveness of his or her peer leader had a statistically significant impact on students' course grade.

2.1.7 Research on Peer Leaders

Thus far, PLTL peer leader research has consisted of two varieties: characterization of peer leader behavior and assessing the impact of the PLTL experience on the peer leaders themselves. For example, the Light group at Northwestern University developed an observation protocol to characterize peer leader behavior from their observations of their Gateway Science Program's STEM workshops (Pazos, Micari, &

Light, 2010), which are analogous to PLTL workshops (Streitwieser & Light, 2010). Using exploratory factor analysis, the researchers determined two factors from their observation survey: group interaction style and problem-solving focus. The two factors, mapped as a two-by-two matrix to generate four types of interaction/problem-solving styles, enabled the research team to hone their observation protocol instrument to ten scalar questions. Likewise, the Light group conducted a pre- and post-semester phenomenographic study (Streitwieser & Light, 2010) to characterize peer leader beliefs and actions as either teacher-centered or learner-centered. The researchers found that nearly half of the peer leaders in their sample who began as teacher-centered style transitioned to a more facilitative, or learner-centered, style as the semester progressed and the peer leaders grew to be more concerned with students' learning growth than transmitting information.

During approximately the same timeframe, a series of intertwined studies (Brown, Sawyer, & Frey, 2009a, 2009b; Brown, Sawyer, Frey, Luesse, & Gealy, 2010) were conducted to determine the impact of peer leader style on general chemistry PLTL student discourse. Given identical PLTL materials, the researchers found that students lead by a facilitative peer leader "acknowledged, built upon, and elaborated on each other's ideas" with equal involvement (Brown et al., 2010). In contrast, students with an instructional peer leader tended to work individually when not listening to the peer leader, be answer-focused, and unequally participated. Lastly, the researchers suggested that student discourse was related to problem structure. Namely, the researchers recommended that PLTL problems encourage students to discuss concepts and relevant experiments, not merely utilize equations or formulae (Keith Sawyer, Frey, & Brown, 2013).

Nine studies have endeavored to assess the effect of PLTL leadership experience on the peer leaders themselves. Johnson, Robbins, & Loui (2015) reported that engineering peer leaders’ journals revealed a progression from focusing on trying to be content experts to seeking effective facilitation techniques by the end of the semester. Murray (2011) reported a significant increase in knowledge of statistics and research methods knowledge of PLTL-trained psychology mentors compared to non-PLTL-trained mentors on a 100-item instrument, although Cronbach’s alpha was not reported for the instrument. Four of these studies about the impact of the PLTL experience on peer leaders utilized questionnaires to enable the peer leaders to self-report perceived learning gains (Gafney & Varma-Nelson, 2007; Hug et al., 2011; Snyder & Wiles, 2015; Tenney & Houck, 2004). Tenney & Houck (2004) reported that peer leaders attributed greater content learning, exam preparedness, and improved interpersonal skills to their PLTL involvement. Similarly, Hug, Thiry, & Tedford reported a significant increase in peer leaders’ perception of their decision-making skills, facilitation skills, and content knowledge (Hug et al., 2011). Furthermore, Gafney & Varma-Nelson (2007) described that at least 92% of former peer leader survey respondents positively-rated their peer leader experience for: (1) appreciation of small-group learning and different learning styles; (2) gained confidence in presenting and working as a team; and (3) greater appreciation of what it takes to be a teacher. Both current and former peer leaders expressed that they thought their teaching skills were improved by being peer leaders

(Gafney & Varma-Nelson, 2007; Tenney & Houck, 2003, 2004). In fact, Tenney & Houck (2003) credited the influence of PLTL on their academic culture as the reason the institution saw an increase in percentage of chemistry majors declaring intentions to teach as a career after PLTL implementation. Peer leaders reported gains in their content mastery and learning from multiple viewpoints in two studies (Gafney & Varma-Nelson, 2007; Snyder & Wiles, 2015), although there was no significant changes in overall of subscale scores between peer leaders and qualified non-peer leaders who were administered the California Critical Thinking Skills Test (CCTST) (Snyder & Wiles, 2015). However, the researchers reported that peer leaders' pretest mean score was higher than the national average already. Snyder & Wiles'(2015) finding are in sharp contrast to an earlier content-specific pretest/posttest study which revealed that there was a statistically significant interaction between critical thinking and PLTL involvement (Quitadamo et al., 2009). Furthermore, Amaral & Vala (2009) reported that even mentors who had been deemed underprepared for a first-semester general chemistry course based on pre-test results later proceeded to earn higher grades and persist in more subsequent chemistry courses than non-mentors. Therefore, I propose that the small learning community formation, frequent content review, increased confidence, and exposure to different approaches to learning may impact peer leaders in ways that the CCTST does not measure. In fact, Gafney & Varma-Nelson (2007) stated that nearly 90% of the participants in their study who had earned their undergraduate degree were enrolled in medical or graduate school, employed in a science field, or engaged in teaching.

Likewise, Flores et al.(2010) reported that the six-year graduation rate for peer leaders of gateway math and science courses for engineers was 48% higher than the overall undergraduate graduation rate (97% vs. 49%).

2.1.8 Variants of the PLTL Model

Four types of PLTL variants of the standard PLTL model were identified from the literature review: utilization of in-class peer leaders instead of recent completers of the course; online PLTL; PLTL in the chemistry laboratory; and a hybrid of PLTL and Process Oriented Guided Inquiry Learning (POGIL), dubbed Peer-Led Guided Inquiry (PLGI).

2.1.8.1 In-class Peer Leaders

Schray et al (2009) modified the standard PLTL model by assembling their roster of organic chemistry peer leaders as a combination of typical peer leaders, who are recent completers of the course, and current enrollees of the course, which they called “in-class peer leaders”. The rationale of the researchers was that hiring a sufficient quantity of qualified and reliable peer leaders can sometimes be problematic (Merkel & Brania, 2015), while enlisting current, promising members of the course would preserve the vital Zone of Proximal Development dynamic in a way that utilization of a faculty member would not. Both types of peer leaders were trained identically, at a pre-semester retreat as well as weekly. The researchers reported that there was no significant difference in students’ grades, regardless of peer leader type. Moreover, student perception surveys suggested that typical peer leaders were more likely than their in-class counterparts to convey information to students instead of facilitating discussions (Schray et al., 2009). However, the researchers did not address how they ensured that in-class peer leaders and non-peer leader classmates had equitable assessments, given the extra content training provided to in-class peer leaders. Furthermore, in this study, students were given answer keys at the end of workshop sessions, which is not a recommended practice among PLTL programs because “students without answer keys tend to focus on understanding the problem-solving process, engaging in critical thinking, questioning, and reflection to arrive at more-reasoned conclusions and deeper learning” (Gosser et al., 2001; Smith et al., 2014).

2.1.8.2 Online PLTL

The PLTL literature included two approaches to transition PLTL to an online setting. First, synchronous online collaborative groups were created in the PLTL variant called cyber Peer-Led Team Learning (cPLTL) (NSF-DUE #0418902) (Mauser et al., 2011; Smith et al., 2014). These researchers evaluated the impact of replicating the general chemistry PLTL in an online setting by utilizing a web conferencing program as the means for online students to interact with their peer leaders. In this setup, students were able to see and hear one another via webcam as well as see one another’s worksheets by the use of a document camera as they collaborated in real time. Discourse analysis revealed instances in which students built on one another’s ideas to construct meaning, which demonstrated that social constructivism was occurring in the online setting (Smith et al., 2014). Both cPLTL and PLTL students were provided the same workshop materials and program evaluation was performed on a limited subset of the student population called comparison groups, in which peer leaders led one section each of PLTL and cPLTL in the same semester. The researchers reported that the students in the comparison groups earned comparable mean student course grades and scores on the First-Semester General Chemistry Exam. However, the researchers also uncovered some interesting differences in the dynamics of PLTL and cPLTL, including: greater use of online resources by cPLTL students; lower incidence of off-task behavior by cPLTL students; and higher probability of cyber students discussing problem-solving process prior to answer-checking than their PLTL counterparts. Subsequent evaluation was performed to identify web conferencing platforms that could replicate the cPLTL experiences for a lower cost to students and institutions (McDaniel et al., 2013).

Second, asynchronous online “discussion” groups were created in which students used a Moodle to share their ideas about controversial healthcare issues, then create weekly summaries (Pittenger & LimBybliw, 2013). Students were tasked with taking turns as discussion leaders from week to week. Although the researchers claimed that the student collaborations were an example of PLTL, there were at least two crucial components of PLTL which were absent from the design: solving problems collaboratively (which is distinctly different than collaborative summarizing) and weekly training of dedicated peer leaders. I propose that summarizing is a lower-order cognitive activity, while solving problems is a higher-order activity, so collaborative summarizing cannot be equated with solving problems collaboratively. Pittenger & LimBybliw (2013) did not include an assessment of the impact of their implementation on students’ grades, as compared to previous versions of the course, but 96% of the students responded by survey that their leadership experience enhanced their learning.

2.1.8.3 PLTL in Laboratories

The third variant of the PLTL model consisted of implementing PLTL in a laboratory. The Center for Authentic Science Practice in Education (CASPiE) created a collaboration between research scientists and teaching faculty to generate research modules that could be accomplished in 6-8 week sessions, yet contribute to ongoing, publishable research efforts. Similarly, CASPiE team developed a network of Internet-accessible, research-quality instruments that the students could utilize for sample analysis. The PLTL pedagogy informed the integration of peer leaders as laboratory group mentors who fostered the students' development as scientists, including: explaining laboratory notebook techniques, discussing the evaluation and interpretation of data; brainstorming experimental design; reading scientific papers; considering scientific misconduct and ethics; preparing an abstract, presentation, or poster; familiarizing students with the peer review process; and asking students reflective questions each week to contextualize the laboratory techniques (Weaver et al., 2006, p. 127). Early findings from the CASPiE program indicate that this voluntary program appealed more to female students than male students (75% to 25%) and increased students' awareness of the nature of scientific research, while revealing the challenge of understanding primary literature.

Three other initiatives to integrate PLTL in a laboratory setting were closer to the traditional PLTL model as workshops were an integral part of a course (Foroudastan, 2009; McCreary, Golde, & Koeske, 2006; Shapiro et al., 2013). For example, PLTL was implemented in a multi-semester experimental vehicles program (Foroudastan, 2009), which has increased an engineering program's retention rate (95% for PLTL students). PLTL workshops were also implemented in several sections of general chemistry laboratory (McCreary et al., 2006), where undergraduate peer leaders facilitated groups of eight laboratory students, in lieu of faculty or a graduate teaching assistant. The peer leaders questioned pairs of students with prepared reflection prompts in addition to performing the normal supervisory/explanatory activities of a teaching assistant. Furthermore, special emphasis was placed on the development of four aspects of student development as scientists, including: understanding the organizational structure of an experiment; assessing the quality of measurements; explaining results; and applying lab skills to novel situations (McCreary et al., 2006, p. 805). After the researchers coded and statistically compared PLTL and non-PLTL students' laboratory reports, they reported that the non-PLTL students had comparable descriptions of data analysis and logical reasoning quality, but the PLTL students' laboratory reports were significantly better in several categories, including: descriptions of experimental procedure; awareness of factors for high quality; goals for preparing for lab; application to specific experiment; accuracy of chemistry; clarity of writing; and length of responses (McCreary et al., 2006, p. 808). Lastly, PLTL was implemented in a bioinformatics computer laboratory course, but the impact of the implementation was indeterminable since the data for instructor-led and peer-led sections were aggregated in the publication (Shapiro et al., 2013).

2.1.8.4 Peer-Led Guided Inquiry (PLGI)

Process-Oriented Guided Inquiry (PLGI), is a melding of PLTL with another social constructivist pedagogy: Process-Oriented Guided Inquiry Learning (POGIL). In PLGI, students collaboratively develop content understanding through a three-phase learning cycle, including: data collection (or exploration); concept invention; and application (Abraham & Renner, 1986; Farrell, Moog, & Spencer, 1999; Spencer, 1999). During the exploration phase, students examine a model, consisting of “pictures, tables, equations, graphs, or prose,” and try to extract patterns of meaning from it (Eberlein et al., 2008, p. 263). New terminology is introduced during the concept invention phase to connect students’ newly-identified pattern or phenomena with course content (Spencer, 1999). Students “extend and apply the concept to new situations, augmenting their understanding of the concept” during the application phase (Eberlein et al., 2008, p. 263).

PLGI peer leaders facilitate groups of approximately ten students during the PLGI activities and check for understanding. Like PLTL, PLGI is an integral part of the course, is implemented by replacing one of the 50-minute lectures with the collaborative learning experience, and includes weekly training of dedicated peer leaders (Lewis & Lewis, 2005). Although both PLTL and PLGI pedagogies are based on the social constructivist theoretical framework, PLGI students encounter concepts first in the workshops and then in lecture, while PLTL students are introduced to content in lecture first, then practice in workshops (Eberlein et al., 2008; Farrell et al., 1999).

Lewis & Lewis (2005) reported a significant correlation between PLGI workshop attendance and higher course and final exam grades (Lewis & Lewis, 2005). Additionally, PLGI students performed significantly higher on course and final exams than non-PLGI students, controlling for SAT scores, although the pedagogy has neutral differential effectiveness for students with different demographics (Lewis & Lewis, 2008). This result is particularly important because female or under-represented minority students could be disadvantaged by a collaborative learning pedagogy if gender- or ethnicity-based stereotypes influence student discussion dynamics (Cohen, 1997; Lewis & Lewis, 2008). Perhaps the rotating assignment of student roles that is an integral part of both POGIL and PLGI (Farrell et al., 1999) deters students from interacting in gender- or ethnicity-based roles within the groups, thus lifting any stereotype-based disadvantages for students.

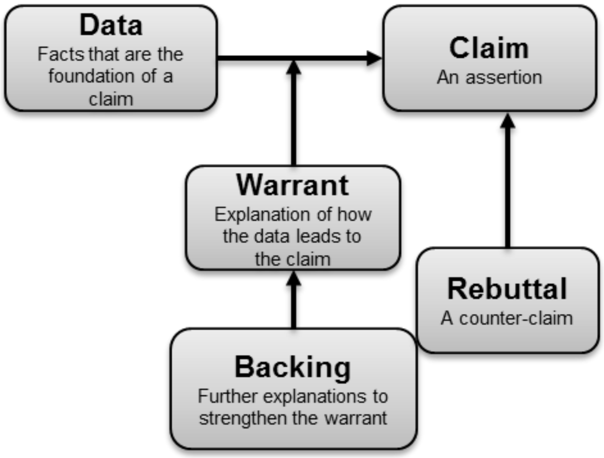


Figure 2-2 Toulmin’s Argumentation Pattern

Next, Kulatunga, Moog, & Lewis (2013) reported that students are more likely to elaborate on their reasoning when co-constructing arguments in a group than when making individual arguments. Their subsequent discourse analysis study of peer leader behavior on students’ TAP (Figure 2-2) (Toulmin, 1958) revealed that convergent questions, which require students’ synthesis of given information to create a response

(Hanson, 2006), lead students to produce higher-level arguments, while directed peer leader questions, which require students to state previously-provided information (Hanson, 2006), tended to lead students to merely provide an answer or claim (Kulatunga, Moog, & Lewis, 2014). Additionally, the researchers found that students could produce productive discourse without peer leader facilitation if the ChemActivity prompts were written to elicit data, warrants, and backing.

2.2 Cyber Peer-Led Team Learning

Cyber Peer-Led Team Learning (cPLTL) is a synchronous online version of PLTL that utilizes web conferencing software to enable a peer leader and up to eight students to work in a virtual conference room, while preserving the students' ability to see one another as well as classmates' work via the use of individual web cameras and document cameras (Mauser et al., 2011; McDaniel et al., 2013; Smith et al., 2014; Varma-Nelson & Banks, 2013). Additionally, web conferencing programs, such as Adobe Connect, provide a chat window for text-based communication and the ability to present applications on the students' desktop, such as drawing applications, files, and videos with their entire cPLTL group. Lastly, Adobe Connect's ability to record sessions enables both students and researchers constant access to workshop recordings. Brown and Kulikowich (2004) studied a statistics course that included students' sharing audiovisual data with remote classmates by using document cameras, but the PictureTele methodology did not include peer-facilitated collaborative group work. Similarly, the Open University of Hong Kong's Interwise synchronous e-learning system provided audio of classmates and visuals of shared files, but did not provide a webcam view of classmates nor feature collaborative problem-solving activities (Ng, 2007).

A recent study revealed that cPLTL general chemistry students were significantly more likely to discuss their problem-solving process, while their PLTL classmates were significantly more likely to check answers with one another before discussing problem-solving process. Therefore, cPLTL students were constructing their knowledge of general chemistry through social interactions to a greater extent than the PLTL student who were enrolled in the same course. Nevertheless, the mean course grades and performance on the American Chemical Society 2005 First-semester General Chemistry exam were comparable for the two groups (Smith et al., 2014). Further research is needed to identify any differences in PLTL and cPLTL students' problem-solving approaches and skills.

2.3 Comparison of Face-to-Face and Synchronous Online Learning

Multiple research studies have reported that student achievement is either comparable between blended and traditional courses (Aragon, Johnson, & Shaik, 2002; Block, Udermann, Felix, Reineke, & Murray, 2008; Du, 2011; Lightner & Lightner-Laws, 2013; Utts, Sommer, Acredolo, Maher, & Matthews, 2003; Ward, 2004) or sometimes better in online education that in traditional classroom settings (United States Department of Education, Office of Planning, Evaluation, 2009; Williams, Duray, & Reddy, 2006; Wilson & Allen, 2011). Anderson proposed in "Getting the Mix Right Again: An Updated and Theoretical Rationale for Interaction," that (2003, p. 2):

> …no single medium is superior to the others for supporting the educational experience. Deep and meaningful learning will occur if at

> least two of three forms of interaction are present: student–teacher; student–student; student–content.

A recent meta-analysis of online versus face-to-face course comparison research identified nine studies which included synchronous online communication (United States Department of Education, Office of Planning, Evaluation, 2009). However, these researchers did not identify studies in which the synchronous online experience included all the features of cPLTL (McDaniel et al., 2013; United States Department of Education, Office of Planning, Evaluation, 2009). The only published study that evaluated the impact of moving a collaborative learning pedagogical intervention for a science course from a face-to-face to an online setting was the recently-reported study of a hybrid general chemistry course in which students could elect to participate in either a face-to-face or online PLTL workshop component of their course. These researchers reported that discourse analysis revealed greater student emphasis on the process of solving problems in the online setting than in the face-to-face setting (Smith et al., 2014).

2.4 Curved-Arrow Formalism in Organic Chemistry

The roots of curved-arrow formalism (CAF), also known as electron-pushing formalism (EPF) and arrow-pushing formalism (Ferguson & Bodner, 2008), extend from a paper about the partial valences in butadiene by Kermack & Robinson (1922), who described the movement of electron density from areas of high electron density to areas of low electron density in the conjugated π system. Furthermore, these scientists defined the developing organic chemistry notation that a single bond dash meant a pair of electrons were shared between the connected atoms, while a double bond meant that two pairs of electrons where shared by the pair of atoms. Then, curved-arrows are “a symbolic device for keeping track of electron pairs in chemical reactions… as covalent bonds are formed and broken” (Bhattacharyya, 2013; Ferguson & Bodner, 2008, p. 102; Grossman, 2003; Scudder, 1992) and should be drawn such that “the tail of the curved-arrow indicating where an electron pair moves from and the head of the arrow where it moves to (Sykes, 1986, p. 19). ” Since the publication of Morrison & Boyd’s first organic chemistry textbook in 1959, ”Reaction mechanisms have become a mainstay of organic chemistry courses” (Bhattacharyya, 2013, p. 1282; Goldish, 1988; Morrison & Boyd, 1959; Wheeler & Wheeler, 1982). As written by Sykes (1986, p. 1):

> The chief advantage of a mechanistic approach, to the vast array of disparate information that makes up organic chemistry, is the way in which a relatively small number of guiding principles can be used, not only to explain and interrelate existing facts, but to forecast that outcome of changing the conditions under which already known reactions are carried out, and to foretell the products that may be expected from new ones.

Due to the centrality of CAF to organic chemistry, a wealth of CAF instructional strategy literature exists (Brisbois, 1992; Buncel & Wilson, 1987; Caserio, 1971; Friesen, 2008; Grossman, 2003; Miller & Solomon, 2000; Ryles, 1990; Scudder, 1992; Simpson, 1989b, 1988, 1989a; Sykes, 1986; Trost, 1991; Wentland, 1994). Likewise, the organic chemistry textbooks utilized at the institution in which this study occurred both provided explanations of the rules and assumptions of this formalism to the students (Carey, 2002; Klein, 2012).

Curved-arrow formalism is not only fundamental for communication and problem-solving among practicing organic chemists to predict the products of reactions (Bhattacharyya & Bodner, 2005; Grove, Cooper, & Rush, 2012), explain the regio- or stereo-chemistry of products, or rationalize reactive areas of starting materials, but also an alternative to copious rote memorization for organic chemistry students because mechanisms give students “students a logical means to predict products” (Straumanis & Ruder, 2009, p. 1389). Unfortunately, a number of studies of novices’ understanding of curved-arrow formalism have revealed that the symbolism of CAF has limited meaning for students (Anzovino & Bretz, 2015; Bhattacharyya & Bodner, 2005; Bhattacharyya, 2013; Cartrette & Dobberpuhl, 2009; Cooper et al, 2009; Grove, Cooper, & Rush, 2012).

One study reported that students only consider nucleophiles and electrophiles or Brønsted-Lowry acids and bases when prompted to do so (Cartrette & Dobberpuhl, 2009), although these identifications of compounds’ role in reactions are critical for ascertaining the areas of high and low electron density which lead to reactions occurring. Similarly, Anzovino & Bretz (2015) reported that students were unable to recognize nucleophile/electrophile or acid/base pairs unless shown a mechanism or product, which suggests that the students in their study were not utilizing mechanistic, or process-oriented, reasoning (Strickland, Kraft, & Bhattacharyya, 2010).

Grove, Cooper, and Rush (2012) reported that students neglected to show reaction mechanisms to predict products, even when instructed to do so. Bhattacharyya & Bodner

(2005) postulated that curved-arrows have no physical meaning for struggling organic chemistry students when they could reproduce the sequence of curved-arrows in reaction mechanisms, but not explain them. Therefore, the curved-arrows cannot rightly be called symbols or representations since they don't represent a "physical reality"(Bodner & Domin, 2000, p. 27; Domin & Bodner, 2012; Kozma, 2003). Likewise, Grove, Cooper, & Rush (2012) reported that only 60% of the students in their study showed mechanisms when instructed to do so and 15-20% added the arrows after predicting the product. Rather than curved-arrow formalism being a means for students to deduce products, therefore, supplying curved-arrows after predicting the product of a reaction was "decorating with arrows (Grove, Cooper, & Rush, 2012, p. 848)" or an "academic exercise" (Ferguson & Bodner, 2008, p. 109). Likewise, Rushton et al (2008) reported that students did not consider reaction mechanisms to be essential for the process of predicting products of reactions, although "students who do use mechanisms are more likely to succeed in more difficult tasks" (Grove, Cooper, & Cox, 2012, p. 853). There have been no studies to date to characterize either PLTL or online students' utilization of curved-arrow formalism to predict the products of organic chemistry reactions.

The following frequent student errors in curved-arrow formalism were reported in the literature (Grove, Cooper, & Rush, 2012; Scudder, 1992):

- An electron-deficient species attacks an electron-rich species
- An electron-rich species attacks an electron-rich species
- Drawing arrows which would result in the violation of the octet rule for carbon

- Arrows for multiple reaction steps are drawn at once
- Ignoring the pH of the medium, for example proposing an acid-based mechanism in a basic solvent

2.5 Bloom’s Taxonomy of Educational Objectives for the Cognitive Domain

Bloom’s Taxonomy of Educational Objectives are a classification system developed over several years by college examiners who wished to develop a theoretical framework to facilitate communication among examiners (Bloom, 1956, p. 4). The classification system categorizes the types of learning which occur in classrooms within three domains: cognitive, affective, and psychomotor (Bloom, 1956, p. 7). In 2001, Anderson & Krathwohl published an adaptation of Bloom’s Taxonomy of Educational Objectives: Cognitive Domain, in which the six cognitive domains were renamed as action verbs (Table 2-3) (Anderson & Krathwohl, 2001).

Table 2-3 Revised Bloom’s Taxonomy of Educational Objectives: Cognitive Domain *:* (Krathwohl, 2002, p. 4)

Category	**Definition**
Creating	Reorganizing elements into a new pattern or structure through generating, planning, or producing.
Evaluating	Making judgement based on criteria and standards through checking and critiquing
Analyzing	Breaking material or concepts into parts; determining how the parts relate to one another or to an overall structure or purpose
Applying	Performing a calculation or procedure to generate products
Understanding	Constructing meaning with activities like classifying, summarizing, and comparing
Remembering	Recognizing or recalling definitions, facts, or lists from memory

The Revised Bloom's Taxonomy for Educational Objectives: Cognitive Domain has been utilized as an analytic framework for coding dialogue in several studies (Figure 2-3). Hou (2011), who examined students' asynchronous dialogue by coding forum messages, found that the interchanges included infrequent Apply, Evaluate, and Create cognitive domain examples. A similar examination of social media exchanges in an adult continuing education course also found that discourse revealing higher cognitive order thinking, such as Analyze, Evaluate, or Create, was also absent (Lin, Hou, Wang, & Chang, 2013). Likewise, Valcke et al (2009) reported that 95% of coded online transcripts fell into the first four levels of Revised Bloom's Taxonomy for Educational Objectives: Cognitive Domain. Similarly, Meyer (2004) reported that 75% of the online interchanges in a graduate-level online education course were categorized in the first four levels of the taxonomy. Finally, Christian & Talanquer (2012b) reported that over 70% of the student dialogue they classified in their study of face-to-face self-initiated science study groups were lower cognitive order.

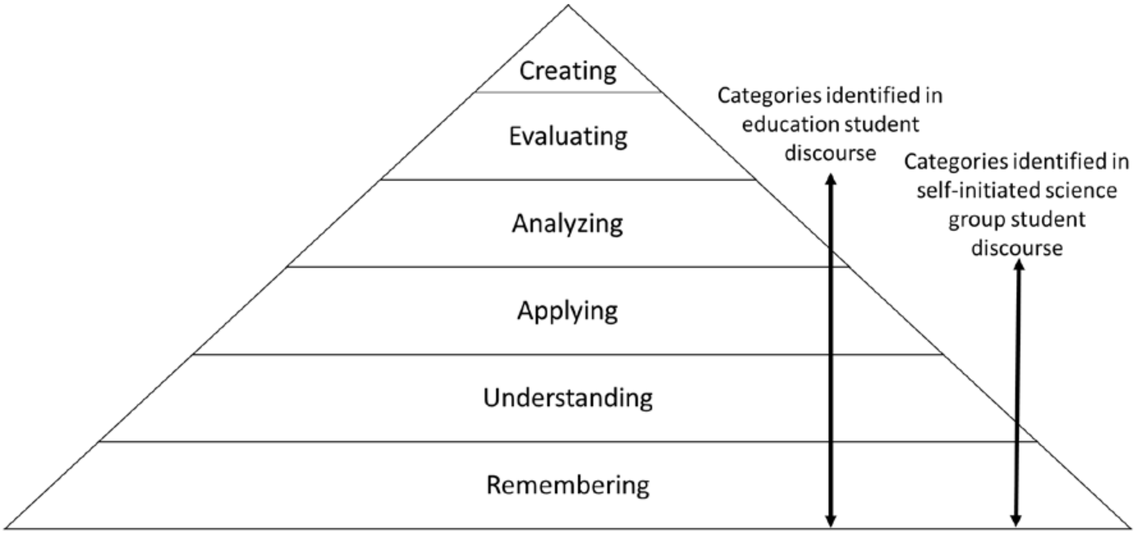


Figure 2-3 Revised Bloom's Taxonomy of Educational Objectives: Cognitive Domain

CHAPTER 3. METHODOLOGY

3.1 Research Design

This study employed a mixed methods design, which is a process for “research in which the investigator collects and analyzes data, integrates the findings, and draws inferences using both qualitative and quantitative approaches or methods in a single study”(Tashakkori & Creswell, 2007, p. 4). The rationale for combining qualitative and quantitative analyses into this study was that the integration of information from the two types of inquiry will provide more insights regarding both the content mastery of students and the experiences of students and peer leaders in the PLTL/cPLTL settings than either type of analysis could provide in isolation (Creswell, 2012; Jick, 1979). Additionally, the comparing and contrasting of data obtained from various sources and data collection methods, called triangulation, increases the accuracy and reliability of findings (Creswell, 2012, p. 259).

Qualitative research is a means of understanding interpersonal interactions and “how people interpret their experiences” (Merriam, 2009) through the systematic analysis of observations, artifacts, and verbalizations. Although qualitative inquiry was originally developed by anthropologists and sociologists, this methodology is now widely utilized in psychology and education research (Creswell, 2012; Merriam, 2009; Mertens, 2010; Patton, 1990). As a qualitative researcher, I used an inductive approach to identify, analyze, and report themes which emerge from the data (Braun & Clarke, 2006). Quantitative research employs statistical analyses to identify the relationship between variables that have been defined to characterize participants' characteristics (gender, ethnicity, test score) or attitudes (survey responses on a Likert scale) (Creswell, 2012). In contrast to the inductive approach of qualitative research, quantitative research is a deductive exercise that relies substantially on literature basis to justify "the need for the research problem" and suggest "potential purposes and research questions for the study" (Creswell, 2012, p. 13).

This study employed a convergent parallel mixed methods design (Figure 3-1), a model in which I collected both qualitative and quantitative data at approximately the same time, performed the analyses of the two types of data independently, and, finally, integrated the information to develop an overall interpretation of the results of the study. Any contradictions in the information developed from the qualitative and quantitative analyses were presented with an explanation for which findings should be given greater weight in the interpretation phase (Creswell, 2014).

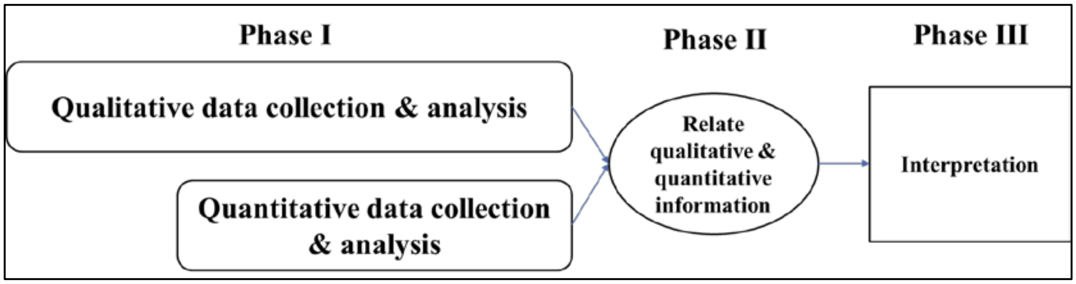


Figure 3-1 Convergent parallel mixed methods study design

3.2 Description of PLTL Implementation in First-Semester Organic Chemistry at the Institution

At Indiana University-Purdue University Indianapolis (IUPUI), a research-intensive Midwestern university, the organic chemistry lecture courses are a two-semester series, enrolling approximately 400 students in the first-semester sections annually. The laboratory courses are independent of the lecture courses. Prior to 2010, the first-semester organic chemistry course was taught in a traditional lecture fashion, in which students attended three 50-minute of lecture presented by the course instructor without an accompanying recitation other supplementary instruction program. From Spring 2010 through Fall 2013, the first-semester lecture course was expanded to include one 75-minute PLTL workshop in addition to the two 75-minute lectures to per week. There was also optional help available for students from the course instructors and the Chemistry Resource Center. The multiple lecture sections each Fall were treated as a single course, having common workshop problem sets, lecture slides, and final exams. The problem sets for each PLTL workshop were collaboratively developed by the workshop coordinator and the lecturers. Two different textbooks were used by the institution in recent years: Organic Chemistry by Carey (2002) from Fall 2008 through Fall 2011 and Organic Chemistry by Klein (2012) from Spring 2012 through Fall 2014.

PLTL workshops were implemented in this institution’s first-semester organic chemistry course in 2010, although the recommended student-to-peer leader ratio was realized in 2011. The percentage of students attending in more than three-quarters of theavailable workshops per semester rose from 94% in Fall 2010 to 97% by Fall 2013 (Figure 3-2), indicating robust student participation rate in the program.

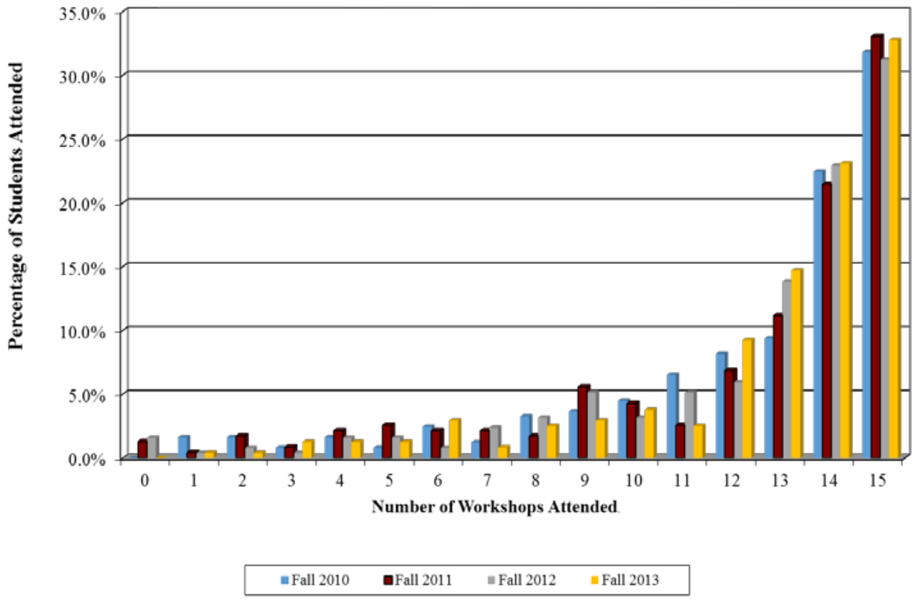


Figure 3-2 Histogram of PLTL organic chemistry workshop series attendance

Since implementing PLTL workshops in the course, the incidence of students earning a D, F, or withdrawing from the course (DFW rate) has dropped from nearly 30% to 10% (Table 3-1). A Mann-Whitney U test indicated that there was statistically significant difference in the distribution of course grades (Figure 3-3) since implementing the PLTL workshops ($p<0.05$). Specifically, the frequencies of students earning C, D, or W grades have decreased, while the frequencies of A and B grades have increased. The institution began utilizing American Chemical Society (ACS) First-Semester Organic Chemistry exams as final exams for the course in Fall 2009. ANCOVA analysis revealed that there was a statistically significant improvement in students' ACS First-Semester Organic Chemistry Exam Z scores (versions 2006 and 2010) after PLTL workshops were implemented, regardless of gender or ethnicity ($p<0.05$, $F = 8.31$, $df = 1$), although the effect size was small (partial eta squared = 0.01). Since the course instructors have utilized different styles of semester exams, dropped each students' lowest semester exam from the course grade calculations, and employed different grade scales during the time period, the statistically significant improvement of students' performance on the nationally-normed ACS First-Semester Organic Chemistry Exams is more compelling evidence of the academic impact of the PLTL program than evaluation of course grade differences, although both indicate a statistically positive impact due to the program.

Table 3-1 Summary of DFW rates by semester

Semester	**DFW Rate**	**N**	**Comments**
Fall 2008	29.7%	236	No ACS exam; no PLTL workshops
Fall 2009	19%	279	ACS exam; no PLTL workshops
Fall 2010	15%	245	PLTL workshops with 15:1 student to peer leader ratio
Fall 2011	16%	233	PLTL workshops with 8-10:1 student to peer leader ratio
Fall 2012	15%	253	PLTL workshops with 8-10:1 student to peer leader ratio; new textbook
Fall 2013	11%	238	PLTL workshops with 8-10:1 student to peer leader ratio

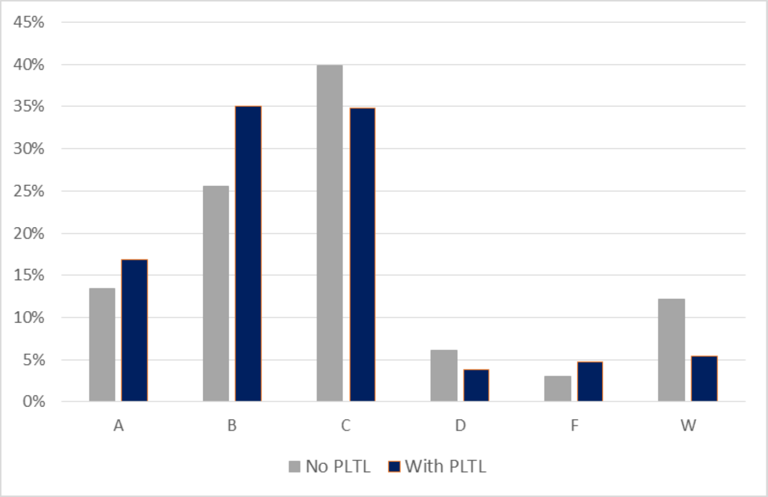


Figure 3-3 Distribution of Organic Chemistry Course Grades with versus without PLTL

(Fall semesters 2009-2014)

3.3 Description of cPLTL Implementation in First-Semester Organic Chemistry

By Fall 2013, the PLTL workshop program was considered a stable environment for both implementing cPLTL and performing a robust research study. Institutional support, including increased funding for peer leaders and longer classroom reservations, allowed the extension of PLTL workshop duration to 1 hour 50 minutes to align with the recommended PLTL model (Gafney & Varma-Nelson, 2008, p. 12) beginning in Spring 2014. Moreover, document cameras were purchased to enable the implementation and evaluation of organic chemistry cPLTL without incurring additional costs for students. The PLTL sections of the workshop series consisted of approximately 30 students, subdivided into three groups of 8-10 students, who were each guided by a trained undergraduate peer leader to work collaboratively on problem sets designed both to challenge the students' conceptual understanding of the course content and to develop the problem-solving skills of the students. Meanwhile, the cPLTL sections of the workshop series consisted of approximately 8 students facilitated by a trained undergraduate peer leader to collaboratively solve problems, using the same workshop materials in an Adobe Connect virtual conference room. cPLTL students were trained to use the document cameras, optimize their computer settings, and navigate the components of the Adobe Connect software during *Workshop Zero*, a content-free workshop prior to the first organic chemistry workshop. Since the emphasis was on problem-solving, no answer keys were provided to either PLTL nor cPLTL students (Gosser et al., 2001). On-time preparedness of the students was encouraged through administration of multiple choice workshop preparedness quizzes during the first ten minutes of each PLTL/cPLTL workshop.

3.4 Participants

3.4.1 Students

Approximately 400 undergraduate students were enrolled in the first-semester organic chemistry course during Spring 2014 and Fall 2014. The students from both semesters were pooled as a single sample population because Chi Square analyses of Spring and Fall 2014 students' gender, ethnicity, and previous chemistry GPA were not significantly different, although significantly more students over age 23 were enrolled in the spring semester (36% vs. 25%). The subjects of the study included a subset of the population who enrolled in the comparison group workshop sections, four pairs of face-to-face and online sections which were led by the same peer leader (1 pair of comparison groups for Spring 2014 and 3 pairs of comparison groups for Fall 2014). Subjects self-selected into either a PLTL or a cPLTL section. Subjects' demographic and previous chemistry course grades were provided by the university's Information Management and Institutional Research (IMIR) Office via a secure online file transfer process, as approved by the Institutional Review Board, in order to ensure the confidentiality of the subjects. The PLTL comparison group subject population consisted of 40 students and featured the following demographic information: 35% were over 23 years old; 45% were female; 40% were from underrepresented minority groups; and mean previous chemistry GPA of 2.88. The cPLTL subject population consisted of 24 students and featured the following demographic information: 38% were over 23 years old; 60% were female; 32% were from underrepresented minority groups; and mean previous chemistry GPA of 2.79. Chi Square analyses for each of the demographic characteristics indicated that the subject populations were comparable. The overall PLTL population's demographics included: 29% over 23 years old; 58% female; 32% underrepresented minorities; and mean previous chemistry GPA of 2.89. A maximum diversity sampling (Patton, 2002) approach was utilized for the selection of interviewees, considering gender and ethnicity. When I asked for volunteers to be interviewed, generally two students per peer leader per setting volunteered. The total of 19 interviewees was consistent with Creswell's suggested sample size for a grounded theory study (Creswell, 2002). I interviewed all participants during the week preceding the final exam in order for the students to have the maximum familiarity with the course material.

3.4.2 Peer Leaders

Peer leaders were students who had recently completed the first-semester organic chemistry lecture course successfully. The peer leaders were selected based on demonstration of good leadership, communication, and teamwork skills, recommendations from current peer leaders, and application essays which included a communicated desire to help others learn organic chemistry. The peer leaders' gender (52% male; 48% female) and ethnicity (63% Caucasian; 8% African American; 23% Asian; 5% Hispanic) consisted of a slightly higher proportion of female or underrepresented minority individuals than the overall IUPUI School of Science student demographics for 2010-2014 (56% male; 44% female; 76% Caucasian; 12% African

American; 4% Asian; 5% Hispanic) (Institutional Research Office). The peer leaders' training, which is grounded in discipline-based education research, includes topics such as: the content emphasized by each week's problem set; social constructivism; student-centered learning techniques; methods to effectively facilitate collaborative problem-solving; and strategies to increase student engagement. Each cPLTL peer leader was selected based on the additional criteria of a desire to lead in the online setting. Pairs of sections, one face-to-face and one online, led by a single peer leader during a semester, henceforth dubbed "comparison groups", were instituted in order to control for peer leader effect; there were four comparison groups: one comparison group in Spring 2014 and three comparison groups in Fall 2014. All peer leaders earned a salary for their participation in the weekly training meeting and facilitating two workshop sessions per week.

3.5 Quantitative Data Collection and Analysis

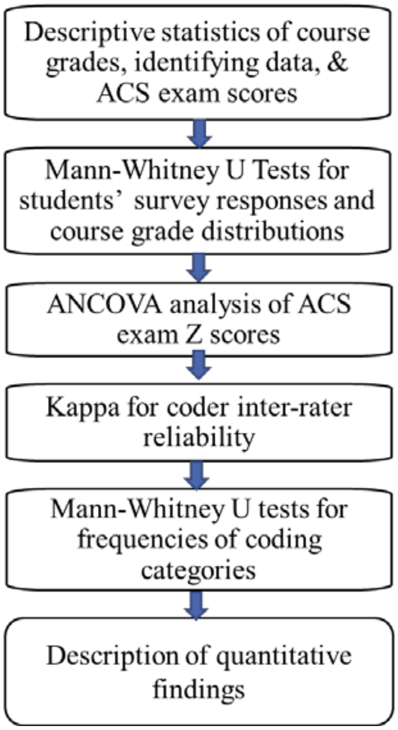


Figure 3-4 Quantitative data collection & analysis

3.5.1 Quantitative Data Collection

The quantitative data collection (Figure 3-4) consisted of student surveys administered to all students in the first-semester organic course during the semester, followed by the post-semester collection of student course grades, identifying data (gender, ethnicity, and previous chemistry GPA), an American Chemical Society (ACS) Organic Chemistry First-Semester Final Exam (version 2010) scores from the course instructors and the institution's Information Management and Institutional Research Office upon approval of the Institutional Review Board. ACS First-Semester Organic Chemistry Exam (final exam) scores were converted to Z scores in order to compare results across exam versions (Chan & Bauer, 2015).

3.5.2 Variables in Quantitative Analysis

Table 3-2 Variables included in quantitative analysis

Independent Variables	**Dependent Variables**
Gender Ethnicity Previous chemistry GPA Setting Survey responses	Organic Chemistry Course grade ACS organic chemistry final exam score

The independent variables (Table 3-2) gender, ethnicity, and setting were assigned nominal values (Male = 0, Female = 1). Student's survey responses and organic chemistry course grades were ordinal values, the first on a Likert scale and the second on a four-point grade scale. Previous chemistry grade point average (GPA) was a continuous variable that was calculated by averaging the numerical equivalent of students' prior chemistry course letter grades on the standard four-point grade scale. Lastly, and American Chemical Society (ACS) first-semester organic chemistry final exam scores were continuous variables that were converted to Z scores since two versions of the ACS exam were utilized by the department during the years prior to PLTL implementation in the course through the study period (Chan & Bauer, 2015).

3.5.3 Quantitative Data Analysis

First, the DFW rate, and distribution of course grades were calculated for each study population as well as for the total population. Next, all quantitative data were collated in Excel spreadsheets, and then transferred to databases in Statistical Package for the Social Sciences (SPSS), version 22 for all statistical analyses. Descriptive statistics were calculated from the students' survey responses, ethnicity, gender, previous chemistry course GPAs, and ACS final exam scores. Mann-Whitney U Tests were performed to compare both students' survey responses, DFW rates, and course grade distributions from the two settings instead of *t* tests since the sample sizes were not large enough to be normally-distributed (Rosner & Grove, 1999). Then, the analysis of covariance (ANCOVA) assumptions (Table 3-3) (Lomax & Hahs-Vaughn, 2012) of independence, homogeneity of variance, normality, linearity, fixed independent variable, independence of the covariate and independent variable, covariate measured without error, and homogeneity of slopes were checked before performing the ANCOVA analysis to examine the relationship between ethnicity, gender, and setting with ACS final exam Z scores, controlling for previous chemistry GPA.

Table 3-3 Assumptions and evidence to examine for a one-factor ANCOVA (Lomax & Hahs-Vaughn, 2012, pp. 22, 151)

Assumption	**Evidence to Examine**
Independence	Scatterplot of residuals by group; check students are not included in two workshop sections
Homogeneity of variance	Formal test of equal variances (Levene's test)
Normality	Graphs of residuals by group; skewness and kurtosis of residuals
Linearity	Assess the best fit line of a scatterplot of dependent and independent variable (repeat for each independent variable)
Fixed-effect	Levels of the independent variable are set by the researcher
Covariate and factor are independent	One-way ANCOVA to confirm the two populations are not significantly different on the covariate (previous chemistry GPA)
Covariate measured without error	SPSS calculation of Cronbach's alpha
Homogeneity of slopes	The slope of the regression line between the dependent variable and the covariate (previous chemistry GPA) is the same for each category of the independent variable (i.e. gender, ethnicity, setting).

3.5.4 Reliability & Validity of the Quantitative Data Collection & Analysis

In order to affirm the reliability and validity of the student survey instrument, while minimizing test fatigue for the participants, I calculated Cronbach’s alpha as the reliability coefficient (Creswell, 2012; Mertens, 2010) as the means to “compare responses within a single administration of an instrument” (Mertens, 2010, p. 382). Furthermore, the reliability and validity of the statistical analyses were fortified through the testing of relevant assumptions, determination of effect sizes, and use of appropriate follow-up tests (Lomax & Hahs-Vaughn, 2012).

3.6 Qualitative Data Collection

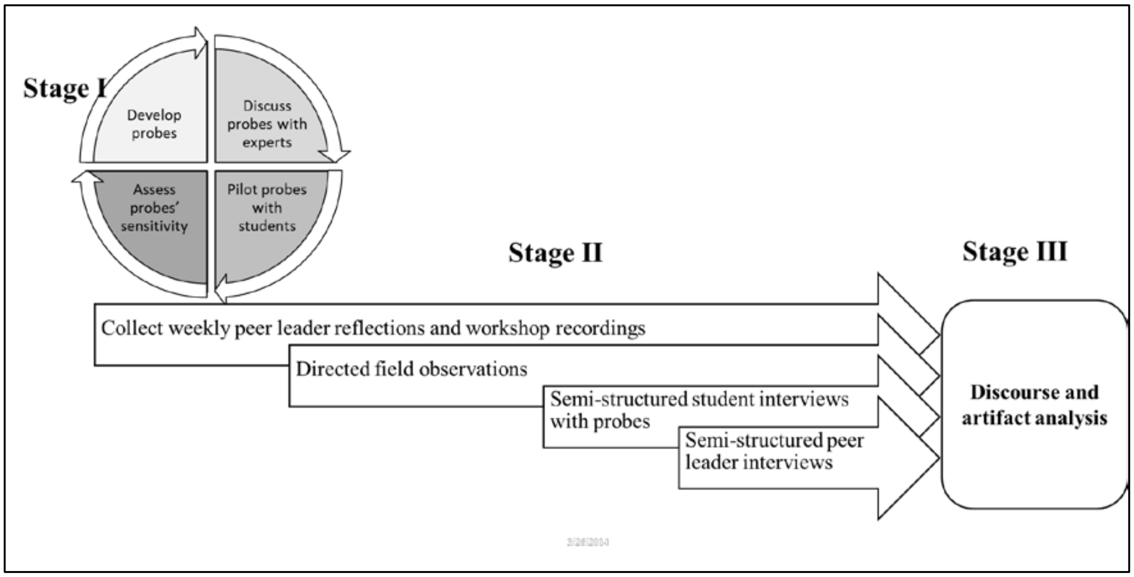
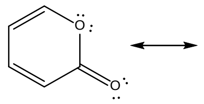


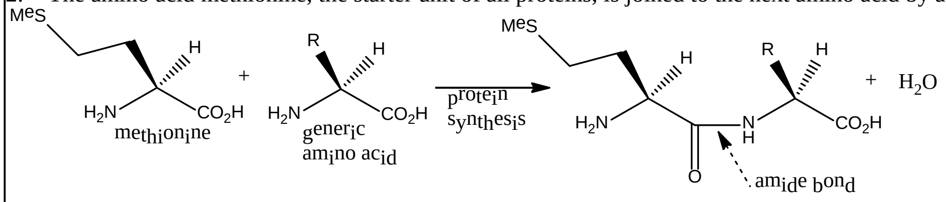
Figure 3-5 Stages of qualitative data collection & analysis

During stage one of the qualitative data collection (Figure 3-4), I developed probes to assess students’ utilization of curved-arrow formalism. The four probes (Figure 3-5) were designed to progress in difficulty as well as provide a diminishing level of scaffolding from one question to the next. For example, the first probe required students to draw curved-arrows to show the movement of electron density between atoms to describe resonance structures of a molecule. The second probe required students to draw curved-arrows which would be consistent with the given intermediates of a peptide bond formation, a typical workshop problem that would seem particularly relevant for the large proportion of pre-professional students who enroll in first-semester organic chemistry. The third probe required students to identify a substitution reaction and draw the mechanism of the reaction. Lastly, the fourth probe required students to leverage their understanding of curved-arrow formalism to draw a plausible mechanism for an unknown reaction that was based on reactions that they had practiced in class and PLTL/cPLTL workshops. I discussed the probes with the course instructors and other subject matter experts. Based on their feedback, I modified the probes before administering them to first-semester organic chemistry students. Using a think-aloud protocol (Ericsson & Simon, 1984) as well as audio & video recording to capture what was being said as the student drew (Cooper, Corley, & Underwood, 2013; Harle & Towns, 2012; Linenberger & Bretz, 2012), I analyzed the pilot study subjects' responses to assess the probes' sensitivity to provide gradations of subject mastery of curved-arrow formalism components. Analysis of the pilot study subjects' responses revealed a range of responses to each probe, so the probes were unchanged for the remaining student interviews of the study.

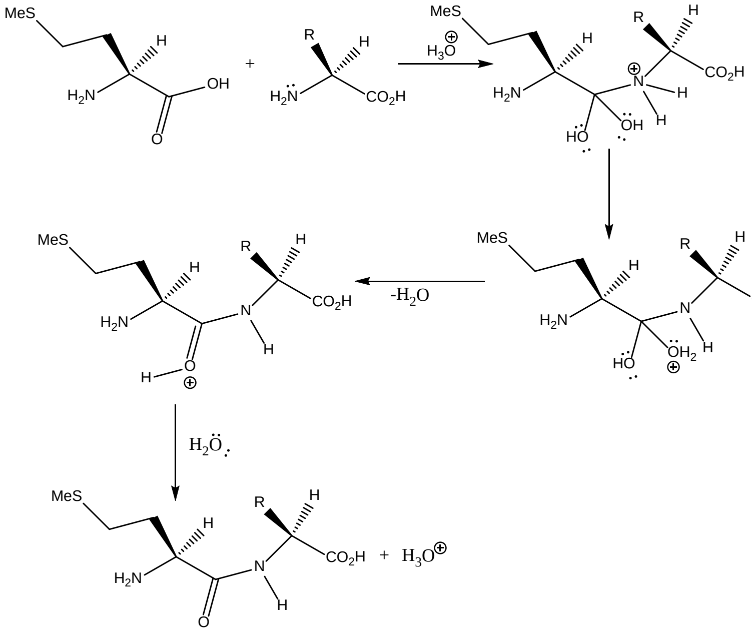
1. Using curved arrow formalism to express the movement of electrons, generate at least three resonance structures of pyrone.



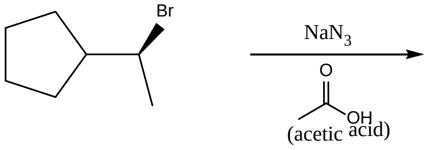
2. The amino acid methionine, the starter unit of all proteins, is joined to the next amino acid by an amide bond.



Draw curved arrows for each step of the following mechanism:



3. Identify the reaction type, draw the mechanism, and identify the final product(s) of the given reaction, noting the stereochemistry of the product.



4. Propose a plausible mechanism for the following transformation.

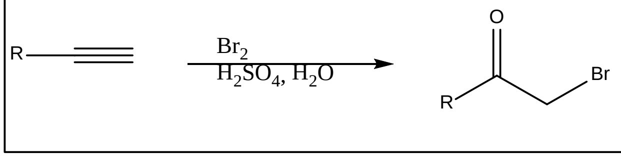


Figure 3-6 Curved-arrow formalism interview probes

During Spring and Fall 2014, subjects from the comparison groups were interviewed to share their PLTL/cPLTL experiences in addition to solving the four finalized probes (Figure 3-6), using a think-aloud protocol (Ericsson & Simon, 1984). The student interviews were audio & video-taped, then the dialogue was transcribed verbatim. I wrote detailed summaries of students' responses to and interactions with the probes by analyzing the audiovisual data simultaneously with the subjects' written responses to the probes. Keys for the four interview probes are provided in Figures 3-7 through 3-10.

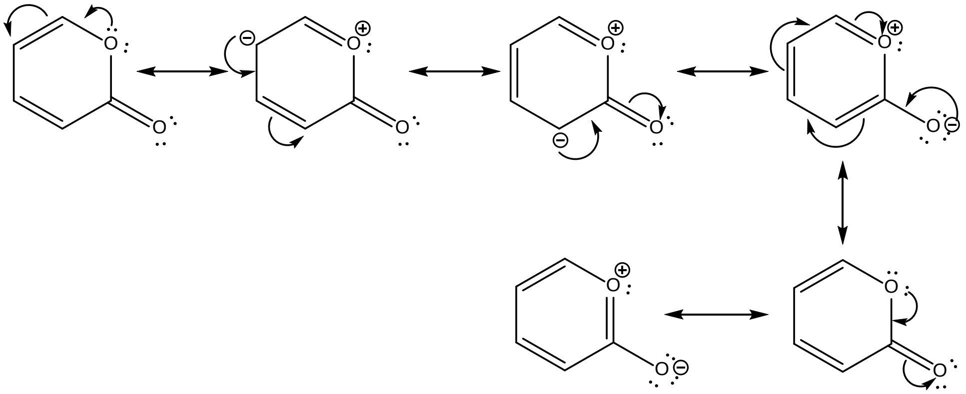


Figure 3-7 Key for interview probe number one

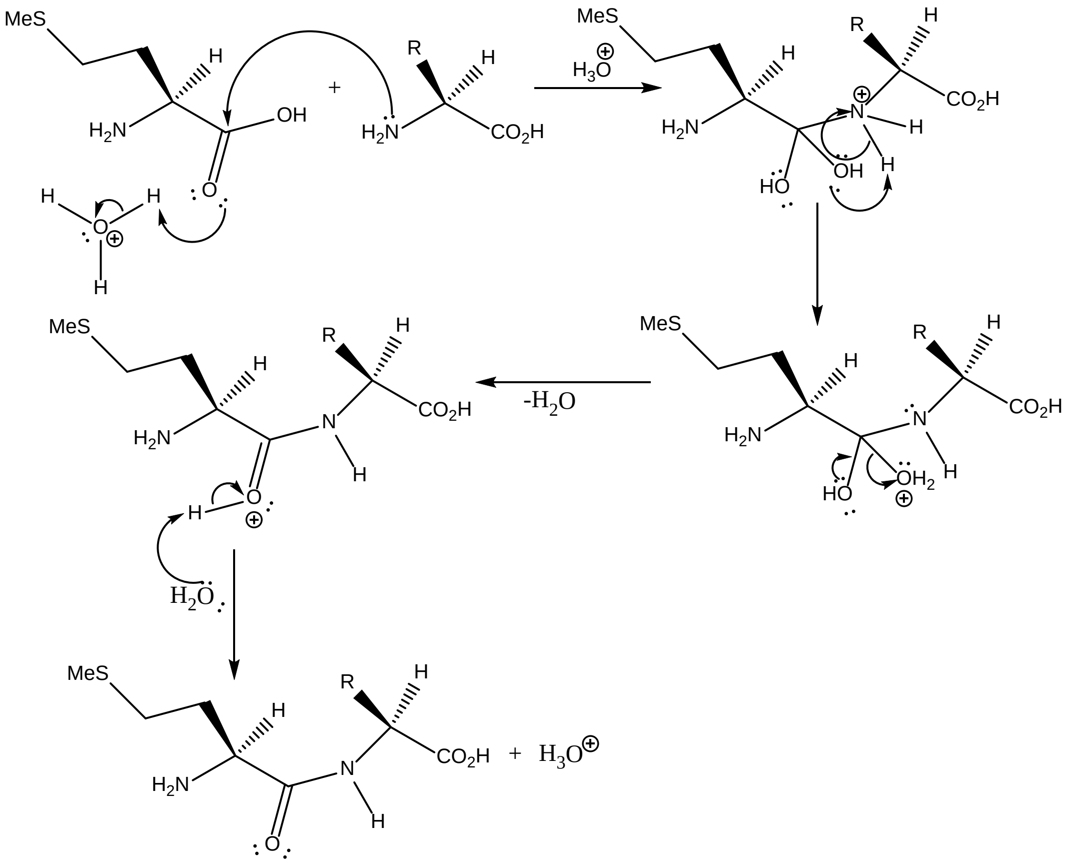


Figure 3-8 Key for interview probe number two

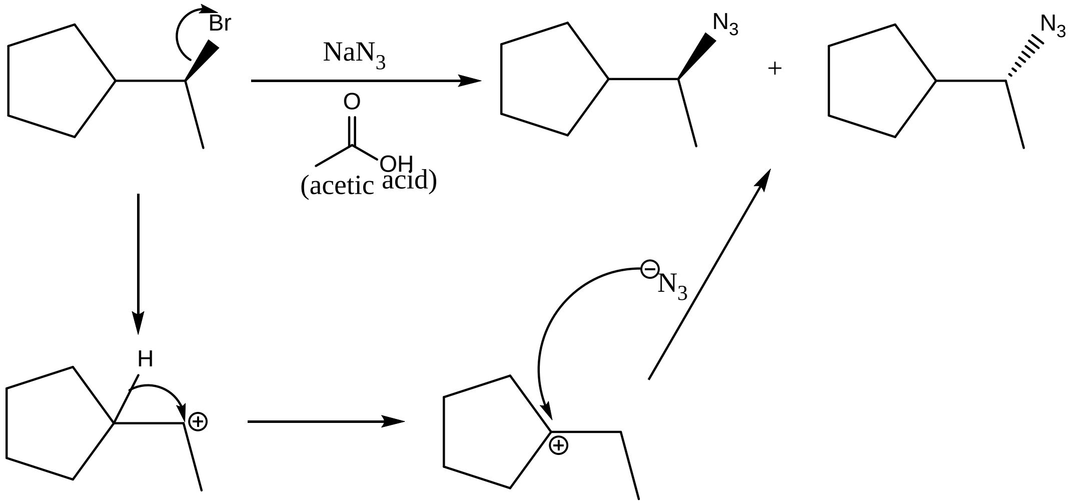


Figure 3-9 Key for interview probe number three

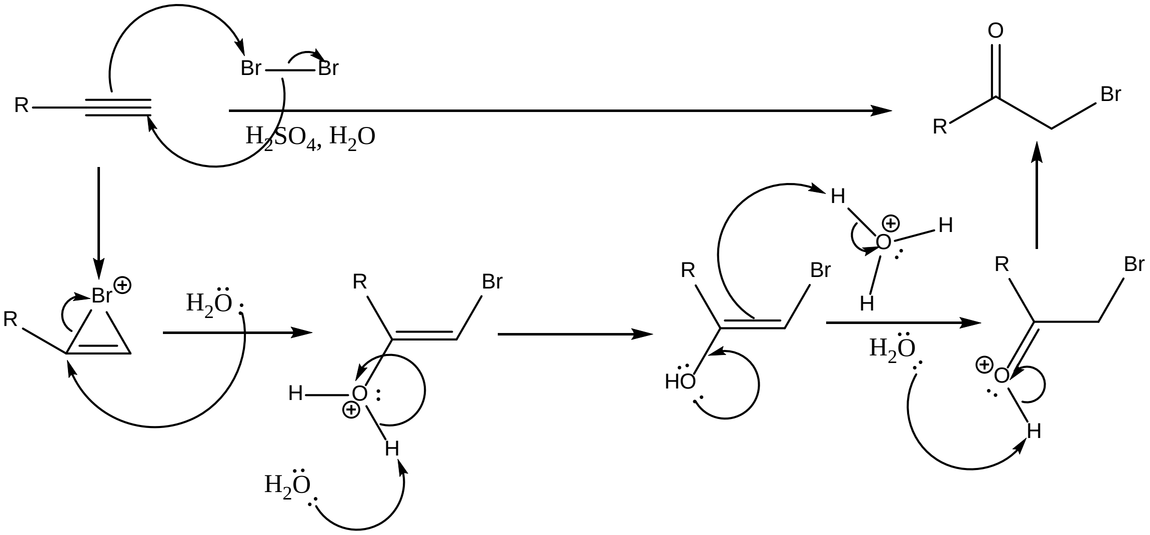


Figure 3-10 Key for interview probe number four

During the second stage of the study, I collected weekly peer leader reflections with WIKI page in Oncourse, the online course management system, throughout each semester of the study. Weekly reflection questions included:

- *Were there any quiz or workshop questions that seemed unclear to the students?*
- *Which workshop question was easiest for the students to answer?*
- *Which workshop question(s) were challenging for the students? Why?*
- *What common misconceptions*[1] *did you encounter?*
- *How did you incorporate what you learned from the professional development article we discussed during the training meeting? What were the outcomes?*

During the last week of the semester, semi-structured interviews were conducted with both peer leaders to learn their perceptions about their experiences in the two settings at the end of each semester and students from the study comparison groups to

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[1] "Common misconceptions" refers to the content-specific misconceptions about which the peer leaders were informed during that week's training meeting.

learn about their perceptions of their experiences in their setting. Audio recordings of student/peer leader interactions and directed field observations were obtained from comparison groups throughout the semester for triangulation purposes (3-4 observations per comparison group per semester). Lastly, audio recordings of workshop sessions and interviews were transcribed.

3.6.1 Qualitative Data Analysis

Debate exists in the literature regarding whether “grounded theory” and “thematic analysis” are distinct methodologies or merely different titles for the same process (Attride-Stirling, 2014; Braun & Clarke, 2006). Grounded theory, an inductive methodology developed by Glaser and Strauss (1967), is a process by which theoretical concepts and hypotheses “emerge” from the researcher’s review of the data, then the theories are grounded in the qualitative data, such as participant interview transcripts (Braun & Clarke, 2006; Richardson, 1999). Attride-Stirling (2014) suggests that the theoretical foundation for grounded theory can be traced to classical argumentation theory (Toulmin, 1958) in which the terms claim, warrant, and backing have been renamed as grounded theory’s concepts, categories, and propositions (Strauss & Corbin, 1990). I would also draw the reader’s attention that the roots of Toulmin’s argumentation scheme are also reflected in the thematic network developed through thematic analysis: basic theme; organizing theme; and global theme (Attride-Stirling, 2014) (Figure 3-11).

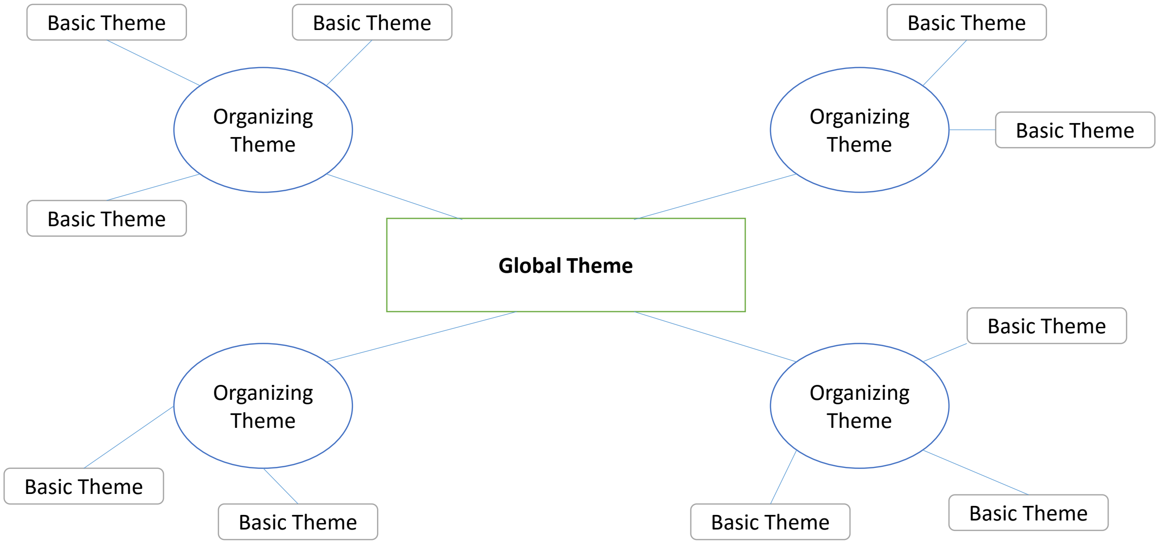

Figure 3-11 Structure of a thematic network (Attride-Stirling, 2014, p. 388)

After the interviews were conducted, I utilized a six-phase approach to qualitative analysis (Table 3-2) described as thematic analysis by Braun & Clarke (2006), but aligned with the description of the grounded theory process utilized by Cooper, Corley, and Underwood (2013). After familiarizing with the complete qualitative data set, I generated initial codes for both workshop dynamics and curved-arrow formalism utilization by using open coding (Braun & Clarke, 2006; Strauss & Corbin, 1990). Codes were collated, reviewed, defined, and revised into basic themes and organizing themes in a constant comparison process (Attride-Stirling, 2014; Braun & Clarke, 2006; Strauss & Corbin, 1990). Furthermore, the student discourse in workshop transcripts were coded with Revised Bloom's Taxonomy of Educational Objectives: Cognitive Domain (Anderson & Krathwohl, 2001; Bloom, 1956) and Toulmin's Argumentation Scheme (Toulmin, 1958). Likewise, the workshop transcripts and student interview transcripts were coded for emergent themes, Revised Bloom's Taxonomy of Educational Objectives:

Cognitive Domain, and the curved-arrow formalism analytic framework by a second coder, an undergraduate research assistant. In the case of me coding a passage that the research assistant did not code initially, I provided the research assistant a spreadsheet of filename and line numbers of passages to consider. Then, the research assistant responded with identification of emergent theme, Revised Bloom's Taxonomy of Educational Objectives: Cognitive Domain, or curved-arrow formalism analytic framework categories that pertained to the given passages. Additionally, a third coder, a fifth year doctoral candidate with more than two decades of industry experience as a synthetic organic chemist, was asked to code both an interview transcript and artifacts for curved-arrow formalism of a randomly-selected participant as well as a random workshop transcript for Revised Bloom's Taxonomy of Educational Objectives: Cognitive Domain.

Table 3-4 Phases of thematic analysis (Braun & Clarke, 2006, p. 87)

	Phase	**Description of the process**
1	Familiarizing yourself with your data	Transcribing data (if necessary), reading and re-reading the data, noting initial ideas
2	Generating initial codes	Coding interesting features of the data in a systematic fashion across the entire data set, and then collating data relevant to each code
3	Searching for themes	Collating codes into potential themes
4	Reviewing the themes	Checking if all the themes work in relation to the coded extracts (Level 1) and the entire data set (Level 2), and then generating a thematic 'map' of the analysis
5	Defining and naming themes	Generating clear definitions and names for each theme
6	Producing the report	Selection of vivid, compelling extract examples, final analysis of selected extracts, relating back to the research questions and the literature, producing a scholarly report of the analysis

The frequencies of the workshop dynamics and curved-arrow formalism emergent theme analytic frameworks by setting were compared using Mann-Whitney U Tests, the nonparametric equivalent of *t* tests, to identify differences between the two settings. I selected compelling examples for analysis, relating them to the research questions and literature, in order to summarize the qualitative findings. Finally, I compared and contrasted the Global and Organizing themes to the findings from the quantitative data analysis during the correlation and interpretation stages of this convergent parallel mixed methods research study.

3.6.2 Reliability & Validity of the Qualitative Data Collection & Analysis

Three processes were an integral part of this study to ensure its reliability and validity, including: calculation of inter-rater reliability; triangulation, and member checking (Creswell, 2012; Jick, 1979; Mertens, 2010). Cohen's Kappa was calculated for the coding of each of the analytic frameworks to measure inter-rater reliability between two coders (Finn & Campisi, 2015, p. 165), and then Light's Kappa was calculated to assess the inter-rater reliability among three coders by calculating the average of the pairwise kappas since SPSS version 23 isn't capable of calculating an inter-rater reliability statistic for three coders (Hallgren, 2012). The process of triangulation entailed corroborating evidence from different individuals (i.e. a student and a peer leader), types of data (i.e. observational field notes and interviews), and methods of data collection (i.e. peer leader reflections and interviews) to demonstrate the credibility of each proposed theme. Similarly, member checking was performed during the interpretation of findings phase of the research study in order to provide students and peer leaders an opportunity to comment on both the accuracy of report and the fairness of interpretations.

3.7 Advantages & Limitations of the Convergent Parallel Mixed Methods Design

The strength of a convergent parallel mixed methods design is the combined advantages of the generalizability from the quantitative analysis and the information-rich description of setting and participant experiences from qualitative inquiry. The potential limitation of this research design were small sample sizes (Creswell, 2012).

3.8 Research Permission & Ethical Considerations

Ethical issues will be addressed at each phase of this research study. Before launching the full study, permission for conducting the research was obtained from the Institutional Review Board (IRB). The application for IRB approval included the following information: principal investigator (Pratibha Varma-Nelson); Co-PI (me); affiliated research staff, such as a research assistant; project title and type; rationale for inclusion of students’ gender, ethnicity, and previous chemistry GPA; number of participants; criteria for participant inclusion; study information sheets for students and peer leaders; informed consent forms; semi-structured interview protocols; directed field observation protocol; student perception survey; descriptions of data collection protocols; and data management plan.

During the qualitative data analysis phase of the research study, the six-phase thematic analysis process was employed to ensure thorough analysis of all data. Any contrary findings were reported as well as discussed for implications to overall findings. Aliases were assigned to all participants to protect their identity for reporting purposes. Participants provided feedback to affirm the accuracy of their interview transcripts. Similarly, descriptive statistics, checking of assumptions, and appropriate statistical follow-up tests were performed and reported to ensure the reliability and validity of the quantitative analysis (Creswell, 2014; Ivankova, 2006).

3.9 Role of the Researcher and Research Bias

My role in this research project can be classified as a variation of "observer as participant", as defined by Gold (1958) and Merriam (2009). According to Merriam (2009, p. 124):

> The researcher's observer activities are known to the group; participation in the group is definitely secondary to the role of information gatherer. Using this method, the researcher may have access to many people and a wide range of information, but the level of information revealed is controlled by the group members being investigated.

Gold proposed that the "observer as participant" role was appropriate for studies in which the observer would visit the setting only a single time, but I suggest that as an "observer as participant," I was protected from "going native" (Gold, 1958, p. 221) despite several field observations of each section through both the performance of directed field observations and utilization of semi-structured interview protocols. Thus, I was an observer in the sense that I generated field notes during directed field observations and interviews, while I performed as a participant in the sense that I was the interviewer during student and peer leader interviews. Furthermore, I was the coordinator of the PLTL workshop series in which the study occurred. My roles and responsibilities as a workshop coordinator included: collaborative development of workshop problem sets; writing workshop preparedness quizzes; training peer leaders weekly in workshop content, collaborative learning techniques, and group facilitation skills; and statistical analyst of course grades, DFW rates, and ACS exam scores. My perspective was aligned with the ethnomethodological nature of the qualitative portion of this parallel convergent mixed methods research study (Bodner & Orgill, 2007, p. 180).

I minimized the possibility of bias through a two-fold approach suggested by Weiss (1994). Firstly, I interviewed participants from comparison groups until saturation, when no additional themes arose. Secondly, I highlighted and interpreted contradictory qualitative and quantitative findings, including the rationale if one type of data receives more weight. In addition, I prevented bias by analyzing grade information only after the student interviews are completed.

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CHAPTER 4. RESULTS

4.1 Comparison of PLTL and cPLTL Students' Performance Measures

Four PLTL/cPLTL comparison groups, PLTL and cPLTL groups led by the same peer leader, were implemented in first-semester organic chemistry in 2014 in order for me to assess the effects of cPLTL in an organic chemistry course, since positive collaborative problem-solving behaviors and no statistically significant differences in student performances were reported in an evaluation of cPLTL implementation in a General Chemistry course at the same institution (Smith et al., 2014). Likewise, Mann-Whitney U tests indicated that there were no statistically significant difference in the distribution of course grades (Figure 4-1).

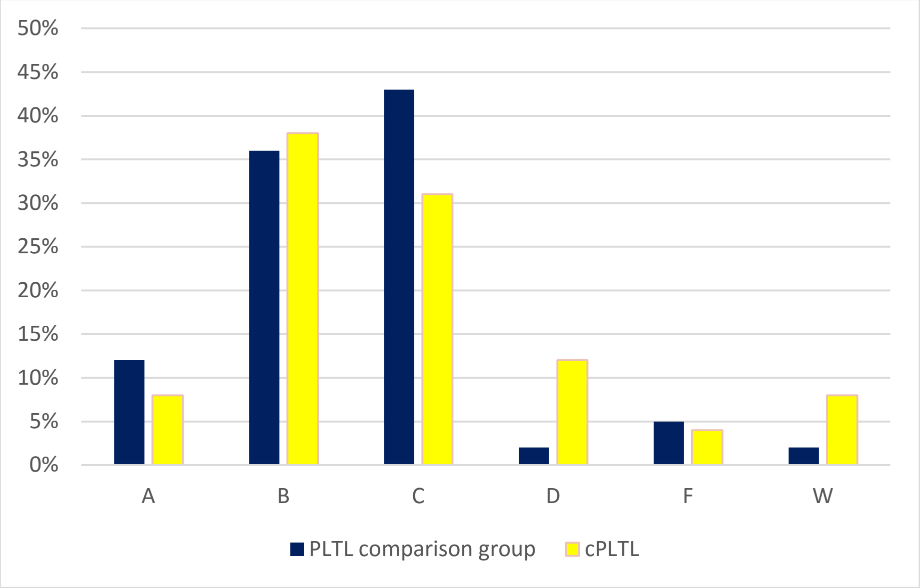


Figure 4-1 Distribution of course grades for PLTL and cPLTL comparison groups

Mann-Whitney U tests indicated that there is no statistically significant difference in the performance of PLTL and cPLTL students on the ACS first-semester organic chemistry exam for PLTL and cPLTL students. Lastly, Chi Square analysis indicated there was no statistically significant difference in student attendance in workshops. Displaying course grades for the comparison groups in AB, C, and DFW categories revealed that the proportion of AB grades appears comparable for PLTL and cPLTL students, while there is notable shift in the proportion of C grades to DFW grades for cPLTL students as compared to their PLTL counterparts (Figure 4-2), which raises the concern that, assuming the characteristics of the students are the same, cPLTL students who earned a D, F, or W course grade could perhaps have earned a higher grade in the course if they had participated in PLTL.

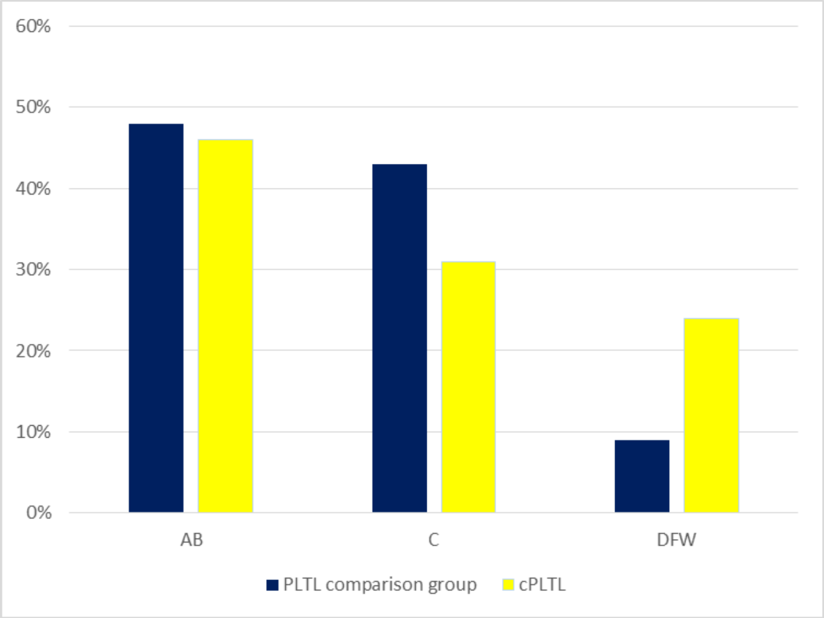


Figure 4-2 Distribution of course grades for PLTL and cPLTL comparison groups

4.2 Analysis of Students’ Experiences in PLTL and cPLTL Settings

Fifty-two comparison group students (33 PLTL students; 19 cPLTL students; 76% response rate overall) responded to a Likert-scale perception survey to communicate their perceptions of workshop dynamics. For questions 1-9, the students utilized a Likert-scale range to report their perception of how much each type of activity benefitted their learning in the course (1 = contributed least through 5 = contributed most). For questions 10 & 11, the Likert-scale responses corresponded to how frequently throughout the semester the two activities occurred (1 = Never; 2 = Rarely; 3 = Sometimes; 4 = Almost Always; and 5 = Always). For questions 12-18, the students utilized a Likert-scale range to report how important each parameter was on their workshop setting choice decision (1 = contributed least through 5 = contributed most). Cronbach’s alpha, calculated in SPSS (version 22) as an assessment of the reliability of the student perception survey instrument, was computed to be 0.71, which is the appropriate level for a low stakes testing situation (Cronbach, 1984; Cronbach, 1951). I employed the six-phase process described earlier to identify emergent themes from the interview transcripts (Figure 4-3).

Figure 4-3 Emergent themes from student and peer leader interviews

Both PLTL and cPLTL students reported that the impact of peer leader and classmate discussions of concepts were important or very important to their learning of course content, although the mean Likert-scale responses were statistically higher ($p<0.05$) for PLTL students than their cPLTL counterparts (Table 4-1). As stated by one workshop student,

> He [my peer leader] put forth a lot of effort and you could tell he really cared about if we could understand the material. I really appreciated that.

Similarly, another workshop student said,

> She [my peer leader] really know organic chemistry. Then, she makes it understandable… she'll make metaphors.

Table 4-1 Student perception of workshop activities on their learning survey results

	PLTL (N=33)	**cPLTL** (N=19)
	Mean (SD)	Mean (SD)
One-on-one discussion with the Peer Leader.	4.70* (0.64)	4.00* (1.29)
Peer Leader speaking to my small group.	4.67 (0.65)	4.74 (0.65)
One of my small group members explaining a concept to me.	4.55* (0.71)	3.89* (0.88)
Collaborating with my small group members.	4.61* (0.61)	4.05* (0.78)
Explaining concepts to other members of my small group.	4.61 (0.56)	4.32 (0.75)
Discussing and answering the workshop problem set.	4.42 (0.87)	4.05 (1.18)
The influence of your participation in the workshops on your organic chemistry problem-solving skills.	4.27 (0.80)	4.11 (0.74)
How frequently throughout the semester that you understood one or more of the workshop questions based on explanations from your small group members.	4.00 (0.66)	3.63 (0.76)

* $p<0.05$

Interestingly, PLTL students were significantly more likely to perceive that their peer leader engaged in one-on-one discussion with them that impacted their learning of the course material (Table 4-1). In an earlier general chemistry PLTL/cPLTL study (Smith et al., 2014), those peer leaders had interacted with PLTL students *en masse* instead of as individuals to check for understanding, while peer leaders checked individual cPLTL students for understanding. In response to that study's finding, these organic chemistry peer leaders were specifically trained throughout the semester to involve each PLTL and cPLTL student in conversations to confirm conceptual understanding. Therefore, it is a surprising finding that the peer leaders were more likely to be involved in more one-on-one discussions with PLTL students without engaging in a comparable frequency of one-on-one discussions with cPLTL students since each peer leader led **both** PLTL and cPLTL sections.

PLTL students reported statistically higher perception of the workshop questions being more challenging than their cPLTL perceived ($p<0.05$). This inflated difficulty perception could be related to the lower rate of workshop preparedness (Table 4-3) observed in the face-to-face setting. Peer leaders reminded students in both settings to come to workshops prepared, i.e. having attempted all of the problems. Nevertheless, the screen-sharing feature of the cPLTL environment contributed to cPLTL students' sense of enhanced accountability to be prepared for workshop. Isaac, who was a cPLTL student during the pilot study that became a peer leader for the full study, communicated a sense of shared responsibility for learning:

> You were just like, 'I gotta do this because someone else might not know it or I might just have what we need to get through this problem and finish it up'.

A different peer leader conveyed that a student had told her that she felt motivated to do her workshop problem set when she learned about the screen-sharing feature of cPLTL, "[because] it would be embarrassing if I blew up their screen and they didn't have anything done". Organic chemistry cPLTL student Kenneth, who was also a cPLTL peer leader in the general chemistry course, said:

> I felt like I was able to see other people's work more than [in] regular PLTL. Like obviously when in normal PLTL you sit next to each other and … you look. But since I could look at four different people's [work in cPLTL] and see how they went about it which was cool.

Table 4-2 Frequency of discourse revealing lack of workshop preparedness by setting

PLTL N = 5		**cPLTL** N = 2	
Mean (SD)	**Example**	**Mean (SD)**	**Example**
1.25 (1.50)	S4: I don't know this whole backside attack thing. S1: Me either! S3: I've been studying for the test, so I haven't done anything. S1: So this means it's polar aprotic? S4: Okay. S1: So that means…ha-ha. S4: Let's skip this. I don't know how to do it. S1: Yeah, skip. S4: E2 reaction? What? I don't even know what that is. S1: NaH? S4: What is that?	0.50 (0.56)	S9: Did anyone do this? S1: I'll be honest I didn't. I've been working nights. I looked at it a little before class.

Although the difference between the populations' responses was not significantly different, PLTL students reported that they almost always understood one or more of the workshop questions based on explanations from their small group members, while cPLTL students reported an average Likert-scale response that corresponded with sometimes understanding workshop questions based on explanations from classmates.

One of the peer leaders, Naji, conveyed in her end-of-semester interview that she felt like her online students were more dependent on her to progress through the problems than her face-to-face students, but other peer leaders did not suggest that trend. For example, Brody thought that his online students had more in-depth content discussions than his face-to-face students. Furthermore, Naji's perception that cPLTL students were more dependent on her may stem from her heightened sense of responsibility as a cyber peer leader than a face-to-face peer leader:

> I feel like I have to do more because I am just labeled that way [Host]. But that's so silly. But it's like a psychological thing. You feel like that when you see that [label in the web conference screen]. Then in face-to-face, I'm literally on their level. Same desk, same everything. Yeah.

The impact of setting on peer leader Naji's sense of responsibility in the online setting raises a unique research question for further investigation: *How does the online classroom environment influence teacher behavior?* K-12 teachers are taught during teacher preparation courses that the arrangement of furniture in the classroom environment influences student behavior, as revealed in the education literature (Ames, 1992; Guardino & Fullerton, 2010; Haghighi & Jusan, 2012; Simmons, Hinton, Simmons, & Hinton, 2015). Likewise, studies have demonstrated that teacher behavior is also influenced by the classroom environment (Duncanson, 2014; Manke, 1994). Namely, teachers' encouragement of students to engage in creative, self-directed, collaborative learning, called P-time, occurs in more spacious classroom settings with mobile furniture (Duncanson, 2014). cPLTL workshops often have extended time due to the lack of classroom scheduling constraints (Smith et al., 2014), so one would expect cPLTL peer leaders to naturally be more encouraging of students being self-directed and collaborative. Nevertheless, Naji was not affected by the online setting in that manner, but, instead, felt heightened responsibility to direct student learning in the cPLTL setting that she didn't feel in the PLTL setting.

Table 4-3 Student perception of workshop preparedness survey results

	PLTL (N=33)	**cPLTL** (N=19)
	Mean (SD)	Mean (SD)
Seeing from the preparedness quizzes what I didn't understand yet.	3.67 (1.32)	3.32 (1.29)
How challenging the workshops problems are.	4.30* (0.95)	3.84* (0.77)
How frequently throughout the semester that you attempted the workshop questions in advance of the workshop session	3.88 (0.99)	3.84 (1.02)

* $p<0.05$

Both PLTL and cPLTL students perceived that the workshop preparedness quizzes were neutral in helpfulness as a means for them to identify content that they didn't understand yet (Table 4-4), although the peer leaders were trained to ask if there were any unclear quiz questions and wrote the feedback in their weekly reflections. This finding suggests that students had limited metacognitive skills and were unable to independently identify which concepts they didn't understand.

Another interesting finding from this section of the survey was that PLTL and cPLTL perceived that difficulty of the course significantly differently. An earlier PLTL statistics study (Curran et al., 2013) found that PLTL students perceived their statistics course to be significantly less difficult than the non-PLTL students had rated the course difficulty. Therefore, one may conclude that there is an additional cPLTL student perception that they can count on their classmates and peer leader to develop their understanding of course content even than PLTL students perceive.

Students from both settings reported in the survey that they sometimes attempted the workshop problems in advance of their workshop sessions, although students were reminded throughout the semester, both verbally as well as by course management system messages, by their peer leaders that is an expectation of the workshop series.

> I sent out an announcement the night before, telling my students they needed to attempt all the workshop problems.

Additionally, face-to-face peer leaders occasionally reward students for attempting their workshop problem sets with donuts.

Table 4-4 Student workshop setting choice survey results

	PLTL (N=33)	**cPLTL** (N=19)
	Mean (SD)	Mean (SD)
Best fit my schedule	3.88 (1.47)	4.32 (1.25)
My advisor recommended it	1.64 (1.45)	1.47 (1.12)
Avoid the commute to campus	1.73*(1.55)	2.95* (1.84)
Prefer learning online	1.39* (1.12)	2.42* (1.58)
Prefer taking courses on campus	3.82* (1.69)	2.11* (1.37)
Prefer face-to-face learning	4.45* (1.25)	3.16* (1.71)
Do not have access to the internet at home	1.24 (1.09)	1.11 (0.74)

* $p<0.05$

PLTL and cPLTL students reported statistically different ($p<0.05$) rationale for workshop setting choice (Table 4-5): cPLTL students preferred working online and avoiding the commute to campus, while PLTL students preferred to learn face-to-face even if they had to commute. For example, Kenneth said:

> I feel like I would be too hesitant to ask any questions if I have never met the person in person.

Debbie also emphasized the personal connection and ease of meeting in the same physical location:

> It’s kind of a different feel. I think that [this] setting is what works best for me.

Finally, Veronica’s reason for her choice to enroll in the face-to-face setting suggested that some students have an aversion to working online:

> I like being with other students. Interacting through the computer is not my favorite.

Matthew summed up the face-to-face students’ perspective in his interview:

> Matthew: It’s a drive for me because I don’t have any other classes on Thursday. I’m coming down from [removed town name]. It’s a 45-minute drive.
>
> Interviewer: Just for PLTL?
>
> Matthew: I think it’s worth it.

Each of the face-to-face students interviewed for the study communicated that they would select face-to-face PLTL in future classes, too, due to a strong preference for interacting in person. In contrast to their face-to-face counterparts, cPLTL students conveyed a variety of reasons for their selection of the online setting. Several cPLTL students conveyed that they chose to participate in cPLTL simply because the time best fit their schedule, rather than considering the workshop setting in their decision. Alternatively, Joyce was curious about the new PLTL approach:

> I kind of just wanted to try it out. I wanted to see what it’s all about.

Moreover, several students articulated that they relished the opportunity to stay home instead of commuting, a phenomenon previously described as “PLTL in pajamas” (Alberte, Cruz, Rodriguez, & Pitzer, 2013):

> I liked that I could be at home in the morning, which I don’t get to do that very often. Thursdays were the only mornings I was **home** home.
>
> I liked the flexibility of it. I could be at home in my pajamas and I could also be at school. That’s a flexibility only online classes can provide.
>
> I liked it and it’s hard sometimes to go to class that late in December on campus, but when you are at home it’s just easier to log in online and do it.

Ashley stated that a classmate recruited her to cPLTL:

> She [my neighbor and friend] was like, “I'm in this online section you should get in it, too”. She was like, “you’ll really like it”...so that kind of urged me, too.

Lastly, one student said that he selected cPLTL because the group size was slightly smaller.

4.3 Analysis of PLTL and cPLTL Students’ Workshop Discourse for Emergent Themes

In addition to soliciting students’ perceptions of the workshop dynamics and benefits with a survey, workshop transcripts were coded for several variables, including: students’ emphasis on answer-checking versus collaborative problem-solving and student discourse which reveals a sense of community among themselves. Mann-Whitney U tests revealed no statistically significant difference by setting in the distribution of these coding categories across six weeks of one paired set of comparison group workshop transcripts from the Spring term and five weeks of three paired sets of comparison group workshop transcripts from the Fall term (41 total transcripts, since one week of PLTL was not recorded by one peer leader). Likewise, the Kruskal-Wallis test, the nonparametric equivalent of analysis of variance (ANOVA), revealed that there is no significant difference in the distribution of answer-checking or problem-solving behavior discourse in the transcript sample set (Figure 4-4), nor sense of community based on peer leader (Table 4-5).

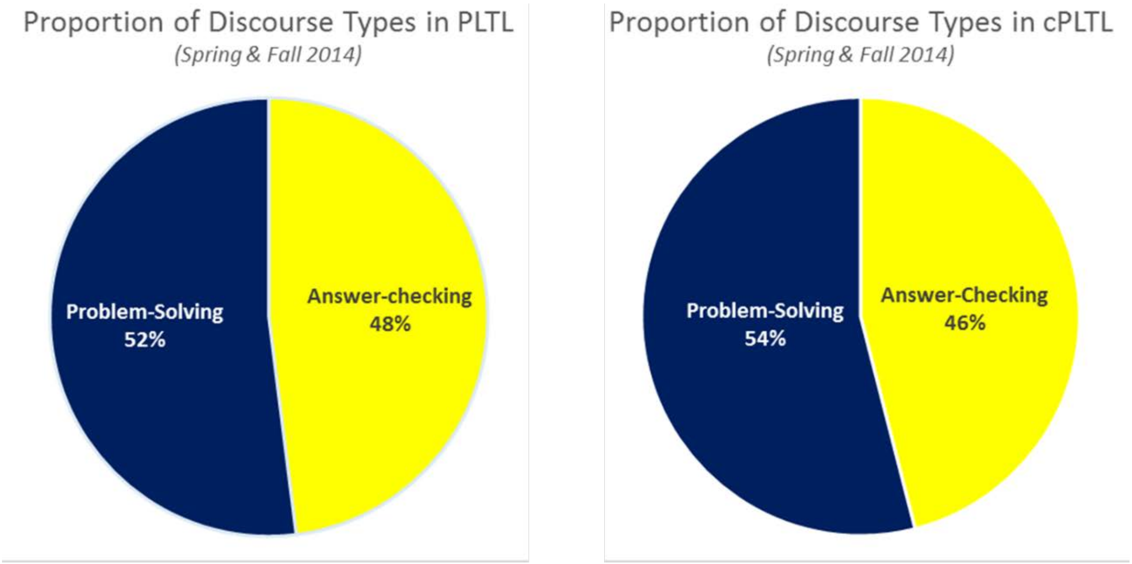


Figure 4-4 Distribution of discourse type in PLTL & cPLTL

Table 4-5 Frequency of answer-checking discourse by setting

PLTL N = 6		cPLTL N = 16	
Mean (SD)	Example	Mean (SD)	Example
1.50 (1.29)	S2: So, this is 4-chloro-2-ethyl, right? S3: Yeah, that's what I did there. S2: Heptane? S3: Heptane.	4.00 (4.76)	S8: What did you get? S3: I said C D A B. S8: Me too! Yay! S3: Yay!

Although not statistically significant, the frequency of answer-checking behavior was higher in the online setting than the face-to-face setting (Table 4-5), which is a notable contrast to the general chemistry student behavior reported by Smith et al (Smith et al., 2014). Nevertheless, collaborative problem-solving was both comparable in the two settings as well as a far more frequent characterization of student interactions than answer-checking (Table 4-6). Furthermore, the answer-checking rather than problem-solving behavior for students in both settings corresponded to the question type: students compared answers before discussing their rationale for nomenclature and hybridization warm-up questions, but focused on the problem-solving process for problems in which they solved reactions or drew energy diagrams of substitution reactions.

Table 4-6 Frequency of problem-solving discourse by setting

PLTL N = 61		cPLTL N = 62	
Mean (SD)	Example	Mean (SD)	Example
15.25 (7.27)	S2: So, this is 4-chloro-2-ethyl, right? S3: Yeah, that's what I did there. S2: Heptane? S3: Heptane.	15.50 (6.61)	S1: This one is a lot like the last one we did. So let's employ that logic. So the first thing we would do is play with the electrons, the lone pair electrons. Then the double bond, we would have to do a ring shift. Or no? S2: You can just move the dots and make a double bond and carbon is perfect. S1: AGREED. S2: So that's one. Then there will be more resonance structures. S1: From here on out, we are just giving carbon, just moving that electron around the wheel, right? So now we are going to take that lone pair and make it into a double bond and then make this double bond onto that carbon. S2: Say that again and point. S1: None of that made sense because I'm talking that and this. Here I'll zoom in a little. Would it make sense to take this charge and make a double bond? Move this. Put a negative charge on that? S2: Yeah, so they [the double bonds] would just be shifting counterclockwise [in the benzene ring].

Table 4-7 Frequency of sense of community discourse by setting

PLTL N = 4		**cPLTL** N = 2	
Mean (SD)	**Example**	**Mean (SD)**	**Example**
1.00 (0.82)	PL: Hey, I don't know if you guys already did this in the lecture. Maybe they did this on the first day. But maybe just sort of optional, put down contact information here for your group and like if you guys have questions you can text each other. I mean if you already have friends in the class and stuff…but I just think if you have contact with your recitation group it's nice.	0.50 (1.00)	S2: Anya, I'm going to bug you on Thursday and crank it out for the exam. PL: Are you going to come live or into the chat room? S2: Whatever is convenient for you. S3: It's convenient for me to go to your live hours.

Lastly, the face-to-face organic chemistry student dialogue revealed slightly higher incidence of students' dialogue revealing a sense of community among themselves than the dialogue of the cPLTL students (Table 4-7), a finding which aligns with the phenomena reported by Smith et al (Smith et al., 2014). Likewise, student and peer leader interview comments at the end of each semester were aligned with the my analysis of workshop discourse. Peer leader Kenneth said, "You can't do social chatting online without someone noticing… because everyone hears every conversation." Similarly, peer leader Naji suggested that there is a greater sense of camaraderie among her face-to-face students, while she said of her online students:

> I think it's not that they are not polite and kind to each other. You know, like, they laugh at each other or whatever, but it's like I would never image them being out of class [buddies].

Peer leaders Isaac and Brody suggested that the greater emphasis on taking turns to talk in the online setting in order to avoid noise issues lead to a more formal interaction pattern.

Table 4-8 Frequency of peer leader praise by setting

PLTL N = 83		**cPLTL** N = 126	
Mean (SD)	**Example**	**Mean (SD)**	**Example**
20.75 (13.82)	PL: Yeah, that's a good way to think of it. Nice.	31.50 (15.78)	PL: Sounds like a good thought process. That's really good.

Although not statistically significant, the peer leaders tended to praise students more frequently in the online setting than the face-to-face setting (Table 4-8). I suggest that the tendency to praise cyber students more than face-to-face students stems from peer leaders wishing to reward cyber student effort verbally since tangible gifts, such as donuts, are not possible in the virtual meeting room.

Table 4-9 Frequency of mentoring discourse by setting

PLTL N = 8		**cPLTL** N = 7	
Mean (SD)	**Example**	**Mean (SD)**	**Example**
2.00 (1.16)	PL: Have you guys been doing the book problems? Do them. You need exposure and practice. It's like everything you've done in the past two weeks, you need to review it and you need to look at it outside of class. Maybe on the weekend spend some time on it. You need to spend a lot of time on organic outside of recitation and lecture.	1.75 (1.50)	PL: You need to do these for practice. You can't go into the exam just from understanding. You have to practice.

Peer leaders displayed comparable mentoring behavior in both settings (Table 4-9), although the PLTL students were more apt to discuss this aspect of peer leader behavior in their end-of-semester interviews than the cPLTL students. For example, the students reported that the peer leaders discussed study strategies with their students, shared helpful websites, and emphasized the importance of practicing problems, not just reading. For example, peer leader Naji said in her interview:

> We talked a lot about how they could study or how they should be studying or what they are doing or what they are not doing and what my suggestions were. Um, I just kept reiterating practice.

Similarly, peer leader Brody delivered studying advice to students during one workshop session, based on Cook et al’s article (2013) that was discussed in the peer leader training meeting:

> The best study cycle is to preview before lecture so you know what he’s talking about. How do you even know what he’s talking about if you haven’t previewed? You want to review. Here’s where a lot of students get tripped up. They think that when they’re reading, that they’re studying. Nine times out of ten, students our age that think they are studying [but they] are just reviewing. Reading the book and going back to these slides is not studying, that’s reviewing. So you need to preview before lecture, attend lecture, review the same day. The next day go back through and spend some time…Go back and do the practice exams that they give to you. That’s studying. Going through the book and doing practice

> problems, that's studying. Reading the book is not studying. That's just reviewing. Make sure that while you're studying, that beforehand you review. When you're actually studying, you're practicing problems.

Notably, his student, Keith, became a peer leader in the subsequent semester and reported in a peer leader training meeting that both his adoption of the study cycle described by Brody (Cook et al., 2013) and his inspiration to start fresh despite poor performance on the first exam because Brody believed he could succeed were crucial in his successful completion of the course.

Table 4-10 Frequency of online resource use during workshops by setting

PLTL N = 3		**cPLTL** N = 6	
Mean (SD)	**Example**	**Mean (SD)**	**Example**
0.75 (1.50)	PL: Yeah, so what is a vocabulary word that means separation of a racemic mixture into its enantiomer components? S1: I don't know what that means. S4: I kept reading it….I put "resolved". S3: Resolution. I Googled it.	1.50 (1.00)	S3: What is DBU? S8: That's a great question. Let me Google that.

Students from both settings conveyed that they utilized online resources during their weekly workshop preparation process. Although there wasn't a statistically significant difference in the distribution of online resource use during the workshop sessions (Table 4-10), the cPLTL students were more likely to access online resources more frequently than their face-to-face counterparts, as also seen in the Smith et al study (Smith et al., 2014). Although students in the cPLTL setting could easily have shared videos or other online materials with classmates in real time while participating in the Adobe Connect cPLTL environment, several students said in their end-of-semester interviews that they only shared links to resources because they didn't realize that they could share the full resources. This gap in student understanding of the web conferencing environment's capabilities should be rectified in future peer leader and student training. For example, peer leaders should guide students in information-gathering and website sharing activities during their pre-semester Workshop Zero event, where the students learn how to set up and optimize their equipment before the content discussions and collaborative problem-solving begin.

4.4 Analysis of PLTL and cPLTL Students' Workshop Discourse for Revised Bloom's Taxonomy of Educational Objectives: Cognitive Domain Categories

Once the workshop discourse transcripts were analyzed using grounded theory by both the research assistant and me, the transcripts were coded, using Revised Bloom's Taxonomy of Educational Objectives for the Cognitive Domain as the analytical framework (Anderson & Krathwohl, 2001; Bloom, 1956). Both I and my undergraduate research assistant used the Revised Bloom's Taxonomy of Educational Objectives for the Cognitive Domain Action Verbs list (Anderson & Krathwohl, 2001) (Table 4-11) as a reference for consistent interpretation of the six cognitive domain categories after the I confirmed alignment of the action verbs with the original descriptions proposed for Bloom's Taxonomy of Educational Objectives for the Cognitive Domain (Bloom, 1956).

Table 4-11 Excerpt from Revised Bloom’s Taxonomy of Educational Objectives: Cognitive Domain Action Verbs (Anderson & Krathwohl, 2001)

	Remembering	**Understanding**	**Applying**	**Analyzing**	**Evaluating**	**Creating**
Verbs	Define Label Recall	Classify Explain Summarize	Organize Solve Utilize	Compare Contrast Conclude	Criticize Deduce Defend	Combine Develop Estimate

I and my research assistant achieved nearly perfect agreement (Cohen’s Kappa = 0.87) (Landis & Koch, 1977, p. 165). For further validation of the use of this analytic framework, an additional coder, a fifth year doctoral candidate with more than two decades of industry experience as a synthetic organic chemist, was asked to code a randomly-selected workshop transcript. His coding was in the range of “Substantial” agreement with the two original coders (Light’s Kappa =0.65) (Landis & Koch, 1977, p. 165). Thereupon, I independently interpreted the frequencies of each category, triangulating with peer leader interview transcripts, student interview transcripts, and workshop observations for this dissertation. Although there was no statistically significant difference in the distribution of discourse categorized by the Revised Bloom’s Taxonomy for Cognitive Domains by setting (Figure 4-5), the I note that the students’ discourse most often was classified among the lower cognitive dimensions, which is aligned with the findings of previous studies (Christian & Talanquer, 2012b; Hou, 2011; Lin et al., 2013; Meyer, 2004; Valcke, De Wever, Zhu, & Deed, 2009).

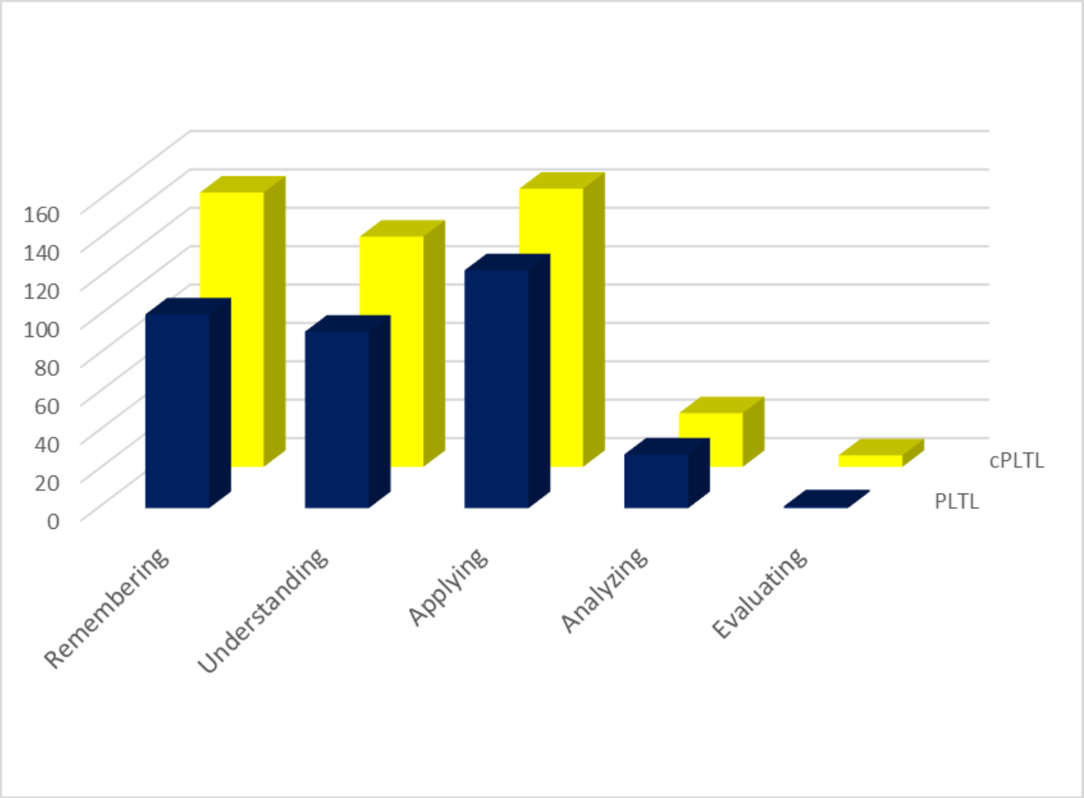


Figure 4-5 Frequency of revised Bloom's Taxonomy-classified discourse by setting

Table 4-12 Frequency of discourse revealing Remembering by setting

PLTL N = 101		**cPLTL** N = 143	
Mean (SD)	**Example**	**Mean (SD)**	**Example**
25.25 (6.99)	S1: What is a strong and weak base? S3: Strong base is the conjugate of a weak acid.	35.75 (12.74)	PL: What is an enantiomer? S6: Stereoisomer. S3: Non-superimposable. PL: Yes. Good Job.

I expected to observe a high frequency of discourse that revealed the students' remembering facts since problem-solving in organic chemistry requires that the participant remember some basic concepts, such as valence of atoms and definitions of concepts. While the distribution of Remembering discourse was not statistically significant for the transcripts in the sample (Table 4-13), the total frequency of such discourse was higher in the online setting. I suggest that this phenomenon may be attributed to the smaller view of classmate's worksheets afforded in the online setting, so students verbally confirm baseline facts before solving problems.

Table 4-13 Frequency of discourse revealing Understanding by setting

PLTL N = 92		**cPLTL** N = 120	
Mean (SD)	**Example**	**Mean (SD)**	**Example**
23.00 (7.26)	PL: Okay so what's the second reason that these radicals are so stable? They are tertiary and stabilized by triple bonds. What else? S1: Because of resonance. PL: Perfect. Why do you say that? S1: I guess one of the pi bonds from the triple bond could cleave and form a double bond with one of the radicals, and then a radical would go on the nitrogen.	30.00 (7.96)	I'm pretty sure DMSO is aprotic but everything else says S_N1. So it's a tertiary carbon and tosylate is a good leaving group but it's in aprotic solvent.

Similarly, the difference between the PLTL and cPLTL distributions of Understanding discourse (Table 4-14) was not statistically significant for the transcripts in the sample, but the total frequency of such discourse was higher in the online setting. I believe that this phenomenon of higher frequency of discourse related to explaining and summarizing in the cPLTL setting may be an indicator of the greater emphasis on turn-taking in that setting, which one peer leader characterized as a more formal interaction style. In particular, I propose that students may be more deliberate to articulate their problem-solving process step-by-step online, which is aligned with the observation reported in Smith et al (2014) study of student behavior in PLTL & cPLTL general chemistry workshops. The elevated frequency of Applying discourse in the cPLTL setting reinforces this proposition (Table 4-16).

Table 4-14 Frequency of discourse revealing Applying by setting

PLTL N = 124		**cPLTL** N = 145	
Mean (SD)	**Example**	**Mean (SD)**	**Example**
31.00 (2.94)	S2: $^{-}$SH is coming from the back. It’ll push this methyl forward. S1: Oh okay. S2: So that’ll change the dash to a wedge. S4: So this will attack this and it’ll flip. S2: Yeah.	36.25 (15.76)	PL: How do we determine which hydrogen gets taken? S8: Well, so there’s only one right? Because alpha carbon is attached to tosylate. So the beta carbon is attached to hexane. That’s a tertiary carbon. So there’s only one hydrogen available. I think I’m still getting used to where to draw the arrows. Because after it takes the proton… S3: Does it just make a double bond as the OTs leaves? S8: Yeah.

Table 4-15 Frequency of discourse revealing Analyzing by setting

PLTL N = 28		**cPLTL** N = 28	
Mean (SD)	**Example**	**Mean (SD)**	**Example**
7.00 (1.41)	S3: Yeah. So when you donate a proton it'll donate to a bad leaving group. You had hydrogen to it and it becomes H_2O then it can break off by itself. S3: Hydrogen is attached to an electronegative…so for example this is a bad leaving group because of the OH. It can steal a proton from there to become a good leaving group. Polar protic [solvents] will be most likely in S_N1 and polar aprotic will be S_N2. If it's primary or tertiary [substrate], then you already know which one it is. It's just if you get past that point and don't know if it's S_N1 or S_N2.	7.00 (2.83)	S2: Yeah, I think there's a radical on each side. What do you think, David? S1: That makes sense to me. I was wondering if Brooke was trying to tell us that when the cleavage happens, they form the third bond …the two radicals form the third bond. But I could see them both having a radical on there, too. S2: Well, if there's a radical on the chair, we didn't start with a radical, so wouldn't there be an extra electron? One electron is going onto the chair and one is going to the nitrogen, right? I don't know. I could be wrong. S5: That's why I thought the radical was on the chair.

The critical thinking which is the hallmark of Analyzing discourse was equally prevalent in both settings (Table 4-16), although the overall frequency of this higher order thinking pattern was markedly lower than the frequencies of lower order thinking discourse (Remembering, Understanding, and Applying). I suggest that this phenomena is a product of the lack of workshop preparedness noted in workshop discourse, peer leader reflections, and end-of-semester interviews. Recall, one peer leader had noted that students felt embarrassed in the cPLTL environment, for example, to have their document camera view expanded when the worksheet was blank. This emphasis on completion could correspond with less attention on the quality of the work.

The trend of decreasing frequency of discourse relating to higher order thinking as one progresses up the Revised Bloom's Taxonomy of Educational Objectives: Cognitive Domain triangle from Remembering to Creating continued; only seven instances of discourse that revealed students performing conceptual activities that were aligned with Evaluating in the sample (Table 4-16), six of which occurred in the online setting, although the distribution of this discourse type was not statistically significant according to the Mann-Whitney U Test. No instances of discourse which revealed students' performing cognitive tasks related to Creating were identified in either setting in the sample.

Table 4-16 Frequency of discourse revealing Evaluating by setting

PLTL N = 1		**cPLTL** N = 6	
Mean (SD)	**Example**	**Mean (SD)**	**Example**
0.25 (0.50)	S4: I have a question. When you have these two things on your reaction arrow, right? One is the reagent and one's the solvent. But how do you know when to use each one? PL: You can just use them anytime. They are all in the mixture together in lab. S1: I think she said sometimes the solvent gets used or part of the solvent gets used and then other times the solvent doesn't actually get used. PL: I guess you just have to look at what will be a feasible reaction, what would occur. S4: See when I look at that, how do I know what really occurs?	1.50 (1.29)	S1: I haven't figured out the product yet, but I disagree with it being S_N2. S6: Oh, I just kind of wrote that on the side. S1: Because it's tertiary [substrate] and CN^- is a strong nucleophile.

4.5 Analysis of Students' Use of Curved-arrow Formalism

4.5.1 PLTL Students

4.5.1.1 Holly

Holly was quick to volunteer to be interviewed about her PLTL experience and thoughts about reaction mechanisms. She belonged to a close-knit workshop group that was dedicated to making the most of each minute of the weekly workshop sessions. They smiled often and were noticeably energetic in their problem discussions during each of the workshop observations. In her own words, "We had this thing of nobody left behind. We wanted to make sure we all understood what was going on in the problem set." Consequently, her group was focused on every member of the group understanding each problem's concepts and solving each problem, whether their peer leader was interacting with them at that time or not.

A forty-year-old African American student, she exuded pride and confidence when speaking, both in the workshop setting as well as during her interview. She performed slightly above average on the first exam of the semester, but below average on the subsequent two course exams and final exam that required use of curved-arrow formalism. Nevertheless, she had perfect attendance in the weekly PLTL workshops and moderately high workshop preparedness quiz grades. Her eraser-less pencil used in the end-of-semester interview reinforced my perception that she worked hard at a class that did not come easily to her.

Holly accomplished the generation of resonance structures for interview problem number one, reflecting that:

> Brody [my peer leader] told us when trying to come up with resonance structures that ‘you always make a bond, then break a bond,’ so I’ll start with these lone pairs…

Moreover, she was meticulous about drawing in all lone pairs before indicating the relevant formal charge for each resonance structure.

Holly was more hesitant in her approach to interview problem two. She said, “I’m looking to see what’s different, so I know where to place arrows.” For this problem, she draws arrows consistent with homolytic cleavage, rather than heterolytic cleavage, and doesn’t seem to realize that the arrows she drew wouldn’t lead to the indicated product. When asked how she knows which direction to draw arrows, Holly states:

> Does it matter which direction? I mean as long as they are all flowing in the same direction?

Moments later, however, she corrects herself, saying:

> The tail [of the arrow] comes from the lone pairs and the head goes to form a bond.

Holly struggled to identify the reaction type or propose a mechanism for interview problem three. She said:

> Hmmm… I'm going to say, elimination. It's just a pure guess. I don't know what the name of the reaction would be, but I believe the bromine would end up by itself and this [acetic acid] would end up attached to that [structure I]… This is where my creativity is going to come into play.

Holly confessed that she wasn't certain of the role of sodium azide in the reaction, but indicated (R)-2-cyclopentylpropanoic acid since "there would be backside attack," a characteristic of S_N2 reaction mechanism. Holly's depiction of fishhook arrows instead of double-headed arrows and illustration of products without drawing the mechanism to accomplish them continued during her effort on interview problem number four. Overall, Holly's discourse revealed both a lack of ability to reason with the external representation of curved-arrow formalism as well as gaps in her conceptual knowledge.

4.5.1.2 Katherine

Katherine was a twenty-one-year-old Caucasian student, who was quiet and intense during workshop observations, was recommended as an interview candidate by her classmates. I had already noted that her workshop group members sought her explanations of problems whenever their peer leader was involved in conversation with other students. Katherine, mindful of this dynamic, had perfect workshop attendance and mentioned in the interview that she was diligent to prepare for workshops because she knew her classmates depended on her.

Katherine communicated that she chose the face-to-face workshop setting since she was repeating the course because she thought that the ability to turn the same paper or use a model kit would enhance explanations:

> I think you get a lot more interaction. I took an online class last semester and I’m taking one next semester that are all computer based. Which with those it makes more sense. With these, when you’re drawing things out, it’s easier for them to stop you or say look at it this way and actually physically turn the paper or do things that way is a little bit easier than trying to do it cyber.

Indeed, Katherine noted in her interview that she appreciated that her peer leader brought a model kit, so the students could manipulate it individually while learning to draw Newman projections.

Katherine earned a below average grade on the first exam of the semester, above the average on the second semester exam, and 54th percentile on the ACS final exam. She struggled to complete the first interview problem, largely because she did not always adhere to the octet rule. Eventually, she drew the correct sequence of curved-arrows, but neglected to indicate the formal charges. She communicated that she was finished working on the problem by saying, “Alright. Maybe. I don’t know.” For problem two, Katherine said, “I usually look at what changes between the two” and drew correct curved-arrows to proceed from step to step in the sequence, but not in the order that would indicate recognition of the sequence of events for the underlying physical phenomena. Similarly, her curved-arrow in the mechanism for interview problem three indicated that the acidic proton of acetic acid abstracted bromine to produce hydrobromic acid, rather than bromine being the leaving group which eventually abstracts a proton from solvent. Thus, Katherine’s areas of difficulty from a C-R-M perspective were largely gaps in conceptual knowledge.

4.5.1.3 Matthew

Matthew was an African American student who exuded confidence and friendliness during the interview. He was noted as a particularly out-going student during the workshop observations, as well. Matthew described his weekly routine as reading the textbook and supplementary material on the same topic in advance of lecture, then answering the workshop problem sets in advance of his workshop sessions. He earned well above average on each of the semester exams, although only 54th percentile on the final exam.

Before attempting the first interview problem, Matthew shared that he vividly recalled an incident at the beginning of the semester in which his peer leader helped students understand the meaning of a double-headed curved-arrow:

> So I remember he [my peer leader] had this white board…it was one of the girls early on in the semester and he had her, he was like, ‘just write out the problem.’ It was one of the acid ones. She really didn’t know how the electrons moved and what happens when a bond breaks, so…he replaced the bonds with two electrons. Then he was like, “If this goes away what

> happens to this one? That's where the lone pair comes from." And it just clicked. She was like, "Oh I see it!"

Matthew articulated his process for determining resonance structures before drawing curved-arrows:

> Okay, resonance. Alright…the first thing I'm looking for is lone pairs, charge, and double bonds. And those are my starting points for drawing resonance structures.

Then, he proceeded to draw a series of five resonance structures for interview problem one, stopping only when he had returned to the original structure, which he called the "home drawing." He seemed to write with a flourish, so I commented on his apparent enjoyment:

> Interviewer: It looks like you enjoyed that.
>
> Matthew: I did. I may have spent too much time enjoying it, but yeah.
>
> Interviewer: No, not at all. Here's the next one. [Pause] Do you practice mechanisms a lot?
>
> Matthew: I do. I have lots of fun with them.
>
> Interviewer: How do you practice them?
>
> Matthew: I just like drawing them and once I draw it out I like to go back and pick a random point and I'll draw that structure and see where I can go from there. I can do maybe four or five in a row and I'll pick a random one and then choose a random one in the mechanism and I'll be like okay

> what now? Sometimes the negative charge may or may not have been there. The lone pair may or may not be shown.
>
> Interviewer: Sure.
>
> Matthew: Sometimes you have to start from the double bond. It’s something that keeps me on my toes.

Matthew progressed through the next two interview problems with confidence and speed, then halted when he encountered the fourth interview problem, a problem constructed to draw from mechanistic reasoning instead of recollection of problems presented in the course. At that point, he drew several curved-arrows that moved toward, rather than from, high electron density areas. Although he recognized that reaction of an alkyne could cause the formation of a bromonium ion intermediate, he did not persist to solve the problem. I had the impression that perhaps he was very practiced at drawing the mechanisms, like a martial arts master meditates while moving through the motions of a Kata, but Matthew didn’t exhibit using curved-arrow formalism as a problem-solving process in which the relevance of concepts were connected to the graphical representations. Perhaps that is why his semester exam grades seemed mismatched to his final exam performance.

4.5.1.4 Keith

Keith, a nineteen-year-old Indian male, was a member of the same close-knit workshop group as Holly. I had noted his enthusiasm for discussion of problems during observations and he reinforced this perception during his interview:

> Keith: I try to usually debate a problem. Even if I know I'm wrong, I'll try to argue it, just to see.
>
> Interviewer: Just to see if they can defend the right answer?
>
> Keith: Yeah.
>
> Interviewer: That's tricky.
>
> Keith: Then that way if a similar problem comes up on the exam, I'll remember, 'Oh I was arguing about that.'

Keith's emphasis on having students and peers explain their rationale continued throughout the semester that he was a student in the course. He had perfect workshop attendance and earned scores well above the class average on all three semester exams. Furthermore, he utilized the study cycle recommended by his peer leader in addition to habitually arriving early for lectures and workshops to discuss problems with classmates.

Keith continued his emphasis on the rationale for problem-solving as he completed the interview problem set. He carefully drew in all lone pairs, then drew curved-arrows to proceed from one resonance structure to the next until he had drawn four resonance structures, saying to himself, "Make a bond, break a bond." While working through interview problem two, he added notations for partial positive and partial negative charges for the relevant carbonyl group before drawing the correct curved-arrows for the amide bond formation mechanism. Simultaneously, Keith identifies the nucleophile and electrophile of the first step in the reaction without being prompted to do so, which revealed that he was indeed rationalizing the reaction, not "decorating with arrows." Likewise, he reasoned mechanistically to solve interview problems three and four, demonstrating a cohesive understanding of concept, mode, and representation.

4.5.1.5 Debbie

Debbie, a 28-year-old African American student with two children, was so soft-spoken during her interview that I was concerned about recording quality. Although Debbie had perfect workshop attendance, she exhibited an unusual combination of determination and indecisiveness during the workshops and interview: she was determined to "do whatever necessary" to pass the course, often staying up at night to read the textbook and do the practice problems in the chapter after her children were asleep, but she was unsure how to solve more complex problems, like those featured in the workshop and interview. During the interview, Debbie pointed back and forth at compounds and seemed reluctant to write on the paper. During the interview, she described her dependence on her PLTL classmates when asked about her workshop preparation:

> I do normally go through and I do the ones that I know how to do and then I'll just save the ones that I have a little confusion on or I don't know how to start it or I don't know how to work it for Friday [her workshop day] and then I'll go through it with the whole group.

I had noticed Debbie's reluctance to offer her opinions about how to solve problems during the workshop observations, also, although her peer leader encouraged participation from all the students. Instead, Debbie leaned in to hear conversation, but deferred to a pair of outspoken classmates whenever asked a question herself. For example:

> When I didn’t understand, they would always take the initiative to explain it if they understood it, but I really didn’t have to say much. I just look at it and I’m like, ‘”Okay I don’t know how to start this,” and someone would just jump in and say this is how you do this.

Debbie worked through the resonance interview problem slowly, being careful not to violate the octet rule and always drawing curved-arrows from areas of higher electron density to areas of lower electron density. However, she left a negative charge on the external oxygen and migrated a cation around the ring in her sequence of resonance structures. During interview problem two, Debbie confessed that she looks at what changes between reactants and products to know where to draw arrows rather than considering the nucleophilicity or electrophilicity of reaction components. Thus, she draws correct curved-arrows, but out of sequence with the physical phenomena. Her approach to interview problem three indicated that she memorized the criteria for determining which substitution reaction rather than reasoning through the mechanism by identifying nucleophile/electrophile or acid/base partners. Consequently, she decided that the reaction was an S_N2 reaction without considering the solvent effect and drew azodicyclopentane with a wedge to indicate inversion of stereochemistry that is consistent with an S_N2 reaction, but did not realize that she lost two carbons. Debbie did not attempt the fourth interview question because it exceeds her recalled reactions, saying:

> There's like a chart at the back of the book and this [alkyne] is in the center and it gives the different solvents that can be used and it shows the reaction that happens when you use it. But then my mind just draws a blank.

Overall, Debbie's discourse revealed that there were significant gaps in her conceptual knowledge and interpretation of the symbolism of organic chemistry that created a situation in which curved-arrow formalism provided little applicability in her problem-solving.

4.5.1.6 Susan

Susan, a nineteen-year-old Asian student, had nearly perfect workshop attendance and was engaged in conversation with her workshop group constantly during each observation, but I noted that she and her nearby classmates progressed through the workshop problems slowly, often asking their peer leader to tell them what to do to solve problems. Their peer leader was persistent, however, in asking leading questions, confirming understanding, then leaving them to make the final mental connections for problem-solving. Susan, who seemed to depend on authority figures to distribute information rather than developing her own reasoning skills to rationalize whether she understood concepts, expressed that she did not appreciate the absence of answer keys for the workshop problem sets because:

> …we could be teaching each other wrong throughout the entire semester and not know it. Then we'd keep missing those points on the exam[s].

Susan described her weekly study routine as "just going through the book and reading stuff," rather than practicing problems or drawing reaction mechanisms. Consequently, Susan, who performed below average on two thirds of the semester exams and final exam, then struggled to write any curved-arrows for the problems discussed during her interview.

Susan was unable to draw any reasonable resonance structures for interview problem one, saying,

> I know electrons form bonds and bonds have electrons that they release. I don't know how to do it, though.

She illustrated this lack of understanding of the physical phenomena being communicated by curved-arrows by drawing repetitive arrows to move electrons from the carbonyl oxygen of 2H-pyran-2-one onto the carbonyl carbon, without regard to the octet rule or indicating the resulting unreasonable formal charges. She drew non-specific curved-arrows for the first step of interview problem two, looking for new bond connections from the reactant to the first reaction intermediate to decide where to draw arrows. Next, she identified the abstraction of an amine proton by an internal hydroxyl group as a hydride shift. She said,

> I’m so glad the final is multiple choice, ‘cause I can look at it and be like ‘that one is right’, but I can’t draw arrows myself… You know, it [a curved-arrow] moves from an atom to a bond or a bond to an atom. It’s just hard choosing which is which.

Susan recognized that interview problem three was a substitution reaction immediately and drew a table for S_N1 and S_N2 criteria (with the wrong solvent type in each category), but was unable to determine which reaction type was suggested by the problem because she couldn’t recall the headers of her memorized table. She said she studied by flashcards, rather than drawing mechanisms. Susan drew a few hydrogen atoms on the reactant and product of interview problem four, but did not attempt to solve the problem. Instead, she said that she learned functional groups in high school and had the highest grade in her high school chemistry class, so she became a Chemistry major. Just as in high school, she studied for this course almost exclusively with flash cards. Her interview discourse suggested that she was an instrumental learner (Skemp, 1979) who was unable to relate concepts and modes of representations in a way that would allow her to reason mechanisms with curved-arrow formalism.

4.5.1.7 Eli

Eli, a 26-year-old Caucasian pre-professional student who returned to college after working for a few years, described that he read each chapter before the topics were covered in lecture, solved each of the textbooks problems, and attempted the workshop problems in advance of the workshop each week. He thought the best way to learn was to explain concepts to others, so he was enthusiastic about his weekly workshop preparation as well as a bit sheepish in his interview that his peer leader, “…actually called me out one time to say, ‘Let's make sure that other people participate.’.”

Eli performed well in the course, earning quite high grades on all three course exams as well as 97th percentile in the ACS first-semester organic chemistry exam. He exuded casual confidence during the interview, wearing a tie-dyed t-shirt and shorts as he worked through the interview problem set quickly and accurately.

Eli drew resonance structures to solve interview problem one via three separate pathways. Although the curved-arrows were drawn accurately and in the correct sequence, he mentioned, “I’m trying to remember the other arrow pattern.” That statement revealed that he had learned patterns, rather than rationalizing nucleophilicity/electrophilicity or acid/base partners to solve problems. Furthermore, Eli drew the correct arrows for interview problem two, but drew them in reversed order, which indicated a dependence on examining bond connection differences to determine where curved-arrows should be. Eli drew the correct products for interview problem three before writing the mechanism for the reaction, which made the interviewer wonder if he had reasoned the mechanism mentally before writing the products since a hydride shift would have occurred to obtain those products. He used a combination of reasoning and pattern recognition to solve problem four correctly, saying, “Oh! This looks like the alkene pattern for a halohydrin reaction.” Notably, he also sketched the key keto-enol tautomerization, a behavior known to be the hallmark of good organic chemistry problem-solvers (Domin & Bodner, 2012). Thus, Eli's interview discourse revealed a robust grasp of all three aspects of the C-R-M model.

4.5.1.8 Veronica

Veronica, a 20-year-old Caucasian student, wore clothing as neat and precise as her tiny handwriting during each of the workshop observations and her interview. She worked all textbook problems in advance of attending the course lectures on related material, completed the workshop problem sets in advance of each PLTL workshop, and attended thirteen of fourteen PLTL workshops. Veronica, who wrote concept summaries for herself and prized the conversations with classmates and peer leaders during workshops, performed above average on all three course exams and 87th percentile on the ACS first-semester organic chemistry exam.

Veronica meticulously drew in all lone pairs before proceeding to solve the resonance interview problem correctly. Similarly, she drew in relevant lone pairs before drawing the curved-arrows to explain the mechanism of interview problem two. Although she looked at bond connection differences between intermediates prior to drawing the curved-arrows, she drew the arrows in the order that suggested that she understood the underlying physical phenomena. Veronica identified the leaving group, nucleophile, substrate type, and solvent for interview problem three, then drew the correct mechanism prior to writing the racemic products. She reasoned through the majority of interview problem four correctly, but was unable to complete the problem because she neglected to draw the double bond necessary for the keto-enol tautomerization step. Veronica appeared to struggle with the interaction between the concepts and mode of representation, curved-arrow formalism.

4.5.1.9 Erin

Erin, a 33-year-old Caucasian working single mother and student, described a weekly balancing act between attending classes, preparing for the weekly workshops, and caring for her external responsibilities. She described during the interview that she read the textbook and attempted the workshop problems in advance, but appreciated that she could count on her classmates to explain concepts to her during workshop, too.

> …it was just nice that you knew that, going in, that if I didn't know how to do this problem somebody else probably did and could explain it.

Erin earned an average grade on the first course exam, slightly below average grades on the other two course exams, and 75th percentile on the ACS first-semester organic chemistry final exam. Based on her course performance and description of her PLTL experience, Erin’s learning was benefitted from the social constructivist environment.

Erin drew correct curved-arrows for the resonance structure interview problem, but neglected to assign correct formal charge to three structures. She drew several non-specific or out of sequence curved-arrows for interview problem two. Erin rationalized: “Sometimes I have to go backwards to go forward,” to explain why she noted bond attachment differences before drawing curved-arrows. For problem three, Erin rapidly drew the mechanism for an S_N2 reaction and the resulting product without discussing the criteria that lead her to select that reaction. She drew a non-specific arrow and an arrow depicting electron-rich attack of an electron-rich center, the oxygen of water attacking the terminal end of the alkyne, for interview problem four. Essentially, Erin's interview discourse revealed a lack of meaning being portrayed with curved-arrow formalism.

4.5.2 Cyber PLTL Students

4.5.2.1 Blake

Blake, a 19-year-old Caucasian student, pushed his grey knitted hat up halfway before starting to solve the interview problem set, suggesting that he was about to concentrate and didn't want anything to obstruct his view. He displayed the same air of determination that I had noticed during workshop observations. Blake had been one of the more vocal, go-to problem solvers in his workshop section, who described that he read the textbook chapters if the content seemed challenging in lectures, but consistently completed the workshop problem sets in advance of workshops. Furthermore, he said that he didn't meet his classmates to study for exams because he felt that activity would have taken away from both his own study time and attention to the study strategies he thought worked best for him. Thus, although Blake didn't participate in study groups, his consistent thorough preparation and willingness to help others during the cPLTL workshops benefitted all of his cPLTL classmates. Like several of the interviewees, Blake said that he accessed online resources during his study time, but rarely during the workshop. Blake earned well above average semester exam scores in addition to 97th percentile for the final exam.

Blake was reluctant to start the first interview problem, stating that he didn't see anything that would prompt the electrons to move, such as separation of charge in a starting structure. After that initial pause, he pushed π electrons from the ring in a manner that resulted in a negative charge on the external oxygen. From there, he adeptly drew a series of curved-arrows and resonance structures with the formal charges migrated around the ring. Although Blake looked at changes in bond connectivity before drawing curved-arrows in interview problem two, he drew appropriate curved-arrows in a rational sequence for each step of the amide bond formation. Furthermore, he identified the starting amine as a nucleophile and the hydronium ion as an acid while speaking during his problem-solving. Blake approached interview problem three systematically; first, he identified the secondary substrate, azide as a good nucleophile, bromide as a good leaving group, and acetic acid as a polar protic solvent; second, he explained how the solvent would stabilize the leaving group; third, he drew the S_N1 mechanism to generate (1-azidoethyl)cyclopentane. Although he neglected to include the likely hydride shift, the other components of the mechanism were drawn clearly and correctly. Finally, he provided a reasonable reaction mechanism to generate the desired product, although there were two common shortcuts included: losing a proton without showing the base abstraction of that proton specifically and protonating the enol with H_2SO_4 by utilizing a non-specific arrow. Overall, he demonstrated skill both utilizing and interpreting electron-pushing formalism, revealing a robust development of curved-arrow formalism understanding from the C-R-M perspective.

4.5.2.2 Kayla

Kayla, a 25-year-old Caucasian student, had razor-sharp posture during each workshop observation as well as her interview. This disciplined pre-professional student had her work, study, and fitness routine scheduled with almost military precision. She valued the way her peer leader provided guidance rather than answers when her group struggled with a problem:

> She's great at jumping in and helping us work through it. She doesn't directly give the answer. She helps us as a group kind of get through the problems that we collectively are kind of like, "We don't know what to do."

Kayla described moderate, but consistent preparation for the workshops, and earned slightly above average grades on all assessments for the course. During the interview, she gestured the movement of electrons before drawing any curved-arrows. Several times, Kayla scribbling out nearly-complete answers to the first interview problem, when denoting the formal charge would have yielded a correct answer. Her behavior was interpreted as tentativeness with regard to her ability to correctly draw curved-arrows. For the second interview problem, Kayla looked for bond attachment differences before drawing curved-arrows to indicate the movements of electrons responsible for each step of the amide bond formation sequence. This trend of predicting products of reactions without drawing the curved-arrows to indicate her rationale continued for the third and fourth interview problems. Furthermore, she suggested a vinylic cation intermediate and the production of hydroxide ion in the acidic milieu of reaction four. These actions suggest that curved-arrow formalism is disconnected from a clear conception of the underlying physical phenomena, which corresponds to disconnect between mode and reasoning wherein Kayla wanted to draw curved-arrows precisely, but didn’t understand the related concepts sufficiently.

4.5.2.3 Ashley

Ashley, a 20-year-old Caucasian student, was effusively friendly and wore blue nail polish and a floral dress to the interview. Her description that she worked on the workshop problems “here and there” from the time they were available each week until her workshop time and often went with questions about how to solve the problems was consistent with the my observations of her interactions with her classmates. She said that she utilized Google searches and YouTube videos to try to understand the course content, but found organic chemistry to be the hardest course in her undergraduate experience. For example, she described that both the stretch from reading the textbook to answering workshop problems and extending workshop concepts to answer exam questions were challenging. Furthermore, she was frustrated that she found the material so challenging since she did well in her general chemistry course. Although the interview occurred three days prior to the final exam, Ashley had already decided to retake the course, likely due to her below average performance on all three semester exams.

Ashley drew repetitive arrows during the generation of two of the resonance structures for interview problem one in addition to neglecting to denote formal charges for three separate structures. She looked at bond attachment differences between starting materials and intermediates before drawing curved-arrows to depict the movement of electrons for the second interview problem, although one of her arrows was non-specific and another showed the amine abstracting a proton from the carboxylic acid instead of attacking the carbonyl carbon from the starting material, not noticing that these arrows wouldn't result in the next intermediate. When faced with interview problem three, Ashley said, "This is what I struggled most with," referring to figuring out products from reactants and conditions. Her comment revealed that she was attempting to memorize reaction conditions to resulting products instead of using mechanistic reasoning to solve organic chemistry problems. Ashley spent seven minutes looking at interview problem four without writing anything, suggesting a critical gap in conceptual understanding needed for solving organic chemistry problems.

4.5.2.4 Thomas

Thomas, a 28-year-old Caucasian student, was quick to mention that he worked 30 hours per week during the semester and commuted to school, almost as if he was apologizing in advance for his limited preparedness. Further, he said that he studied for his classes on weekends, when he didn't work, and only looked over the weekly workshop problem sets immediately prior to workshops. Although he first described his group of classmates as working collaboratively to solve workshop problems, he revealed later in the interview:

> We'd have a question that she [our peer leader] hadn't addressed yet. So then we'd have to put that one on hold and move to the next one. Sometimes you get to the last one and we don't know what to do so we just have to wait.

This waiting for peer leader when faced with a challenge, rather than accessing alternative resources or brainstorming, was observed during workshops, also. Nevertheless, his peer leader encouraged students to brainstorm aloud when she was present. Although Thomas mentioned that he habitually accessed online resources, such as ChemWiki, YouTube, or Google, outside of the workshop, he did not access or share those resources during workshops. Thomas earned below average semester exam scores and 4th percentile on the ACS first-semester organic chemistry final exam.

Thomas exhibited incorrect electron-pushing formalism from the first interview problem, including neglecting to draw formal charges, drawing intermediates that were not suggested by the curved-arrows drawn, and an instance of double arrows to move the same pair of electrons. After drawing three resonance structures, he confessed, "I always have trouble drawing all of them. It feels like I'm drawing five but I'm actually drawing two," then ceased trying to solve that problem. For interview problem two, Thomas drew a curved-arrow to denote nucleophilic attack of the amine on the relevant carbonyl carbon, then erased that correct answer to draw a curved line (without arrowhead to designate direction) between the amine's lone pair electrons to the carbonyl oxygen of the starting material. He continued to suggest implausible electron pushing for the remainder of interview problems two and three, in addition to exhibiting difficulty drawing a plausible Lewis structure for sodium azide. Thomas proposed the key enol intermediate that would transform to the product of interview problem four, but was unable to sketch even part of the mechanism. Thus, Thomas seemed to struggle with the C-M portion of the C-R-M model for reasoning with curved-arrow formalism.

4.5.2.5 Joyce

Joyce, a 31-year-old working student, expressed that she was busy with both work and volunteer efforts outside the classroom. She exhibited a dependence on her peer leader during observations that suggested minimal pre-workshop preparation. Likewise, Joyce said that her small group would wait for their peer leader to come back to them to provide guidance whenever they were involved in learning activities that divided the cPLTL group of seven students. She earned average semester exam scores and 54th percentile on the final exam.

Joyce was detail-oriented in her depiction of curved-arrows, stating in the interview, “The tail has to be on the electrons that are moving.” She was also meticulous when drawing double-headed arrows between her resonance structures for interview problem one, yet didn’t realize that the curved-arrows drawn to produce her final resonance structure didn’t lead to the final resonance structure that she drew. Joyce struggled to draw appropriate curved-arrows that would lead to the provided intermediates for interview problem two, although her verbal rationale for the curved-arrows sounded reasonable, suggesting poor integration of the mode and concept aspects of curved-arrow formalism understanding. She stated, “Oh, gosh. Mechanisms are hard.”

Joyce further illustrated how challenging mechanistic thinking was for her with her handling of interview question three; she was able to identify the bromide leaving group, classify the substrate as secondary, identify the solvent as protic, and classify the reaction as an S_N1 reaction. However, she used two curved-arrows to communicate the hydride shift and mysteriously generated 1-ethylcyclopentan-1-ol as the final product, while saying aloud, “Should it be Markovnikov or anti-Markovnikov addition?” although these are terms that are not applicable to substitution reactions. Similarly, Joyce’s proposed mechanism for interview problem four also included molecular transformations not suggested by the curved-arrows drawn, suggesting a gap in the interrelationship between concept and external representation.

4.5.2.6 Christopher

Christopher, a 21-year-old Caucasian student, removed his sweatshirt in order to wear only the cooler long-sleeved t-shirt while solving problems during the interview. He appeared to be nervous and unsure during both the interview as well as the workshop observations during the semester. Citing part-time work as the reason, he stated that he habitually gave the workshop problem sets only a quick glance to identify topics covered before participating in the weekly workshop sessions. Christopher, who earned below average semester and final exam scores, did not mention reading the textbook or practicing problems as being part of his weekly routine. Instead, he stated that he looked up information on Google sometimes. I noted that Christopher seemed to depend heavily on his peer leader and classmates to explain concepts to him during workshops.

Throughout the first interview problem, Christopher drew unrealistic electron-pushing arrows, resonance structures that were not the product of the arrows shown in the previous step, and structures missing formal charges. The salient feature of curved-arrows, according to him, was that “the electrons move in one direction.” He continued to draw a mixture of curved-arrows going from high electron density to low electron density and curved-arrows going from low electron density to high electron density throughout his proposed mechanism for interview problem two. Additionally, he repeatedly identified protons as hydrides and drew arrows that didn’t explain the generation of the given intermediates. Christopher identified interview problem three as an S_N1 reaction, but showed the mechanism and product of an S_N2 reaction. Finally, he drew a pair of curved-arrows as the proposed mechanism for interview question four, not recognizing that the arrows drawn wouldn’t lead to the given product. Therefore, Christopher’s responses in the interview suggest that he had a gap in his understanding of the interplay between concepts and the external representations of the concepts (mode).

4.5.2.7 Kenneth

Kenneth, a 20-year-old Caucasian student, had an exuberant personality both during the workshop observations and his interview at the send of the semester. His perspective was particularly interesting because he had participated in general chemistry PLTL as a student, then selected the cPLTL setting to both be a peer leader for general chemistry and be a student for organic chemistry. Therefore, he was excited to offer his perceptions about the differences between PLTL and cPLTL experiences. First, Kenneth appreciated the opportunity to benefit more from classmates' questions in the online setting:

> What was really cool was when someone asked a question that I hadn't thought of myself. I would hear [peer leader] Brody's explanation for it. Whereas if someone asked a question I wouldn't have thought to ask myself in a face-to-face workshop, I don't get that explanation as well. I could just pause and go look at their paper and be like, "Oh that's interesting I hadn't thought of that."

Furthermore, he thought that the cPLTL setup made it easier to gain four or five classmates' perspectives on how to do each problem, whereas he would only have seen one or two nearest neighbors' worksheets in the face-to-face setting.

Kenneth did not have a structured chemistry routine, so he had not attempted the workshop problem set in advance of the workshop for the majority of the semester. Instead, he depended on the lecture presentation, tips from his workshop peer leader, Khan Academy videos, and interactive discussions with his workshop group to understand the workshop problems. For example, he thought his peer leader's reference to a popular song, "All About the Bass" (Kadish & Trainor, 2015), reminded him to always look for the Brønsted-Lowry base or nucleophile in each reaction to determine what to do. Likewise, he remembered the directions for absolute configuration by thinking of how to turn a steering wheel, not refer to the direction of hand movement on analog clocks. Kenneth earned average semester and final exam grades.

Kenneth commenced solving interview problem one by quoting his peer leader, “Brody has always said, ‘Make a bond, you break a bond.’” He drew curved-arrows precisely and confidently, moving lone pair on electrons to for a double bond, followed b directing former carbonyl electrons to be an additional lone pair on the second oxygen of the molecule. He continued to draw resonance structures until he had returned to the original structure, saying, “Brody says to go around until we get back to the start.” Kenneth’s emphasis on the suggestions of his peer leader, rather than his instructor or textbook, implied that much of his learning occurred during the workshop. Kenneth repeated the “make a bond, break a bond” heuristic several more times, such as while he was solving the second interview problem. He admitted, “Make a bond, break a bond. I say that 100 times.” When faced with interview problem three, Kenneth classified the substrate and identified the solvent, then predicted the product before drawing the mechanism, although his proposition of the correct product revealed that he had envisioned the appropriate S_N1 mechanism. While drawing, he discussed the fitness of the leaving group, classified the resulting carbocation, said that a hydride shift occurred to produce a more stable carbocation, drew the nucleophilic attack, and offered to draw both dash and wedge representations of the product “since the carbocation is planar.” Although Kenneth was adept at illustrating the movement of electrons to transition from one resonance structure to the next and to solve a substitution problem, he was unable to solve the fourth interview problem. He attempted the problem with a retrosynthetic approach, but neglected to draw any curved-arrows for the retrosynthetic attempt. Next, he re-grouped to try the problem from the forward direction, but stopped working on the problem once he had generated the bromonium ion intermediate. Thus, Kenneth's interview discourse suggested that the area of continued development for him from the perspective of the C-R-M model was reasoning with curved-arrows.

4.5.2.8 Jenae

Jenae, a 26-year-old African American student, wore creative, color-coordinated accessories during the interview. The missing buttons on each coat cuff, however, suggested a lack of attention to functional details. Similarly, I noticed immediately that Jenae drew the second line of double bonds like punctuation in the middle rather than extending from one atom to the next.

Jenae revealed early in the interview that she was frustrated by the difficulty of the course.

> Jenae: I liked 105 and 106 [the two semester sequence for general chemistry], but organic chemistry I can't get.
>
> Interviewer: Why not?
>
> Jenae: I guess some people like chemistry and some like bio, I guess.
>
> Interviewer: I was just curious if there was something about it you realized you didn't like.
>
> Jenae: I don't know maybe I like just learning and memorizing and spitting it out. But this one you had to do sort of like go beyond and analyze it. I don't have a love for chemistry.

Jenae described her weekly workshop routine as attempting the problems, then meeting with her classmates during the workshop to compare answers. If there were lingering questions, she and her group of classmates would wait to ask their peer leader to explain how to do the problem rather than try to employ mechanistic reasoning or access online resources. Although she performed well above average on two of the semester exams, she earned 41st percentile on the ACS first-semester organic chemistry final exam.

Jenae attempted the first interview problem three times, scribbling out early attempts and requesting a fresh copy of the problem set to try again. Each time, she drew a reasonable first arrow, but neglected to draw a second curved-arrow to prevent the octet violations of carbon or oxygen. She confessed, “I’m getting confused because I keep violating this oxygen.” Nevertheless, she circled three unreasonable structures as her responses to the problem. When faced with interview problem two, she stated:

> So for this one I’m going to look at this first product together. Look at the products and the reactant and see how they are connecting to each other.

After this pronouncement, Jenae tapped the reactant’s carbonyl group several times while pausing to think. Then, she drew a curved-arrow from the carbonyl’s oxygen to the double bond of the same carbonyl, followed by an arrow to denote the hydroxyl group of the carboxylic acid would leave with its electrons. Next, she stated that the hydronium would come in and attack, so she drew a double-protonated carboxylic acid with inadequate Lewis charge. Her proposal of unrealistic mechanisms continued throughout interview problem two. Jenae correctly identified the first step of interview problem three’s substitution reaction, but drew 2-cyclopentyl-2λ^5-propane-2,2-diol as the final product without providing mechanistic reasoning or noticing the five bonds to carbon in the side chain. She violated the octet rule, incorrectly referred to an action as a hydride shift, suggested generation of hydroxide in an acidic medium, and twice drew structures not resulting from the curved-arrows drawn during her proposed “mechanism” for interview problem four, suggesting a lack of understanding between the concepts and the external representations of the concepts.

4.5.2.9 Isaac

Isaac, a 24-year-old Caucasian student, was excited to talk about his cPLTL experiences during the interview. He smiled a lot as he described switching from a PLTL workshop section to a cPLTL workshop section early in the semester to take advantage of what he perceived to be the more focused atmosphere:

> …it seemed like in the in class version, if someone wanted to explain what they’re doing, they would have a white board or would be writing on a piece of paper… there was some sort of, like, level of obscurity for me just because of, like, the classroom setting and other things going on and on. The cPLTL, it was just, like, there’s this one camera and everyone’s getting the same feed and it just seemed very, very focused for watching people walk through things -- more so than in person. So that was really helpful.

This pre-professional student had nearly perfect workshop attendance and was noted as a prepared and vocal student in his workshop group during all observations. He described his weekly routine as reading the chapters in advance of lecture and working through all the problems in the book in addition to working on the workshop problems in advance of the weekly workshops. Additionally, he found tests on the internet to practice concepts and read supplementary resources, such as "Organic Chemistry as a Second Language." Isaac revealed during the interview that he both wrote summaries of his understanding of concepts for personal review prior to exams and verbally recapitulated the learning from workshop problems before the group moved on to the next problem. He earned the second highest grades in class on the semester exams and 100th percentile on the ACS first-semester organic chemistry final exam.

Isaac demonstrated adeptness with each of the components of the curved-arrow formalism, content, mode, and reasoning, to work through the first two interview problems in less than ten minutes, even identifying the nucleophile in the first step of the second problem without prompting. Although he noted bond attachment differences before drawing curved-arrows, he drew the arrows in the sequence that would reflect the logical physical progression in all but one occasion. He classified the substrate, nucleophile, and solvent before identifying interview problem three as an S_N1 reaction and drawing the correct mechanism. Likewise, he worked through the fourth interview problem mechanistically after drawing a sketch of a key intermediate, which has been noted in the literature to be a characteristic of successful organic chemistry problem-solving (Domin & Bodner, 2012). He described during the interview that he habitually attempted workshop problems using mechanistic reasoning before looking in his textbook for the reaction type:

> I kind of just start to doodle it out and then go back and usually see if those are plausible things that could happen.

4.5.2.10 Andrew

Andrew, a 27-year-old Caucasian student, left his leather jacket zipped up all the way during the interview, suggesting trepidation to share his thoughts. Indeed, his demeanor was also shy during the interview, although I would only have characterized his deportment as soft-spoken, not necessarily shy, during workshop observations. Andrew described his weekly organic chemistry studying routine as spreading textbook reading, textbook problem-solving, viewing Khan Academy videos or the Mastering Organic Chemistry blog, and working through the workshop problems sets in advance of each cPLTL workshop. Although accessing online resources was a regular part of his study habits, he said he only shared a link to a resource once during the workshops. Though Andrew described consistent preparation for workshops and earned above average semester and final exam scores, he stated in the interview that he wished the answers to workshop problems had been provided.

Andrew drew all of the appropriate curved-arrows to generate five reasonable resonance structures for interview problem one, but drew all of the arrows at once. Therefore, watching the sequence of curved-arrow depiction was key in my assessment of his curved-arrow formalism utilization. For interview question two, Andrew drew appropriate curved-arrows in the correct sequence for each step of the mechanism, although he noted bond attachment differences before drawing arrows at each stage. Nevertheless, he correctly identified molecules acting as base or nucleophile when asked. During Andrew's explanation of interview problem three, he predicted 1-cyclopentylethyl acetate as the product without drawing a mechanism. When prompted to show the mechanism for the reaction, he drew an S_N1 mechanism, leading to 1-ethylcyclopentyl acetate, despite identification of azide as the nucleophile. Likewise, he drew intermediates in the sequence to generate the desired product without including all the mechanistic steps.

4.6 Codification of Curved-arrow Formalism Analytic Framework

Once the individual student's interviews were coded using grounded theory, I noted and defined a list of curved-arrow formalism errors, which lead to the development of a curved-arrow formalism analytic framework (Table 4-17). Error categories in the framework which emerged from the analysis of the subjects' interview transcripts and written artifacts include: (1) drawing repetitive arrows to depict the movement of a single pair of electrons; (2) drawing a product which would not result from the arrows drawn; (3) drawing a single-headed hemolytic cleavage arrow instead of a double-headed heterolytic cleavage arrow; and (4) drawing curved-arrows out of sequence. I and my undergraduate research assistant utilized this framework to code the students' responses to the interview problem set. Their inter-rater reliability, Cohen's Kappa, was calculated to be 0.81, which corresponds to "Almost perfect" agreement (Landis & Koch, 1977, p.

165). For further validation of the analytic framework, an additional coder, a fifth year doctoral candidate with more than two decades of industry experience as a synthetic organic chemist, was asked to code the interview transcript of a randomly-selected participant. The inter-rater reliability calculation for all three raters was in the “Almost perfect” agreement range (Light’s Kappa = 0.91) (Landis & Koch, 1977, p. 165).

Table 4-17 Curved-arrow formalism analytic framework

Correct Curved-arrow Formalism (CAF)	
Electron-rich attacks electron-deficient	Discourse or artifact which indicates that a curved-arrow was drawn (1) from an electron-rich species (nucleophile or base) to an electron-deficient (electrophile or acid) species in a chemical reaction or (2) from a negative charge, lone pair, or pi bond to an appropriate electron-deficient site in a resonance structure
Incorrect/neglected Curved-arrow Formalism (CAF)	
Non-specific curved-arrow	Discourse or artifact which indicates that a student depicted unorthodox curved-arrow head or tail placement, such as a curved-arrow head to the middle of a bond
Electron-deficient attacks electron-rich	Discourse or artifact which indicates that an electron-deficient species attacks electron-rich species
Electron-rich attacks electron-rich	Discourse or artifact which indicates that an electron-rich species attacks electron-rich species
Repetitive arrows	More than one curved-arrow to depict the movement of a single pair of electrons
Octet rule violation for carbon	Discourse or artifact which indicates that a student writes a resonance structure, intermediate, or product with five or more bonds to carbon
Lack of acid/base or nucleophile/electrophile operational knowledge	Discourse or artifact which indicates a student is unable to identify Brønsted-Lowry acid/base or nucleophilic/electrophilic participants in a reaction sequence
Ignoring pH of medium	Discourse or artifact which indicates that a student proposes a mechanism that generates hydroxide in acidic reaction conditions or hydronium ions in basic reaction conditions
Missing arrows	Artifact which indicates that a bond has been broken during a mechanism, but the related curved-arrows were not draw in the previous step
Skipped mechanism	Discourse or artifact which indicates that a student proposed the product of a reaction without providing the mechanism by which that product would be produced
Lewis structure challenges	Artifact which does not portray the correct formal charge on an atom, based on the curved-arrows shown in the previous step
Out of sequence arrows	Discourse or artifact which indicates that the curved-arrows were not drawn in an appropriate sequence
Wrong arrow	Artifact which indicates that a student drew an inappropriate arrow type for the application implied, such as a reaction arrow between resonance structures or single-headed arrow to communicate heterolytic cleavage
Memorization	Discourse or artifact which indicates that a student memorized reaction conditions and product structure, rather than employing a mechanism to determine a products' structure or stereochemistry
Noting bond attachment differences instead of applying mechanistic reasoning	Student notes bond attachment differences between reactants and products to determine how to draw curved-arrows instead of relying on acid/base or nucleophile/electrophile identifications
Next structure wasn't the product from the arrows drawn	Artifact which indicates a structure which would not result from the curved-arrows drawn on the reactant, intermediate, or resonance structure of the previous step

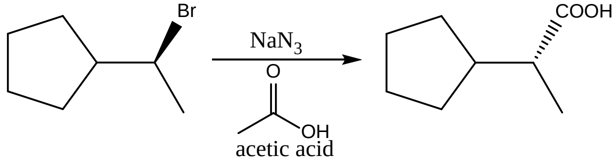
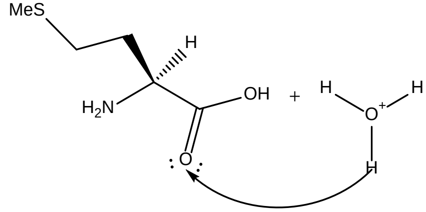
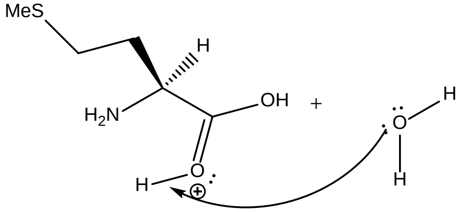
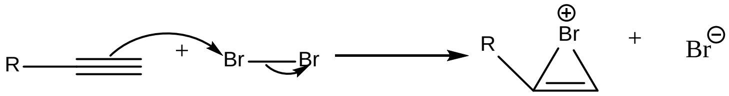
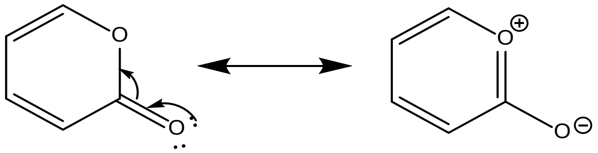
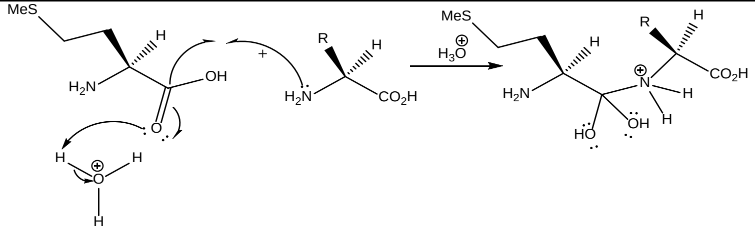
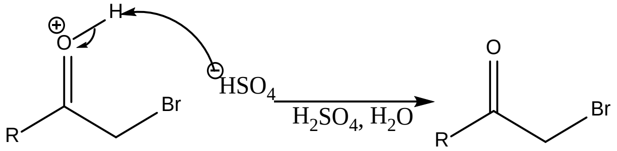
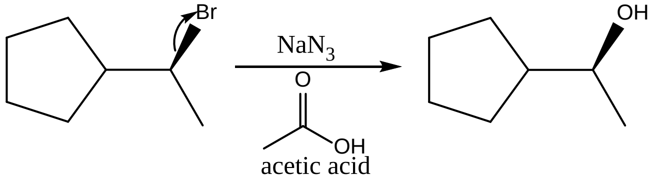
A Mann-Whitney U-test indicated a significantly higher frequency of incorrect curved-arrows drawn by cPLTL students for question four of the interviews (Table 4-18). Furthermore, a Mann-Whitney U Test of the frequencies of the specific error categories of incorrect curved-arrows by setting for the interview responses indicated that cyber students were significantly more likely to draw a product that was inconsistent with the curved-arrows drawn (Table 4-19). Moreover, there was a statistically significant correlation between the subjects' overall course grade and percent correct curved-arrows on both interview question one (Pearson correlation = 0.54, $p<0.05$) and interview question four (Pearson correlation = 0.76, $p<0.05$), which suggests that the ability to interpret the meaning communicated by curved-arrows is a key component of the course being assessed to determine the course grades. Thus, cyber students demonstrated significantly lower ability to use or interpret curved-arrow formalism in their problem-solving process than their PLTL counterparts.

Table 4-18 Frequencies of correct and incorrect curved-arrow formalism by setting

	Correct Curved-arrow Formalism				Incorrect Curved-arrow Formalism			
	Q1 Mean (SD)	**Q2** Mean (SD)	**Q3** Mean (SD)	**Q4** Mean (SD)	**Q1** Mean (SD)	**Q2** Mean (SD)	**Q3** Mean (SD)	**Q4** Mean (SD)
PLTL N = 9	7.00 (4.27)	7.78 (2.17)	2.22 (1.20)	4.89 (5.62)	0.89 (1.36)	3.00 (0.87)	0.56 (0.73)	1.22* (0.67)
cPLTL N = 10	7.50 (3.57)	6.60 (2.72)	2.00 (0.67)	3.60 (3.75)	1.70 (2.06)	2.69 (1.29)	0.70 (0.82)	3.70* (2.36)

*$p <0.05$

Table 4-19 Frequencies of interview students' curved-arrow formalism error categories by setting

	PLTL N = 9	cPLTL N = 10	Example
Skipped mechanism	0.22 (0.44)	0.20 (0.42)	
Electron-deficient species attacks electron-rich species	0.22 (0.44)	0.40 (0.97)	
Non-specific curved-arrow	0.33 (0.50)	0.80 (0.92)	
Missing arrow	0.67 (0.71)	1.70 (1.34)	
Repetitive arrows	0.11 (0.33)	0.50 (0.71)	
Wrong arrow type	0.11 (0.33)	0.20 (0.42)	
Ignored pH of medium	0.00 (0.00)	0.30 (0.48)	
Given product inconsistent with arrows drawn	0.00* (0.00)	1.20* (1.14)	

*p <0.05

4.7 Analysis of Student's Problem-solving Process

Toulmin's Argumentation Scheme is considered the foundation of scientists' "process of thinking and social interaction in which individuals construct and critique arguments" (Nussbaum, 2011, p. 84). Namely, Toulmin asserted that a basic argument (Figure 4-6) consisted of an assertion (Claim), facts that are the foundation of the claim (Data), and an explanation of how the Data leads to the Claim (Warrant). Furthermore, a more sophisticated argument may also include qualifiers or "conditions of exception" (Rebuttals) or further explanations that strengthen the warrant (Backing) (Toulmin, 1958, p. 101).

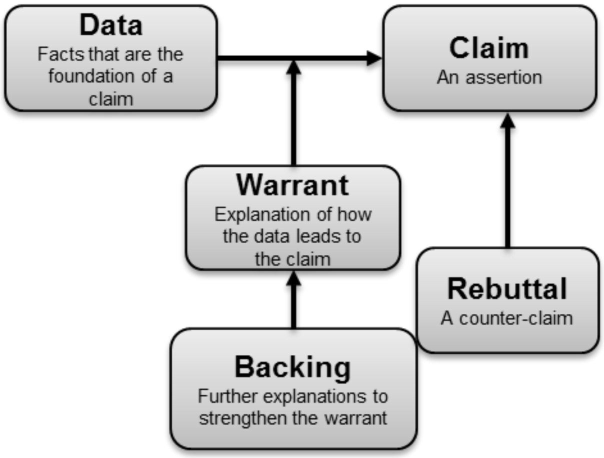


Figure 4-6 Toulmin's Argumentation Scheme (Toulmin, 1958)

Few instances of student interchanges were identified during the coding of workshop transcripts which included all components of Toulmin's Argumentation Scheme. Instead, students from both settings repeatedly followed an alternative problem-solving scheme (Figure 4-7) that was more closely-aligned with the decision-making process utilized by me, who is a synthetic organic chemist. For example, students determining which substitution reaction would occur with given substrate, nucleophile, and solvent combinations would rightly place higher priority on the substitution pattern of the alkyl halide or alkyl tosylate than the other reaction conditions. Although, Cruz-Ramírez de Arellano and Towns (2014) classified several reaction criteria, such as solvent and substrate classification, as equally-weighted data for the classical Toulmin Argumentation Scheme, Toulmin suggested, certain data should have higher priority than others in certain fields because the criteria “to justify such a conclusion vary from field to field (Toulmin, 1958, p. 36).” Furthermore, “the features of an argument in different fields…are field-dependent (Toulmin, 1958, p. 22).”, so an alternative argumentation scheme or problem-solving process should be utilized. Thus, if students’ were discerning physical phenomena from experimental data or characterizing an unknown compound from spectral data, such discourse would align with Toulmin’s Argumentation Scheme, but PLTL students’ evaluation of given reaction conditions to distinguish S_N1 or S_N2 reactions would be outside the scope of the classical Toulmin Argumentation Scheme because the substitution pattern of the alkyl halide or alkyl tosylate is a more important component than solvent, leaving group, or nucleophile.

Students in this study frequently demonstrated all or part of a particular process for determining which substitution or elimination reaction occurred, which is presented as a general (Figure 4-7) or detailed (Figure 4-8) scheme for problem-solving in organic chemistry (SPOC).

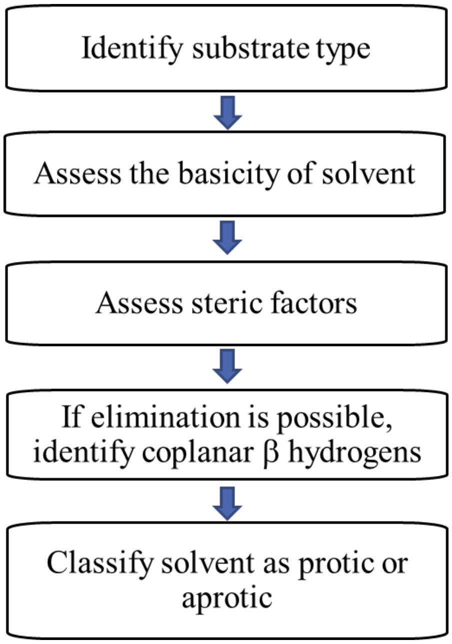


Figure 4-7 General scheme for problem-solving in organic chemistry (SPOC)

This decision-making process is similar to the decision tree proposed by Graham (2014), but students tended to look for β hydrogens only after determining that a base was present, rather than before. In cases where students were solving substitution or elimination problems without either mentioning all or part of SPOC or drawing the reaction mechanism from identifying nucleophile/electrophile partners, students decided which reaction type occurred by one of two methods: (1) listing reaction components as favoring one reaction type over another and selecting the reaction type with the most attributes in common to a tabular summary or (2) identifying a single reaction component, as in the example, “I said S_N2 because it’s a polar protic solvent.” These two approaches are typical of a student with an instrumental learning (Skemp, 1979) approach, rather than a relational learning (Skemp, 1979) approach.

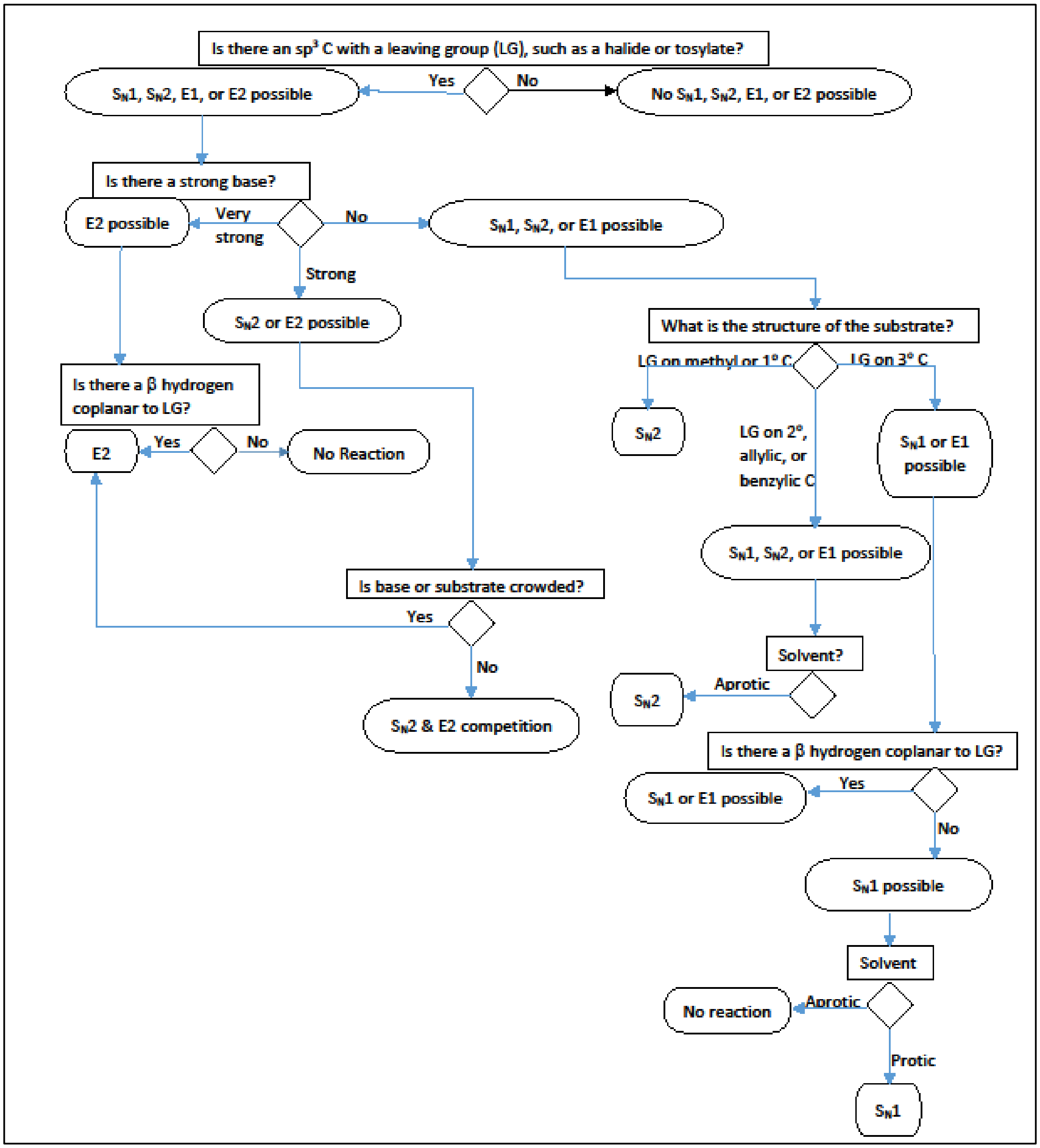


Figure 4-8 Detailed scheme for problem-solving in organic chemistry (SPOC)

CHAPTER 5. DISCUSSION

5.1 Response to Guiding Research Question 1: *How do organic chemistry students experience the PLTL and cPLTL settings?*

First-semester organic chemistry students in the PLTL and cPLTL workshop settings at this institution exhibited comparable workshop attendance frequencies, but reported significantly different dynamics in the student perception surveys. PLTL students reported that they valued both one-on-one discussion with their peer leader and collaborating with their small group members significantly higher for their learning gains than did the cPLTL students. While not statistically significant, the face-to-face students' survey responses also indicated more interdependent problem-solving. The interdependent problem-solving in PLTL workshops often occurred as students took turns writing and explaining concepts on small, portable white boards. At the time of the study, comparable white board applications were still in the development phase and, therefore, were not utilized by cPLTL students. Although students in both settings were frequently reminded of the expectation to attempt workshop problems in advance, the cPLTL students reported in both surveys and interviews that they felt more accountable than the PLTL students for "having something written" on their worksheets.

Students exhibited comparable frequencies of answer-checking versus problem-solving behavior in the two settings for this study, although a similar study of general chemistry PLTL and cPLTL students had reported a higher incidence of answer-checking behavior in face-to-face settings (Smith et al., 2014). Likewise, the cognitive level classification of student dialogue was comparable in the two settings, despite one peer leader's perception that his online students had more in-depth content conversations. Ninety-two percent of the student dialogue from either setting corresponded to lower order cognitive levels (Remembering, Understanding, or Applying). This preponderance of lower order dialogue is consistent with Christian & Talanquer's (2012b) findings from discourse analysis of self-initiated study groups, as well as several studies of synchronous online interactions (Hou, 2011; Lin et al., 2013; Meyer, 2004; Valcke et al., 2009).

My finding that students in the face-to-face setting feel a stronger sense of community than their online counterparts is consistent with Smith et al's (2014) findings. Although the style and frequency of peer leaders' mentoring behaviors were comparable in the two settings, the peer leaders rewarded students differently in the two settings: PLTL students sometimes enjoyed tangible rewards, such as donuts, while cPLTL students were praised more frequently, even when controlling for peer leader. Lastly, organic chemistry cPLTL students utilized online resources more frequently than the PLTL students, just as general chemistry cPLTL students were observed using more online resources in an earlier study (Smith et al., 2014).

5.2 Response to Guiding Research Question 2: *Are organic chemistry students' performance comparable in the PLTL and cPLTL settings?*

Mann-Whitney U-tests revealed that there is no significant difference in the distribution of course grades of PLTL and cPLTL students by either singular grades or grade groupings. Secondly, ANCOVA analysis of PLTL and cPLTL students' ACS first-semester organic chemistry exam scores were comparable, with no interaction effect based on gender or ethnicity.

Although the course grade distributions and final exam scores were comparable for students from the two settings, cPLTL students' interview responses were significantly more likely to exhibit incorrect curved-arrows. In particular, cPLTL students were significantly more likely to have a proposed product that isn't implied by the curved-arrows drawn. Furthermore, there is a significant correlation between the students' course grade and percent correct arrows on the fourth interview probe, which assesses students' ability to solve problems using curved-arrow formalism. Therefore, I suggest that students in the online setting, who did not have access to a collaborative white board for large representations of reaction mechanisms during problem-solving discussions, developed lower mastery of curved-arrow formalism skills than their face-to-face counterparts during the same time period, using the same learning resources.

5.3 Response to Guiding Research Question 3: *Do high- and low-performing students experience the PLTL & cPLTL settings differently?*

Low-performing students from both settings shared frustration during their interview that peer leaders didn't teach them concepts, although peer leaders are trained to facilitate group problem-solving instead of teach students directly or provide answer keys (Gosser et al., 2001). Although these students performed consistently poorly on workshop preparedness quizzes, which are designed to assess student's mastery of low cognitive order tasks, the low-performing students didn't adjust their workshop preparation behavior over the course of the semester. Instead, each were seen depending on either classmates or their peer leader to provide guidance for workshop problems rather than willingly participating in collaborative problem-solving.

In contrast, high-performing students from both PLTL and cPLTL settings voiced enthusiasm about the mentoring of their peer leader and the usefulness of group debate for the merits of different problem-solving approaches. Furthermore, many of the high-performing students shared during the interview that they frequently practice drawing reaction mechanisms over and over. Two students, in particular, stood out to me due to their obvious enjoyment writing clear, meticulous mechanisms.

5.4 Response to Guiding Research Question 4: *Do high- and low-performing students from the PLTL & cPLTL settings use or understand curved-arrow formalism differently?*

Skemp (1979) suggested that there are two kinds of learning: instrumental learning and relational learning. Instrumental learning "consists of recognizing a task as one of a particular class for which one already knows a rule" (Skemp, 1979, p. 259), while relational learning consists of relating a task to a network of connected concepts (Skemp, 1979, p. 260). Low-performing students from both settings revealed evidence of instrumental learning in both workshop discourse and interviews. For example, Susan said that she studied reactions with flash cards in lieu of drawing reaction mechanisms. Similarly, every student interviewed provided an almost identical definition for the meaning of curved-arrows, but the low-performing students were progressively unable to demonstrate correct curved-arrow drawings and interpretation of curved-arrows from the first to the last interview probe. Furthermore, several of these students referred to a memorized table of S_N1 and S_N2 reaction criteria instead of evaluating the reaction conditions holistically. Clearly, these students may have memorized the definition that a "curved-arrow represents the movement of electrons," but the symbols did not actually hold meaning for the students that would enable them to solve problems using curved-arrow formalism.

There were both instrumental and relational (Skemp, 1979) high-performing learners from both settings. Several high-performing students who drew correct mechanisms for the first three interview probes, yet drew the arrows only after predicting the product. This "decorating with arrows" phenomena had been reported by Grove, Cooper, and Rush (2012). Likewise, approximately half of the high-performing students exhibited mapping, pointing from reactant to product repeatedly in order to decide where to draw arrows. This puzzle-solving, rather than problem-solving behavior, had been reported previously by Bhattacharyya & Bodner (2005). These mapping and post-product-prediction curved-arrow drawing behaviors were more frequent among the high-performing cPLTL students, many of whom struggled with the fourth interview probe, which required problem-solving with curved-arrow formalism rather than reproducing a known reaction or deducing curved-arrows from identifying the differences between reactants and products. Furthermore, analysis of PLTL and cPLTL students' interview discourse and artifacts revealed that there was no overall trend in which students from a particular setting were more likely to successfully integrate the three aspects of curved-arrow formalism understanding (content, mode, and reasoning) (Anderson et al., 2013; Schönborn & Anderson, 2008, 2009, 2010) than students of the other setting.

5.5 Implications for Faculty

First-semester organic chemistry PLTL students in this study were statistically more likely to develop curved-arrow formalism understanding than their cPLTL classmates, although both the PLTL and cPLTL students in this study earned higher mean ACS First-Semester Organic Chemistry Exam scores than the historical non-PLTL students. As previously reported in the literature, some of the PLTL and cPLTL made the following curved-arrow formalism errors: (1) an electron-rich species attacks an electron-poor species; (2) an electron-rich species attacks an electron-rich species; (3) curved-arrows were drawn which would result in the violation of the octet rule for carbon; (4) arrows for multiple reaction steps were drawn at once; (5) curved-arrows were drawn to proposed mechanisms which would not exist in the pH of the given reaction medium; (6) skipped mechanism (Grove, Cooper, & Rush, 2012; Scudder, 1992). Likewise, several students in this study exhibited mapping, looking from reactant to product to determine where to draw curved-arrows instead of employing mechanistic reasoning, as Fergusen and Bodner (2008) had previously reported. In addition to the curved-arrow formalism error categories provided in the literature, I identified the following additional error categories exhibited by the PLTL or cPLTL students: (1) non-specific curved-arrows; (2) repetitive arrows; (3) missing arrows; (4) out-of-sequence arrow drawing. The organic chemistry PLTL and cPLTL students' displayed comparable frequencies of having problem-solving discussions rather than answer-checking conversations, unlike the general chemistry PLTL and cPLTL students in an earlier study (Smith et al., 2014). Nevertheless, the cPLTL students were statistically more likely to either incorrectly draw or misinterpret curved-arrows than their PLTL counterparts.

Conceivably, the difference in PLTL and cPLTL students' view of one another's work and the specific collaborative techniques being utilized in PLTL workshops were the root of this curved-arrow formalism performance difference. Namely, PLTL students collaboratively generated mechanisms on a small, portable white board, while the cPLTL students in this study had small screen shots of one another's worksheets during mechanism conversations. Therefore, I emphatically recommend piloting collaborative white board applications, which have been developed since the study, to assess the impact of virtual and physical white board collaborative mechanism activities during PLTL and cPLTL workshops on students' curved-arrow formalism understanding development.

My new curved-arrow formalism analytic framework would be useful for the development of diagnostic curved-arrow formalism probes for formative and summative assessments. The distractors of multiple choice versions of these questions should be based on the modes of incorrect curved-arrow drawings which I reported in this study. Furthermore, my curved-arrow formalism analytic framework should inform the way that organic chemistry instructors diagnose students' drawings and interpretations of curved-arrow formalism for solving mechanistic problems because instructors will be better equipped to coach students' development of curved-arrow formalism from the C-R-M perspective when this finer-grained rubric is utilized in lieu of a “right or wrong” dichotomous grading practice.

Next, I suggest that students feel a different sense of accountability to stay on task and be better prepared for cPLTL workshops as compared to the PLTL workshops because their peers see and “hear every conversation” between participants. I suggest that this phenomenon may be one of the reasons that an earlier study reported that general chemistry cPLTL students felt less of a sense of community than their general chemistry PLTL counterparts (Smith et al., 2014). Namely, the “off-task talking” may be influential in relationship development between classmates. Therefore, I reinforce the recommendation that either pre-semester face-to-face community-building events or ongoing ice breaker activities should be incorporated in cPLTL groups in order to encourage relationship development and community formation (Smith et al., 2014).

My analysis of PLTL and cPLTL student workshop and interview dialogue revealed both instrumental and relational thinking (Skemp, 1979) . Therefore, further research is needed to create and assess workshop materials which advance students with an instrumental thinking approach to a relational thinking approach since we know that the workshop materials can influence student’s approach to discussing and solving problems (Brown et al., 2010; Kulatunga et al., 2014). Specifically, I believe that PLTL workshop questions which elicit student’s explanation of the role of all substances in reactions could propel students from being tempted to memorize substrates or solvents leading to specific reactions (instrumental thinking) to a more robust evaluation of reaction conditions (relational thinking). Equally, my suggestion for additional organic chemistry PLTL material development is also aligned with my finding that student dialogue was most commonly affiliated with the lower cognitive order characteristics of Revised Bloom’s Taxonomy for the Cognitive Domain (Anderson & Krathwohl, 2001). Moreover, I strongly suggest that students of both PLTL and cPLTL should be explicitly told in the beginning of the semester about the significant impact to their own learning that is caused by their explaining concepts to one another (Coleman & Coleman, 1998; Palinscar & Brown, 1984), which is the hallmark of this social constructivist pedagogy.

Furthermore, my analysis of PLTL and cPLTL students’ interview discourse and artifacts revealed that there was no overall trend in which students from a particular setting were more likely to successfully integrate the content, reasoning, and mode (Schönborn & Anderson, 2009) aspects of curved-arrow formalism understanding than students of the other setting. Therefore, I suggest that faculty explicitly train peer leaders to encourage students to articulate how their understanding of organic chemistry concepts and exhibition of curved-arrow formalism enable successfully solving organic chemistry problems.

Lastly, our research group expected that both students and peer leaders would perceive the virtual learning environment as less constrained than the physical setting, since they could extend the duration of workshops if desired as well as utilize several virtual side rooms during workshops (Mauser et al., 2011). Instead, both students and peer leaders reported that they felt the interaction style was more formal in the online setting. Kenneth, an organic chemistry cPLTL student who had formerly been a general chemistry PLTL participant, described his perception that the cPLTL environment was more intrusive than that of PLTL. Furthermore, one peer leader reported that she felt a heightened sense of responsibility to direct student activities and be authoritative in the online setting. However, Duncanson (2014) reported that less constrained classrooms influenced teachers to encourage students to be more self-directed and collaborative. Therefore, the cPLTL students and one peer leader did not perceive the online setting as less constrained.

5.6 Conclusions

The purpose of this study was to assess PLTL and cPLTL students' experiences and mastery of curved-arrow formalism as a means to solve organic chemistry problems. I found that, although there was no statistically significant difference in the distribution of course grades, there were several noteworthy differences in PLTL and cPLTL students' attitudes and ability to reason with curved-arrow formalism. Firstly, fostering students' integration into learning communities has been one of the goals of PLTL (or Workshop Chemistry) implementation since the mid-1990s (Gosser et al., 1996) because participation in an intellectual learning community is a high-impact educational practice (Astin, 1993), but cPLTL students apparently develop less of a sense of community than their PLTL classmates. I believe that, unless the social dynamics are altered by modifications to the way cPLTL is implemented, this phenomenon could lead to lower success rates of cPLTL students in first-semester organic chemistry courses.

Secondly, I observed that both PLTL and cPLTL students exhibited a preponderance of lower-cognitive order dialogue, comparable evidence of instrumental thinking, and under-development of concept-reasoning-mode understanding of curved-arrow formalism. Since students can be prompted to have more sophisticated content and argumentation discourse through question design (Brown et al., 2010; Kulatunga et al., 2014), the PLTL/cPLTL workshop materials should be redesigned to elicit students' articulation of both curved-arrow formalism and mechanistic reasoning in order to develop effective organic chemistry problem-solvers.

Thirdly, I have seen as the workshop coordinator of the organic chemistry PLTL workshop series that students are most engaged when supplied with a small, portable white board to supplement their discussion of particularly mechanistic problems. Students engaged in taking turns drawing and explaining curved-arrows is not only a key component of practicing organic chemists' communication among their team, but also a vital social constructivist activity among students. I believe that the lack of the dynamic, interactive drawing experience in the cPLTL setting during this study led to both cPLTL students having less practice with the mode and reasoning aspects of curved-arrow formalism and a greater likelihood of simply writing down what a classmate showed as a reaction mechanism. Consequently, the cPLTL students were statistically less likely to demonstrate an ability to draw, interpret, and reason with curved-arrow formalism when encountering a novel problem like interview probe 4 (51% vs. 20% incorrect curved-arrows drawn for probe 4). Therefore, I recommend that a collaborative white board application be incorporated into future organic chemistry cPLTL implementations in order to equalize the learning environments between PLTL and cPLTL.

Through discourse analysis, I determined that IUPUI's PLTL and cPLTL students approached the deduction of substitution and elimination reaction mechanisms by using an approach that had not previously been reported in the literature, which I have dubbed the Scheme for Problem-solving in Organic Chemistry (SPOC). Unlike the application of Toulmin's Argumentation Scheme (Toulmin, 1958) for these reaction types that had been suggested previously (Cruz-Ramírez de Arellano & Towns, 2014), I propose that some students' approach rightfully placed greater emphasis on certain reaction criteria, such as whether the substrate was a primary, secondary, or tertiary alkyl halide or tosylate, rather than other criteria, like solvent type. SPOC could be utilized by organic chemistry faculty to develop relational thinking (Skemp, 1979) among their students and discourage instrumental learning (Skemp, 1979) approaches, such as the use of tables for deducing substitution and elimination reaction mechanisms. Additionally, further research is required to determine if organic chemistry students at other institutions also exhibit the SPOC approach to solving problems.

I used grounded theory and a thorough review of the curved-arrow formalism literature to develop a curved-arrow formalism analytic framework that could be used by both organic chemistry education researchers and instructors. Researchers should conduct more extensive interviewing of students from a variety of institution sizes and types (Carnegie Classification of Institutions of Higher Education, 2010) in order to develop a database of diagnostic curved-arrow formalism probes. The distractors of multiple choice versions of these questions could be based on the modes of incorrect curved-arrow drawings which I reported in this study. Then, the multiple choice probes could be used for either formative assessments, such as Peer Instruction (Mazur, 1997), or summative assessments, such as a concept inventory. Although there are several chemistry-specific summative assessments, such as the (General) Chemistry Concept Inventory (Krause, Birk, Bauer, Jenkins, & Pavelich, 2004), Thermochemistry Concept Inventory (Wren & Barbera, 2013), and Oxidation-Reduction Concept Inventory (Brandriet & Bretz, 2014), there is not yet a comparable concept inventory for curved-arrow formalism understanding. My new curved-arrow formalism analytic framework will enable the development of a concept inventory for the curved-arrow formalism aspect of organic chemistry. Similarly, additional research should be undertaken to compare the curved-arrow formalism error categories that I reported for students whose course was organized according to functional groups (Carey, 2002; Klein, 2012) and the error categories developed by students from “mechanism first” organic chemistry courses, such as the approach described by Flynn (2015). Furthermore, my curved-arrow formalism analytic framework could inform the way that organic chemistry instructors diagnose students’ drawings and interpretations of curved-arrow formalism for solving mechanistic problems because instructors will be better equipped to coach students’ development of curved-arrow formalism from the C-R-M perspective when this finer-grained rubric is utilized in lieu of a “right or wrong” dichotomous grading practice.

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APPENDICES

Appendix A Tabular Summary of Peer-Led Team Learning (PLTL) & Peer-Led Guided Inquiry (PLGI) Literature

Authors (Year)	Setting	Institution	Level	Discipline	Study Type	Study Purpose	Findings
Akinyele (2010)	F2F	Howard University	Undergraduate	General/ Organic/ Biological Chemistry (GOB)	Quantitative	Program evaluation	PLTL DFW grades lowered from traditional 32.3% to 17.2% for the PLTL students, while the non-PLTL DFW grades was 40.6% (significant; large effect size)
Alger & Bahi (2004)	F2F	Southern Utah University	Undergraduate	General Chemistry	Quantitative	Program evaluation	No sig. difference in ACS General Chemistry Exam scores for PLTL and non-PLTL populations *Caveat: The non-PLTL “Control Group” was treated with a different academic intervention*

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Table Appendix A continued

Alo et al (2007)	F2F	Various (CAHSI)	Undergraduate	Computer Science	Mixed methods	Program evaluation	86% of students reported that PLTL participation helped them better understand course material 60% increase in college algebra ABC grades over 5 years at UHD 18% increase in computer science I ABC grades and 29% increase in computer science III ABC grades at UTEP
Amaral & Vala (2009)	F2F	University of Florida	Undergraduate	General Chemistry	Quantitative	Effect on peer leaders	Mentors earned higher grades in first-semester general chemistry than their counterparts, even if deemed underprepared for the course in the pre-test Mentors took more subsequent chemistry courses and continued to perform higher than non-mentors
Biggers, Yilmaz, & Sweat (2009)	F2F	Various	Undergraduate	Computer Science	Quantitative	Program evaluation	Significantly higher ABC grades for PLTL participants Significant increase in A grades and significant decrease in B grades with PLTL implementation

Continued next page

Table Appendix A continued

Black & Deci (2000)	F2F	University of Rochester	Undergraduate	Organic Chemistry	Quantitative	Autonomy support	Provision of autonomy support through active learning is linked to greater gains in conceptual learning
Chan & Bauer (2015)	F2F	University of New Hampshire	Undergraduate	General Chemistry	Quantitative	Program evaluation; attitude; self-concept	No sig. difference in performance or chemistry self-concept between PLTL and non-PLTL populations Significant, but modest decrease in chemistry attitudes, but no difference between PLTL and non-PLTL populations
Curran, Carlson, & Celotta (2013)	F2F	University of St. Thomas	Undergraduate	Statistics	Quantitative	Program evaluation; student attitudes	Significantly higher exam III & IV grades for PLTL students than non-PLTL students Significantly lower perceived difficulty of statistics course for PLTL students
Drane et al (2005)	F2F	Northwestern University	Undergraduate	Biology, Chemistry, & Physics	Quantitative	Program evaluation	Sig. positive difference for biology and chemistry workshop students, but no sig. difference for physics workshop students Larger positive impact on performance and retention for minority students than majority students

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Table Appendix A continued

Finn & Campisi (2015)	F2F	Merrimack College	Undergraduate	Anatomy/ Physiology	Quantitative	Program evaluation; SALG	Statistically significant improvement in tissues/muscle physiology unit, partial effect in terminology/cells unit; and no effect in other course topics >70% of students positively evaluated the learning gains of PLTL
Flores et al (2010)	F2F	University of Texas at El Paso	Undergraduate	Physics, Chemistry, Math	Mixed methods	Program evaluation	General chemistry students' pass rate increased from 50% to 75% in the first three years for PLTL implementation Peer leader graduation rate was 97%, compared to 49% 6-year graduation rate for overall undergraduate population
Foroudastan (2009)	F2F	Middle Tennessee State University	Undergraduate	Engineering	Quantitative	Program evaluation	Increased retention rate since implementing PLTL (95% for PLTL students)

Continued next page

Table Appendix A continued

Gafney & Varma-Nelson (2007)	F2F	> 10 institutions	Undergraduate	Various	Mixed methods	Effects of former peer leaders	At least 92% of respondents positively rated their peer leading experience for: • Appreciation of small-group learning and different learning styles • Gained confidence in presenting and working as a team • Greater appreciation of what it takes to be a teacher 18% still undergraduates; 43% employed in a science field; 23% in medical or graduate school; 7% teaching; 4% employed in a non-science field; 3% no response/unemployed
Gosser et al (1996)	F2F	The City College of the City University of New York; University of Rochester; New York City Technical School; St. Xavier University	Undergraduate	General Chemistry, Organic Chemistry, & GOB	Qualitative	Program evaluation	Faculty interviews, focus groups, student questionnaires, and peer leader logs indicate that the workshops positively impact students

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Table Appendix A continued

Hockings, DeAngelis, & Frey (2008)	F2F	Washington University	Undergraduate	General Chemistry	Quantitative	Program evaluation	Female, first-year, and pre-health students were statistically more likely to opt for PLTL, while student athletes were statistically less likely PLTL students had statistically lower college entrance exam scores, yet statistically outperformed the non-PLTL counterparts in the course
Hooker (2011)	F2F	Little Big Horn College	Undergraduate	Algebra	Mixed methods	Program evaluation	PLTL students had better attendance (49% vs 40%), completion rates (43% vs 35%), and course grades (43% ABC vs 35% ABC) than non-PLTL students PLTL students continued to gain proficiency in learning objectives, while non-PLTL students stagnated on specific content mastery Peer leaders reported gains in self-confidence, communication skills, time management, and increased problem-solving skills

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Table Appendix A continued

Horwitz & Rodger (2009)	F2F	Various	Undergraduate	Computer Science	Mixed methods	Program evaluation; attitudes	Grades of B or higher and retention rates for PLTL students were significantly higher than non-PLTL students Positive difference in percentage of females and minorities completing the course and earning grades of B or higher Significantly lower perception of instructor covering material too quickly for PLTL students compared to non-PLTL students
Hug, Thiry, & Tedford (2011)	F2F	Various	Undergraduate	Computer Science	Quantitative	Peer leader research	89 peer leaders over 5 semesters from 6 Computing Alliance for Hispanic Serving Institutions institutions self-reported significant increases in decision-making skills, facilitation skills, and content knowledge
Johnson, Robbins, & Loui (2015)	F2F	University of Illinois at Urbana-Champaign	Undergraduate	Engineering	Qualitative	Peer leader research	Peer leader journal entries reflected a transition from content expert focus to seeking effective facilitation techniques as the semester progressed

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Table Appendix A continued

Kulatunga, Moog, & Lewis (2013)	F2F	University of South Florida	Undergraduate	General Chemistry	Qualitative	Discourse analysis for Toulmin’s Argumentation Pattern (TAP)	Students are more likely to elaborate on their reasoning when co-constructing arguments in a group rather than making individual arguments Frequency of constructing individual arguments doesn’t necessarily correlate to a students’ course grade
Kulatunga, Moog, & Lewis (2014)	F2F	University of South Florida	Undergraduate	General Chemistry	Qualitative	Discourse analysis for peer leader influence on students’ argumentation behavior	Convergent questions lead students to produce higher-level arguments, while students tend to only provide an answer (claim) to direct questions Students can produce productive discourse with peer leader facilitation when provided prompts to elicit data, warrants, and backing
Lewis & Lewis (2005)	F2F	University of South Florida	Undergraduate	General Chemistry	Quantitative	Program assessment	PLGI attendance is significantly correlated to higher course exam and final grades PLGI students performed significantly higher on course and final exams than non-PLGI students, controlling for SAT scores

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Table Appendix A continued

Lewis & Lewis (2008)	F2F	University of South Florida	Undergraduate	General Chemistry	Quantitative	Program assessment	Improved performance on the ACS, regardless of student SAT sub-scores or class SAT average Neutral impact on students with differing demographics
Lewis (2011)	F2F	Kennesaw State University	Undergraduate	General Chemistry	Quantitative	Program evaluation	Significantly higher ACS exams percentages and course passing rates for PLTL students, despite comparable SAT scores 15% improvement in student retention for PLTL sections
Lewis (2014)	F2F	University of South Florida	Undergraduate	General Chemistry	Quantitative	Program evaluation	Medium-strength correlation between participation in general chemistry I PLTL and subsequent chemistry courses (general chemistry II, organic chemistry I, organic chemistry II, biochemistry and qualitative analysis) Significant correlation (small to medium effect size) between participation in general chemistry I PLTL and enrollment in later chemistry courses

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Table Appendix A continued

Loui, Robbins, Johnson, & Venkatesan (2013)	F2F	University of Illinois at Urbana-Champaign	Undergraduate	Engineering	Quantitative	Program evaluation	Significant interaction between PLTL workshop attendance and final exam score Female PLTL engineering students were significantly more likely to enroll in the next engineering course than non-PLTL female students PLTL students reported better understanding of course material
Lyle & Robinson (2003)	F2F	University of Rochester	Undergraduate	Organic Chemistry	Quantitative	Program evaluation	Regardless of gender or ethnicity, Workshop students performed significantly better than non-Workshop students
Lyon & Lagowski (2008)	F2F	University of Texas at Austin	Undergraduate	General Chemistry	Quantitative	Program evaluation	Learning group participants had significantly higher exam and course grades than non-participants The DFW rate was significantly lower for learning group participants (24% vs 43%)

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Table Appendix A continued

Mauser et al (2011)	F2F & Online	Indiana University-Purdue University Indianapolis	Undergraduate	General Chemistry	Mixed methods	Program evaluation	Comparable student performance across settings Preliminary discourse analysis revealed: • Peer questioning & collaboration • Articulation of problem-solving process • Critical thinking/reflection Greater use of online resources and less off-task behavior in cPLTL
McCreary et al (2006)	F2F	University of Pittsburgh	Undergraduate	General Chemistry Laboratory	Quantitative	Program evaluation	Workshop students had significantly descriptions of experimental goals and length/clarity of responses, but comparable quality of data analysis/logical reasoning
McDaniel (2014)	Online	Indiana University-Purdue University Indianapolis	Undergraduate	General Chemistry	Qualitative	Web conferencing platform evaluation	Adobe Connect was the best fee-based web conferencing platform Google Hangouts was the most functional free web conferencing platform, although additional applications would be needed to use a polling feature or record sessions

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Table Appendix A continued

Merkel & Brania (2015)	F2F	Morehouse College	Undergraduate	Calculus I	Quantitative	Program evaluation	No significant difference in learning gains or retention of PLTL students Variable peer leader dependability and abbreviated workshop duration cited as potential reasons for lack of workshop impact
Mitchell, Ippolito, & Lewis (2012)	F2F	Kennesaw State University	Undergraduate	General Chemistry	Quantitative	Program evaluation	Higher pass rate in GC2 for students who had GC1 PLTL (35% vs 30%) PLTL GC2 classes had statistically higher pass rates than traditional GC2 students (70.2% vs 57.1%)
Mottley & Roth (2013)	F2F	University of Rochester	Undergraduate	Engineering	Mixed methods	Program evaluation	Positive correlation between workshop attendance and course grade
Murray (2011)	F2F	Indiana State University	Undergraduate	Psychology	Quantitative	Peer leader research	PLTL students' perform significantly higher on a statistics and research methods instrument than non-PLTL students

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Table Appendix A continued

Pazos, Drane, Light, & Munkeby (2007)	F2F	Northwestern University	Undergraduate	Engineering	Quantitative	Program evaluation	After adjusting for SAT-math score, gender, and ethnicity, students who participated in 2 or more PLTL workshops were 5X more likely to complete the 4-course engineering analysis sequence than those who participated in fewer than 2 PLTL workshops
Pazos, Micari, & Light (2010)	F2F	Northwestern University	Undergraduate	Various STEM	Mixed methods	Observation instrument development	They developed 10-question scaled protocol to evaluate peer-led group dynamics on two dimensions: Group interaction style & problem-solving approach
Peteroy-Kelly (2007)	F2F	Pace University	Undergraduate	Biology	Quantitative	Program evaluation; SALG; Reasoning skills	PLTL students were significantly more likely to: • Use concept maps to answer a conceptual question • Perform better on semester and final exams • Earn better course grades

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Table Appendix A

Pittenger & LimBybliw (2013)	Online	University of Minnesota	Graduate	US Healthcare System	Mixed methods	Program evaluation	Students communicated that the discussion groups, particularly when they acted as the discussion leaders, were a very positive experience Implementing a peer review process for end-of-semester proposals was the most impactful activity to decrease instructor workload, not the discussion groups
Preszler (2009)	F2F	New Mexico State University	Undergraduate	Biology	Quantitative	Program evaluation	Significant improvement in grade distributions pre- and post-implementation, particularly for females and URMs
Quitadamo, Brahler, & Crouch (2009)	F2F	Washington State University	Undergraduate	Various	Quantitative	Critical thinking	A significant interaction was observed for critical thinking gains and PLTL involvement • Particularly positive performance and retention gains for females
Rein & Brookes (2015)	F2F	Florida International University	Undergraduate	Organic Chemistry	Quantitative	Program evaluation	No significant difference in students’ exam grades with and without PLTL implementation. *Note:* The study occurred during a period of multiple course format changes.

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Table Appendix A continued

Reisel, Jablonski, & Munson (2013)	F2F	University of Wisconsin at Milwaukee	Undergraduate	Algebra & Calculus	Quantitative	Program evaluation	Significantly higher average course grades for calculus I & II PLTL students and notably better average course grades for PLTL college algebra students.
Reisel et al (2012)	F2F	University of Wisconsin at Milwaukee	Undergraduate	Algebra & Calculus	Quantitative	Program evaluation	Significantly higher course grades for calculus I & II PLTL students and increased grades for PLTL college algebra and trigonometry students.
Reisel et al (2014)	F2F	University of Wisconsin at Milwaukee	Undergraduate	Algebra & Calculus	Quantitative	Program evaluation	Regular or frequent (9 or more) PLTL participation led to A & B grades more frequently than non-PLTL participation. Significantly higher average course grades for calculus I PLTL students and notably better course grades for PLTL college algebra students.
Roach & Villa (2008)	F2F	University of Texas at El Paso	Undergraduate	Computer Science	Mixed methods	Program evaluation	Increases in %ABC grades for computer science I (18%) & computer science III (29%) since implementing PLTL

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Table Appendix A continued

Sawyer, Frey, & Brown (2009a, 2009b, 2010)	F2F	Washington University	Undergraduate	General Chemistry	Qualitative	Student discourse & peer leader impact thereupon	Students led by a facilitative leader “acknowledged, built upon, and elaborated on each other's ideas” with equal involvement In contrast, students with an instructional leader tended to work individually when not listening to the peer leader, be answer-focused, and unequally participate Student discourse was related to problem structure
Schray et al (2009)	F2F	Lehigh University	Undergraduate	Organic Chemistry	Quantitative	Peer leader type	No significant difference in students’ course grades, regardless of peer leader type Surveys suggest that standard peer leaders are more likely to “teach” than in-class peer leaders, but better manage disruptive behavior

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Table Appendix A continued

Shapiro et al (2013)	F2F	University of California at Los Angeles	Undergraduate	Bioinformatics	Mixed methods	Program evaluation	Instructor-led and peer leader-led performance data was aggregated as PLTL data No significant difference in gene annotation skills for PLTL and non-PLTL students Students were more likely to seek technical and conceptual assistance from peer leaders than classmates
Shields et al (2012)	F2F	Washington University	Undergraduate	General Chemistry	Quantitative	Program evaluation	Significant improvement in students' course grades after PLTL implementation, with accentuated effect if the workshop is extended an additional 30 minutes and coupled with a peer mentoring program

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Table Appendix A continued

Smith et al (2014)	F2F & Online	Indiana University-Purdue University Indianapolis	Undergraduate	General Chemistry	Mixed methods	Program evaluation	Comparable mean student course grades and ACS exam scores Differences in social dynamics: • Reward/recognition • Personal accountability • Focus on problem-solving process vs. answer-checking • Frequency of off-task behavior • Use of online resources
Snyder & Wiles (2015)	F2F	Syracuse University	Undergraduate	Biology	Mixed methods	Critical thinking	No statistically significant changes in overall or subscale CCTST scores between groups • *Note*: The peer leader pretest mean score was higher than the national average Peer leaders reported perceived gains in: • Learning from multiple viewpoints • Experiencing new and different approaches to learning

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Table Appendix A continued

Streitwieser& Light (2010)	F2F	Northwestern University	Undergraduate	Various STEM	Qualitative	Peer leader style characterization	Characterized conceptions and approaches of teacher-centered and learner-centered peer leaders 19 peer leaders transitioned from 12 teacher-centered/5 learner-centered to 7 teacher-centered/10 learner-centered by end of semester
Tenney & Houck (2003)	F2F	University of Portland	Undergraduate	Biology & Chemistry	Quantitative	Program evaluation	Significant increase in chemistry students' % AB grades Significant correlation between workshop attendance and biology course grades Notable increase in proportion of chemistry majors' declaring intentions to teach

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Table Appendix A continued

Tenney & Houck (2004)	F2F	University of Portland	Undergraduate	Biology & Chemistry	Mixed methods	Effect on peer leaders	Students attributed greater learning and exam preparedness to PLTL involvement Peer leaders reflected they benefitted by: • Better learning content • Collegial relationship with college instructor • Enhanced teaching skills and love of teaching • Improved people skills
Tien, Roth, & Kampmeier (2002)	F2F	University of Rochester	Undergraduate	Organic Chemistry	Mixed methods	Program evaluation	Significant increase in course grades of all students post-implementation of PLTL • Although males outperformed females and majority students outperformed minority students (medium-large effect sizes) Significant increase in ABC grades for PLTL students PLTL students were significantly more likely to credit workshop involvement with increased learning than non-PLTL students perception of recitation

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Table Appendix A continued

Utschig & Sweat (2008)	F2F	Georgia Institute of Technology	Undergraduate	Computer Science	Mixed methods	Attitudes	Students highly rated the format of the course with PLTL implemented Peer leaders self-reported gains in skills and abilities
Wamser (2006)	F2F	Portland State University	Undergraduate	Organic Chemistry	Quantitative	Program evaluation	Workshop students achieved higher: • Success rates in the course (85% vs 69%) • Three-term persistence (57% vs 28%) • ACS exam scores (77th percentile vs 69th percentile)
Weaver et al. (2006)	F2F	Purdue & Ball State Universities	Undergraduate	Chemistry laboratories	Qualitative	Program evaluation	75% of students who opt-in to the CASPiE program are female Students appreciated participating in meaningful research, not confirmatory experiments, but needed more support to understand primary literature

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Table Appednix A continued

White, Rowland, & Pesis-Katz (2012)	F2F	University of Rochester Medical Center	Graduate	Nursing	Qualitative	Program evaluation	Students thought PLTL workshops were “pivotal” to: • Increased content understanding • Increased problem-solving and critical thinking skills • Decreased course anxiety

Appendix B Student Perception Survey

On a scale of 1 to 5 (one being least, five being greatest), rate each of the following activities according to how much each activity benefitted your learning.

1. One-on-one discussion with the Discussion Leaders.	1	2	3	4	5
2. Discussion Leader speaking to my small group.	1	2	3	4	5
3. One of my small group members explaining a concept to me.	1	2	3	4	5
4. Collaborating with my small group members.	1	2	3	4	5
5. Explaining concepts to other members of my small group.	1	2	3	4	5
6. Discussing and answering the workshop problem set.	1	2	3	4	5
7. Seeing from the preparedness quizzes what I didn't understand yet.	1	2	3	4	5

8. On a scale of 1 to 5 (one being least, five being greatest), rate the influence of your participation in the workshops on your organic chemistry problem-solving skills.
1 2 3 4 5

9. On a scale of 1 to 5 (one being least, five being greatest), rate how challenging the workshops problems are. 1 2 3 4 5

10. Select the answer that best represents how frequently throughout the semester that you attempted the workshop questions in advance of the workshop session.
Never Rarely Sometimes Almost Always Always

11. Select the answer that best represents how frequently throughout the semester that you understood one or more of the workshop questions based on explanations from your small group members.
Never Rarely Sometimes Almost Always Always

On a scale of 1 to 5 (one being least, five being greatest), rate each of the following activities according to how important each item was in making your decision to enroll in a face-to-face or an online workshop.

12. Best fit my schedule	1	2	3	4	5
13. My advisor recommended it	1	2	3	4	5
14. Avoid the commute to campus	1	2	3	4	5
15. Prefer learning online	1	2	3	4	5
16. Prefer taking courses on campus	1	2	3	4	5
17. Prefer face-to-face learning	1	2	3	4	5
18. Do not have access to the internet at home	1	2	3	4	5

19. What improvements could be made in the workshops to assist your learning?
[free response section]

Appendix C Semi-Structured Student Interview Protocol

Session Identifier: *Provide the interview date, time, recording's file name, and student identifier.*

Setting: *Describe the physical setting in which the interview occurred. May also include a sketch here.*

Time	**Interviewer Notes**
For each interviewer note, record the time of the statement	*Researcher to note gestures, tone of voice, or other notable features of the student during the interview*

To be spoken by interviewer when the interview starts: Thank you for volunteering to be interviewed about your experience in the C341 PLTL Organic Chemistry Workshop Series. I want to know if there are differences in student experiences and the way they think about mechanisms depending on their PLTL setting. So, we'll spend approximately 30 minutes discussing your experience this semester, then discuss the resonance structures for one compound and mechanisms for two to three reactions.

Student Interview Questions

Why did you select cPLTL or PLTL?

Tell me about your weekly organic chemistry routine.

What do you do to prepare for the workshops?

What do you do after the workshops?

What online resources do you use to learn organic chemistry or answer workshop problems?

How frequently do you use model kits or other hands on tools during the workshop?

Do you communicate with your group members outside of workshop? How?

How does your peer leader interact with your group?

Did your peer leader discuss study strategies with you? What did he/she suggest? Did you try some of those techniques? How did they work for you? Are some of those techniques part of your normal routine now?

Are there particular students who tend to answer problems during the workshop at the beginning of the semester?

How about now, at the end of the semester?

How does your peer leader try to engage more people?

What do you like best about the workshops?

What would you change about the workshops?

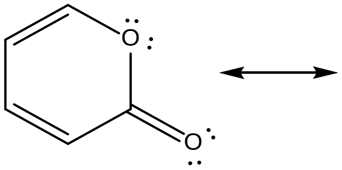
Would you take another cPLTL workshop if it were offered in another course?

What do the arrows communicate in a mechanism?

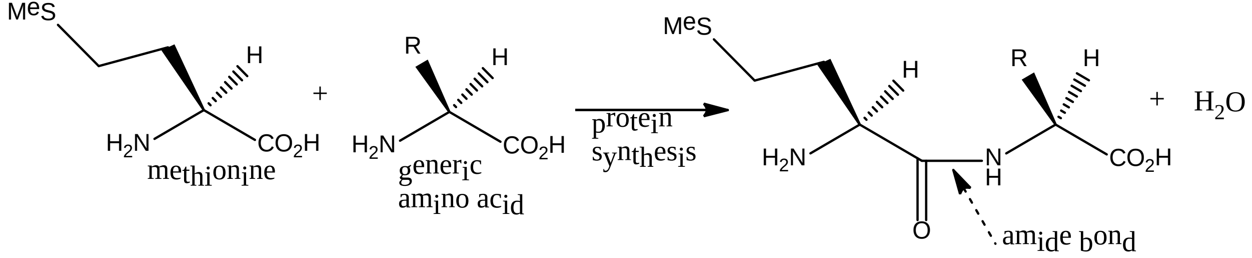
Is there anything else that you'd like to share about your experience that you haven't had a chance to say yet?

To be spoken by interviewer: For each of the following questions, talk aloud about your thinking while you write. [*Note*: The student is provided a paper copy of the following pages upon which to write while speaking.]

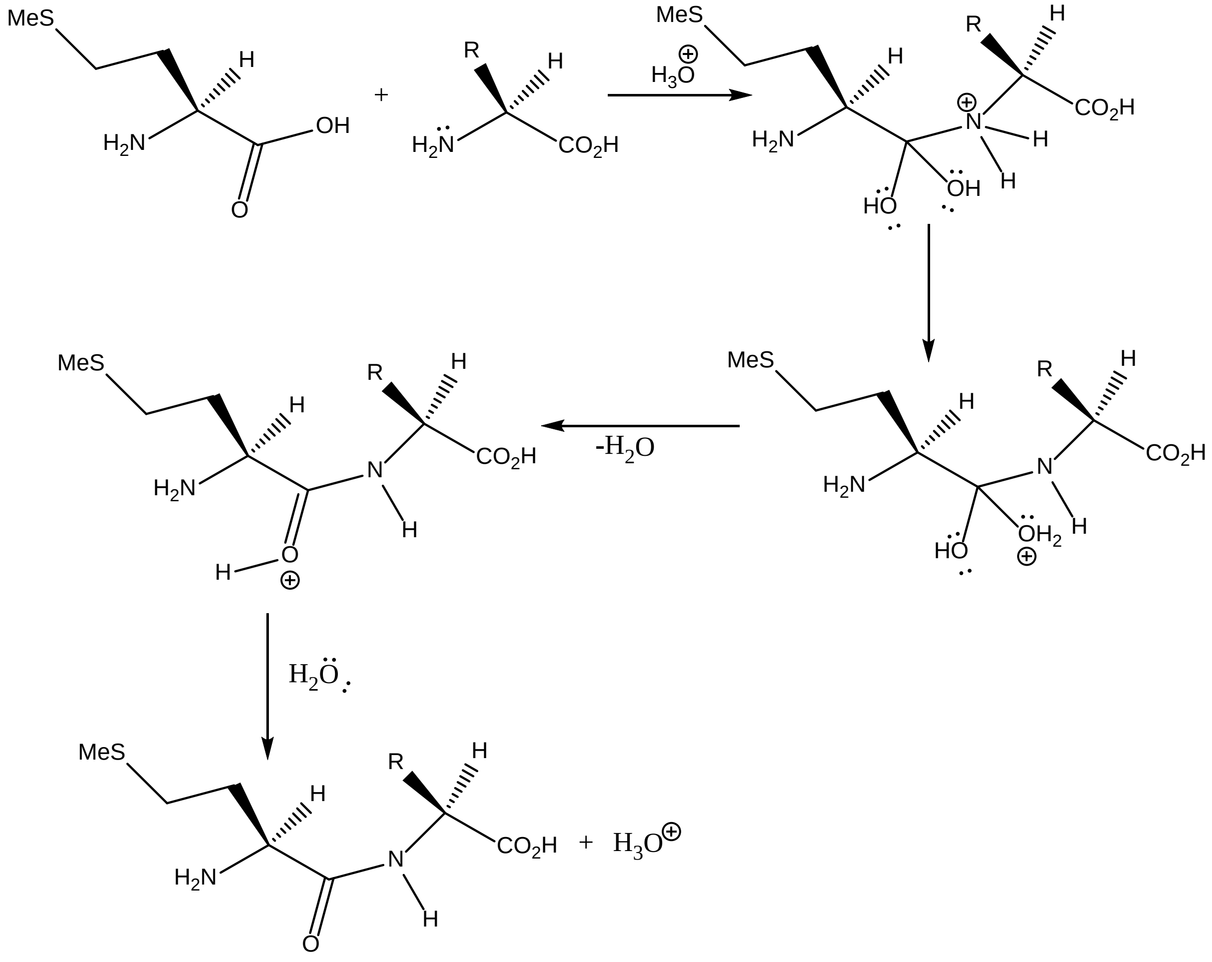
1. Using curved-arrow formalism to express the movement of electrons, generate at least three resonance structures of pyrone.



2. The amino acid methionine, the starter unit of all proteins, is joined to the next amino acid by an amide bond[2].



Draw curved-arrows for each step of the following mechanism:



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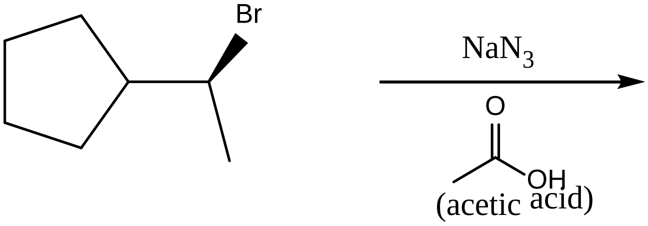
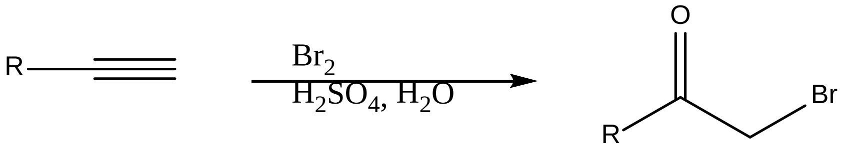
[2] Clayden, J.; Greeves, N.; Warren, S.; and Wothers, P. (2001) Organic Chemistry. 2001. New York: Oxford University Press,

3. Identify the reaction type, draw the mechanism, and identify the final product(s) of the given reaction, noting the stereochemistry of the product.



4. Propose a plausible mechanism for the following transformation.



Appendix D Semi-Structured Peer Leader Interview Protocol

Session Identifier: *Provide the interview date, time, recording's file name, and student identifier.*

Setting: *Describe the physical setting in which the interview occurred. May also include a sketch here.*

Time	**Interviewer Notes**
For each interviewer note, record the time of the statement	*Researcher to note gestures, tone of voice, or other notable features of the student during the interview*

To be spoken by interviewer when the interview starts: Thank you for volunteering to be interviewed about your experience in the C341 PLTL Organic Chemistry Workshop Series. I am interested in understanding if there are differences in your experiences in the two settings: online and face-to-face.

Peer Leader Interview Questions

What inspired you to be an organic chemistry peer leader?

Tell me about the learning activities you use in face-to-face PLTL.

How do you make students feel comfortable making mistakes in front of peers?

What do you like best about face-to-face PLTL?

What are the biggest challenges about face-to-face PLTL?

What would you change about face-to-face PLTL?

How would you change the beginning of the semester cPLTL training for students? For peer leaders?

Tell me about the learning activities you use in cPLTL.

What do like best about cPLTL?

What are the biggest challenges about cPLTL?

What would you change about cPLTL?

Do you sense a feeling of camaraderie between the students in either setting? How do you know?

Do you think the face-to-face PLTL students depend more on you or each other? How has that progressed over the semester?

Do you think the cPLTL students depend more on you or each other? How has that progressed over the semester?

In which setting do you find your students have more in-depth discussions of the chemistry concepts?

In which setting do you prefer to be a peer leader? Why?

What advice would you give a new face-to-face peer leader?

Would you give the same, different, or additional advice to a new cyber peer leader?

How has your experience as a peer leader affected you?

Would you like to be a cyber peer leader again?

Is there anything else that you’d like to share about your experience that you haven’t had a chance to say yet?

Appendix E Course Grade and Percentage Correct CAF during Interview

Setting	Pseudonym	Course Grade	Course Score	Question 1 Percent Correct CAF Arrows	Question 2 Percent Correct CAF Arrows	Question 3 Percent Correct CAF Arrows	Question 4 Percent Correct CAF Arrows
PLTL	Holly	B-	2.7	100.0	77.8	33.3	33.3
	Eli	A	4	91.7	90.9	75.0	93.8
	Susan	C+	2.3	25.0	70.0	0.0	0.0
	Veronica	A	4	100.0	62.5	100.0	100.0
	Erin	B	3	72.7	60.0	66.7	0.0
	Katherine	B	3	60.0	75.0	100.0	75.0
	Keith	A-	3.7	100.0	84.6	100.0	84.6
	Debbie	C+	2.3	100.0	69.2	100.0	0.0
	Matthew	B	3	100.0	72.7	80.0	66.7
cPLTL	Kayla	B-	2.7	93.3	72.7	50	66.7
	Thomas	D	1	66.7	66.7	33.3	0.0
	Blake	A+	4	100.0	100.0	100.0	50.0
	Christopher	C+	2.3	20.0	50.0	100.0	20.0
	Kenneth	B	3	100.0	88.9	100.0	50.0
	Isaac	A+	4	100.0	81.8	100.0	91.7
	Jenae	B	3	70.0	20.0	66.7	0.0
	Ashley	C	2	58.3	80.0	100.0	0.0
	Andrew	B+	3.3	100.0	75.8	100.0	44.4
	Joyce	B	3	100.0	60.0	50.0	38.5

VITA

VITA

SARAH BETH WILSON

EDUCATION

Purdue University West Lafayette, IN
Ph.D., December 2015. Major: Organic Chemistry
Thesis: A Comparison of First-Semester Organic Chemistry Students' Experiences and Mastery of Curved-arrow Formalism in Face-to-Face and Cyber Peer-Led Team Learning.
Thesis advisor: Pratibha Varma-Nelson.

Indiana Wesleyan University Marion, IN
Teaching Certification, 2009. Subject Areas: Chemistry, Physics, Mathematics, Physical Science.
Settings: High School/Junior High School/Middle School.

Brandeis University Waltham, MA
M.S. Department of Chemistry, 1999. Major: Organic Chemistry.

Saint Michael's College Colchester, VT
B.S. Department of Physics, 1997. Major: Physics. Internships: Solid State Physics, Material Science, Forensics

Areas of Specialization

Organic Chemistry, Chemical Education

TEACHING EXPERIENCE

Indiana University Purdue University Indianapolis, Indianapolis, IN 2014
Organic Chemistry Guest Lecturer
Taught several Organic Chemistry I and Organic Chemistry II lectures to accommodate professor travel. Conducted formative assessment activities to ensure student understanding of new concepts. (Class sizes: 100-140 students).

Indiana University Purdue University Indianapolis, Indianapolis, IN 2010-2015

Organic Chemistry Workshop Series Coordinator

Obtained Institutional Review Board (IRB) approval to perform research to assess the impact of Peer-Led Team Learning (PLTL) and cyber PLTL in the first-semester Organic Chemistry course. Obtained internal grant funding to support PLTL implementation and research. Designed and administered weekly peer leader training curriculum, which incorporated primary literature. Collaborated with 1-2 Organic Chemistry lecturers per semester to write workshop materials. Prepared workshop assessments and grading rubrics. Reported research findings at local and national meetings. Impacted >1,500 students and 60 undergraduate peer leaders.

University of Indianapolis, Indianapolis, IN

Adjunct Faculty 2010-2011

Developed syllabi. Created presentations to facilitate discussion of course content. Designed and administered assessments. Provided oversight of laboratory activities. Generated learning activities for Introduction to General, Organic and Biochemistry and Elementary Algebra courses. Provided additional tutoring to students. Administered all grades. Average class size: 24 students.

Herron High School, Indianapolis, IN

Chemistry & Mathematics Teacher 2007 - 2009

Developed syllabus and curriculum to teach the academic standards through meeting the needs of the students by matching their learning styles and multiple intelligences. Administered all grades. Tutored students in Mathematics, Chemistry, and Physics. Certified by the College Board to teach AP Chemistry. Founded and facilitated an after-school book club. Average Class size: 24 students.

Eli Lilly & Company, Indianapolis, IN

Business Operation Associate 2006-2007

Collaborated across organizations to develop a concise Time Entry System (TES) nomenclature. Developed and administered training for multi-national TES users.

Brandeis University, Waltham, MA

Chemistry Teaching Assistant 1998 – 1999

Performed laboratory set-up and take-down for undergraduate Chemistry courses. Demonstrated proper laboratory techniques, while presenting laboratory lectures. Supervised Chemistry students and answered questions during experiments. Tutored students in Chemistry upon request.

Saint Michael's College, Colchester, VT

Physics Teaching Assistant 1994 - 1997

Performed laboratory set-up and take-down for undergraduate Chemistry courses. Demonstrated proper laboratory techniques, while presenting laboratory lectures. Supervised Chemistry students and answered questions during experiments. Tutored students in Physics and Mathematics upon request.

HONORS

June 2012	Transforming Research in Undergraduate STEM Education Conference Graduate Student Travel Grant, Purdue University, IN
June - Aug 1997	Howard Hughes Research Fellowship, Dartmouth University and Thayer School of Engineering, Dartmouth, NH
Sept 1997 - May 1998	National Institute of Health Training Grant, Brandeis University, Waltham, MA
Sept 1993 - May 1994	New England Colleges Fund Scholarship, Saint Michael's College, Colchester, VT

PUBLICATIONS

PEER-REVIEWED ARTICLES

Smith, J., **Wilson, S.B.,** Banks, J., Zhu, L., & Varma-Nelson, P. (2014). Replicating Peer-led Team Learning in Cyberspace: Research, Opportunities, and Challenges. *Journal of Research in Science Teaching*, 51(6), 714-740.

Design and Synthesis of α-Aryloxy-α–Methylhydrocinnamic Acids: A Novel Class of PPARα/γ Dual Agonists. Journal of Medicinal Chemistry 2004, 47, 2422-2425.

PRESENTATIONS AT PROFESSIONAL MEETINGS

Varma-Nelson, P., Smith, J., **Wilson, S.B.**, Banks, J.,& Zhu, L. (March 2015). *Replicating peer-led team learning in cyberspace: Research, opportunities, and challenges*, Chemistry Education Research Symposium: New and Noteworthy in 2013-2014 Symposium, 249th ACS National Meeting, Denver, CO.

Wilson, S.B. & Varma-Nelson, P**.** (October 2014). *Social Constructivism in Cyberspace*, Transforming Institutions: 21st Century STEM Education Conference, Indianapolis, IN

Wilson, S.B. & Varma-Nelson, P**.** (September 2013). *Cyber Peer-Led Team Learning (cPLTL) Peer Leadership Study*, 246th ACS National Meeting, Indianapolis, IN.

Wilson, S.B., Minto, R.E., & Varma-Nelson, P. (September 2013). *Study of the Differential Effectiveness of an Organic Chemistry Workshop Series*, 246th ACS National Meeting, Indianapolis, IN.

Wilson, S.B. (April 2013). *cPLTL Peer Leadership Study: A Comparison of Online and Face-to-Face PLTL Peer Leadership Styles*, 5th Annual Edward C. Moore Symposium on Excellence in Teaching, IUPUI, Indianapolis, IN.

Wilson, S.B., Minto, R.E., Denton, R., & Varma-Nelson, P. (July 2012).. *Implementing Problem-solving Discussion Sections in First-semester Organic Chemistry*, 2012 Biennial Conference on Chemical Education (BCCE), Pennsylvania State University, University Park, PA.

Wilson, S.B. & Varma-Nelson, P. (February 2012). *Implementing Problem-solving Discussion Sections in the First-semester Organic Chemistry Lecture*, 4th Annual Edward C. Moore Symposium on Teaching Excellence, IUPUI, Indianapolis, IN.

Wilson, S.B., Minto, R.E., Denton, R., & Varma-Nelson, P. (September 2011). *Reaching Individuals among the Masses: Implementing Problem-Solving Discussion Sections in the First-semester Organic Chemistry Lecture*, American Chemical Society National Meeting, Denver, CO.

Wilson, S.B. (June 2007). *Development of an Integrated Molecule & Non-Molecule Forecast*, 43rd Annual Drug Information Association Conference, Atlanta, GA.

POSTERS

(* denotes undergraduate students)

Wilson, S.B. & Varma-Nelson, P. (June 2015). *Cyber Peer-Led Team Learning (cPLTL) in Organic Chemistry.* Chemistry Education Research and Practice Gordon Conference, Lewiston, ME.

Wilson, S.B. & Varma-Nelson, P. (April 2013). *Peer-Led Collaborative Development of Organic Chemistry Problem-Solving Skills*, 5th Annual Edward C. Moore Symposium on Excellence in Teaching, IUPUI, Indianapolis, IN.

Wilson, S.B., Minto, R.E., Denton, R., & Varma-Nelson, P. (June 2012). *Implementing Problem-solving Discussion Sections in First-semester Organic Chemistry*, Transforming Research in Undergraduate STEM Education (TRUSE) Conference, University of St. Thomas, St. Paul, MN.

Wilson, S.B., Andry*, D., Ekoma*, S., Matthews*, K., Timm*, F., & Varma-Nelson, P. (February 2012). *Reflections from Organic Chemistry Peer Leaders*, 4th Annual Edward C. Moore Symposium on Teaching Excellence, IUPUI, Indianapolis, IN.

Wilson, S.B., Minto, R.E., Denton, R., & Varma-Nelson, P. (February 2011). *Implementing Problem-solving Discussion Sections in the First-semester Organic Chemistry Lecture*, 3rd Annual Edward C. Moore Symposium on Teaching Excellence, IUPUI, Indianapolis, IN.

Wilson, S.B. (June 2006). *Development & Implementation of a "Non-molecule" Project Portfolio in SAP Project Systems*, 42nd Annual Drug Information Association Conference, Philadelphia, PA.

Wilson, S.B. (June 2005). *Project System Changes in a Global Integrated Environment*, 41st Annual Drug Information Association Conference poster presentation, Washington, D.C.

Wilson, S.B. (April 2002). *Cyclic Sulphamidites and Sulphamidates: Versatile Synthetic Intermediates*, Lilly Expo, Eli Lilly Corporate Center, Indianapolis, IN

Wilson, S.B. (May 2001). *Cyclic Ureas: Potent PPARα/γ Dual Agonists*, Discovery Chemistry Research Associate Poster Session, Lilly Corporate Center, Indianapolis, IN.

PATENTS

Feb 2002 Modulators of Peroxisome Proliferator Activated Receptor Agonists, Docket # X-13862

May 2003 Modulators of Peroxisome Proliferator Activated Agonists, Docket # X-15112

ADDITIONAL PROFESSIONAL EXPERIENCE

Eli Lilly & Company, Indianapolis, IN 2003 - 2007

Business Operations Associate

Collaborated with chemistry management, scientists, and project managers to prepare annual Business Plan. Provided analysis of budget and time entry metrics. Created a model to predict personnel needs for upcoming projects.

Eli Lilly & Company, Indianapolis, IN 1999 - 2003

Associate Organic Chemist

Collaborated with chemists, biochemists, and X-ray crystallographers to design compounds to target pharmaceutically-interesting targets. Performed Structure Activity Relationship studies to develop pharmaceutical candidates. Designed and performed syntheses to generate compounds. Purified and characterized organic compounds.

Brandeis University, Waltham, MA 1997 – 1999

Graduate Research

Performed multi-step organic syntheses to create a unique asymmetric catalyst. Performed experiments to analyze catalyst performance. Purified and characterized organic compounds.

Proctor & Gamble Pharmaceuticals, Cincinnati, OH 1998

Chemistry Research Intern

Performed combinatorial chemistry experiments. Purified and characterized organic compounds. Presented research to fellow interns and P& G research employees.

Brandeis University, Waltham, MA Aug 1997-May 1998
Graduate Research Rotations
Performed Organic Chemistry. Physical Chemistry, Biochemistry, and X-ray Crystallography research during six six-week research rotations. Presented research to fellow students and faculty.

Lehigh University, Bethlehem, PA May 1996-Sept. 1996
Material Science Research Intern
Performed fluorinated oxidation of silicon experiments. Presented research to fellow students and faculty.

Saint Michael's College, Colchester, VT/ Burlington Police Department, Burlington, VT
Forensic Science Intern Sept. 1995-May 1996
Classified fingerprints. Assisted in the processing of crime and death scenes. Catalogued evidence. Reorganized photograph filing system.

Lehigh University, Bethlehem, PA May 1995-Sep 1995
Material Science Research Intern
Performed fluorinated oxidation of silicon experiments. Presented research to fellow students and faculty.

PROFESSIONAL SERVICE

NATIONAL MEETING SERVICE

Session organizer and co-presider with Pratibha Varma-Nelson (Indiana University-Purdue University Indianapolis, Learning Chemistry in Cyber Environments Symposium, 246th American Chemical Society National Meeting, Indianapolis, IN. September 2013

Presenter & Facilitator with Pratibha Varma-Nelson, Randy Newbrough, Tom Janke, Julianna Banks, and Lin Zhu, cPLTL National Adoption Workshop**,** Sheraton Indianapolis City Centre Hotel, Indianapolis, IN June 2013

Session chair, Creating Dynamic Product Development Teams, 43rd Annual Drug Information Association Conference, Atlanta, GA. June 2007

REGIONAL SERVICE

Indiana Department of Education Advisory Board, Division of Professional Standards member 2009-2010

REVIEWING

IUPUI Center for Teaching and Learning Curriculum Enhancement Grant review panel

MEMBERSHIPS

American Chemical Society	2011-present
Hoosier Association of Science Teachers, Inc.	2007-2008