WHEN STUDENTS TEACH, EVERYONE LEARNS

THE EVOLUTION OF TEACHING STRATEGIES USED BY PRECEPTORS IN GENERAL CHEMISTRY

By

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Abstract

In general chemistry classes nationwide, peer-led team learning (PLTL) has proven to be an effective teaching method. The general chemistry class in this study, Chemical Thinking at the University of Arizona, uses a modified form of PLTL where preceptor-led sessions supplement lectures to help facilitate student learning. Yet aside from the individual experiences of students and preceptors, it is not well known how preceptors interact with students to help them learn in this model. To investigate this, we video-recorded preceptors interacting with students during weekly review sessions. We characterized many of the teaching strategies used by preceptors and identified an evolution in the use of these strategies as a preceptor gained experience. This evolution supports current research in learning progressions, which suggests that conceptual understanding develops over time. It is important for preceptors to possess a strong conceptual understanding of chemistry as well as teaching strategies specific to the course content, and our research indicates that both of these develop through experience. The results of this study are being used to implement a training program aimed at accelerating the development of teaching skills for new preceptors.

Introduction

Any seasoned college student will tell you that learning does not take place as a professor broadcasts knowledge and transmits it to the minds of hundreds of students sitting in a lecture hall. Research in how people learn shows that true learning takes place when students are active and engaged in the process. College professors have applied the results of educational research to their classes and have developed a diverse range of alternative teaching methods.

General chemistry is one class in particular that has been the focus of much research and change in recent years. General chemistry is often one of the first science classes taken by undergraduates pursuing degrees in science and engineering, and serves as an introduction to the expectations and cognitive demands of studying science at the university level. Class sizes in general chemistry are typically large, and this can create difficulties in implementing change. However, one advantage of large classes is that the students themselves provide a rich educational resource. A class environment where students act as both learners and teachers to build understanding for themselves and others is an attractive alternative to the traditional model where one professor attempts to teach a group of hundreds of students through lecturing.

Peer-led team learning (PLTL) is one way to restructure classes that originated in general chemistry courses at the City University of New York and has since spread to introductory science classes nationwide (Gosser, *et al*., 2008). In the PLTL model, lectures are supplemented by workshops where students work together in small groups to solve problems and build explanations with the assistance of a peer leader. Peer leaders are typically more advanced undergraduates who have previously taken the class. While they have a strong knowledge of the course material and concepts, leaders are not expected to teach students directly. Rather, they act as coaches and guides for students while the professor maintains the role of teacher. Peer leaders serve as a link between faculty and students, particularly in large classes where interactions between faculty and students are rare (Hockings, *et al.*, 2008). In this way, peer leaders are valuable assets in facilitating student learning and success in introductory science courses (Gosser, *et al*., 2010).

Students in general chemistry benefit academically from participating in PLTL. Previous studies have shown increases in grades and standardized ACS test scores where PLTL programs have been implemented as an alternative to traditional lectures (Gosser, *et al.*, 2010; Lewis, 2011). Student attitudes towards learning chemistry are more positive in PLTL classes compared to traditional lectures and students report that working together with classmates in peer-led groups contributes to their success in the class (Hockings, *et al.*, 2008).

Students who act as peer leaders in PLTL classes benefit from the experience in many ways. Peer leaders report gains in communication skills and confidence in their ability to present information to others (Micari, *et al.*, 2006). The opportunity to act in the role of a teacher rather than just a student is unusual for most undergraduates. This experience allows students to better understand the roles of teachers and their own learning process (Micari, *et al.*, 2006). In addition, students learn the scientific content of a class better by teaching. Peer leaders report that their own understanding of course material deepened and they were able to make connections to what they were learning in other classes (Micari, *et al.*, 2006).

Most of the research on PLTL in general chemistry has focused on outcomes for both students and peer leaders based on assessments and surveys, but less is known about the process by which learning actually takes place in this model (Roscoe and Chi, 2007; Micari, *et al*., 2006). Aside from the individual experiences of students, the teaching strategies used by peer leaders have not been well characterized. A few studies have examined the link between behaviors exhibited by preceptors and learning outcomes. Certain behaviors, such as building explanations and answering higher-level questions have been correlated to greater learning (Roscoe and Chi, 2007). However, there was great inconsistency with which students in a peer leader role performed these behaviors, with no explanation for factors that led to these behaviors.

Clearly, there is a lack of understanding of how peer leaders interact with students and what causes them to utilize various teaching strategies. In order to address this, we studied the process of peer teaching, focusing on how peer leaders evolved as they gained experience.

Research Goals

We want to understand how students who act as peer leaders in general chemistry develop teaching strategies as they gain experience and what factors contribute to this. The class we studied uses a modified PLTL approach where preceptors (peer leaders) provide instructional support and additional resources for students, however, it differs from classical PLTL in that preceptor-led sessions are optional for students to attend. In order to understand preceptor teaching and learning, we observed and characterized the strategies used by preceptors with different levels of experience.

The goals of this observational study reflect the desire to better understand the learning processes that take place in a PLTL model in general chemistry. Specifically, we want to:

- Characterize strategies used by preceptors to build explanations and interact with students in the context of both conceptual and quantitative problem solving.
- Model the evolution of teaching strategies as a preceptor gains experience and progresses to deeper knowledge of chemistry concepts.
- Identify factors that contribute to the development of deeper conceptual understanding through gaining experience as a preceptor.

Context and Participants

This study took place in a first semester general chemistry class at the University of Arizona, a large public research university, in the Fall 2012 semester. The format of the class is a large lecture (>250 students) supplemented by mandatory weekly discussion and laboratory sessions, which are conducted by graduate teaching assistants (TAs). The class is composed primarily of freshman and sophomore science and engineering majors.

The general chemistry class in this study follows an alternative curriculum called Chemical Thinking, which was developed at the University of Arizona by Dr. Vicente Talanquer and Dr. John Pollard. This curriculum emphasizes understanding chemistry as a way of thinking rather than a collection of disconnected facts, which is achieved through a carefully designed learning progression. The topics covered in a traditional general chemistry course have been reorganized around core questions to promote interconnected knowledge building. The curriculum also incorporates in-class exploratory and problem-solving exercises, facilitated by the preceptors, which encourage students to work together in small groups (Talanquer and Pollard, 2010).

Role of Preceptors

Preceptors are an integral part of Chemical Thinking. They are advanced undergraduate students who have previously taken the course and provide support for the instructor by helping to facilitate student learning through a variety of outlets. Students who earn an A or B in both semesters of Chemical Thinking and express interest are recruited to serve as preceptors, with an average of 10-15 students in this capacity each semester. Preceptors are responsible for attending all lectures and assisting with in-class activities, as well as holding 2 office hours per week. For this work they receive 3 upper-division credits per semester. Students enrolled as preceptors do not receive any formal training aside from having completed the course and meeting with the instructor periodically throughout the semester.

In addition to these responsibilities, a smaller group of preceptors (3-4) conduct weekly one-hour review sessions, called Friday study sessions (FSS). Attendance at these sessions is not mandatory, but all students are welcome and encouraged to attend. Average attendance ranges between 50-100 students, with the highest attendance right before exams. During review sessions, students work through a series of questions that challenge them to apply concepts covered during that week's lectures. Students are presented with a question and given 5-10 minutes to work with their peers while the preceptors circulate around the classroom providing assistance and answering questions. A preceptor then explains the answer to the question in front of the whole group and answers additional questions. These sessions serve to reinforce course content, facilitate peer learning in small groups, and help students prepare for exams.

While the majority of students serve as preceptors for one year, a few students who demonstrate exceptional interest and dedication are preceptors for two or three years. In this study, preceptors were grouped into categories of novice, intermediate, and expert according to their level of experience, which is summarized in Table 1. Of the preceptors who were part of the study, 4 were classified as novices, 2 as intermediate, and 1 as an expert preceptor.

	Novice	Intermediate	Expert
Years of experience with Chemical Thinking	1	2	3
Semesters of experience as a preceptor	<1	1-2	4+
Class standing	Sophomore	Junior	Senior
Chemistry classes taken	General	General and organic	General, organic, analytical, physical, and biochemistry

Table 1. Experience level of preceptors classified as novice, intermediate, and expert.

According to student surveys conducted in previous years, the preceptors in Chemical Thinking are perceived as a knowledgeable and helpful resource, with office hours and Friday study sessions rated as very helpful (Goodlet, 2011). Students also agree that preceptors were effective at facilitating learning during class (Goodlet, 2011). Course instructors have expressed a high degree of satisfaction with the preceptor program and see the preceptors as an integral part of the class. The preceptors themselves report positive experiences, which for some have led to leadership roles as second and third year preceptors. Thus, the preceptor program in Chemical Thinking is viewed as beneficial to both students and faculty and continues to evolve as new students serve as preceptors each year.

Methods

To study teaching strategies used by preceptors, Friday study sessions were video recorded over the course of the semester and all video footage was later reviewed. In total, 60 individual video clips were recorded, ranging in length from 2-5 minutes on average. Each video clip pertains to a single problem presented to students during FSS. Both one-on-one interactions between preceptors and students as well as preceptors giving explanations to the whole group were included. While the majority of recording for this study took place during Friday study sessions, a small amount of footage was also recorded during preceptors' office hours.

Videos were classified according to preceptor experience level and whether the questions being addressed were conceptual or quantitative (Table 2). This was done to determine if there were any observable differences between strategies used to explain these two types of questions. Questions were classified as quantitative if they required students to perform calculations, while conceptual questions did not.

	Novice	Intermediate	Expert	TOTAL
Conceptual	25	10	16	51
Quantitative	5	2	2	9
TOTAL	30	12	18	60

Table 2. Number of video clips recorded in each category according to question type and preceptor experience level.

Results

Novice

Quantitative Problem Solving

In their explanations, novice preceptors focused on guiding students to the correct answer to a problem. Novices approached quantitative problems by first identifying what equations were relevant to a given situation. In several cases, the preceptor did not immediately know which equation to use, and systematically searched through a list (mental or written) of equations to find one that "matched" the question being asked, a strategy which we termed "equation fishing." A common approach to this was to first identify what information was given and what variable needed to be solved for, and then look for an equation that related these variables. In most cases this approach was successful, though in some instances difficulties arose when more than one possible equation was identified and the preceptor had to make a decision. After the correct equation was determined, another major concern in quantitative problem solving was ensuring that all numbers had correct units when using them in equations, which was repeatedly emphasized by novice preceptors.

This problem solving strategy is very algorithmic, and preceptors often identified similarities between problems in a set where the same algorithm could be applied. For example, when showing light calculations involving the energy equation $E=hc/\lambda$, one preceptor pointed out that the same equation could be used for multiple questions, but a different variable was being solved for. These types of comments help students see recurring patterns so that they have a generalized approach for many problems within a set, rather than looking at each problem separately.

Conceptual Knowledge-Building

For conceptual questions, the patterns identified by novice preceptors appeared slightly different than in quantitative problem solving, and were often in the form of sets of "factors" that could be used to make predictions about a system. Novice preceptors relied heavily on the use of these factors when building explanations for students. They often asked questions such as "what factor are we using here to make a decision?" to focus the students' attention on what is relevant to the problem. Using these factors in making decisions helps students organize their thinking in a systematic way in order to understand and apply concepts.

Another teaching strategy demonstrated by novice preceptors is the elimination of extraneous information to focus on what facts are needed to answer a question. Questions were often approached from the perspective of a student, as the preceptor shared their own strategies and narrated their thinking process. For example, when showing how to balance a chemical reaction, one preceptor walked through her own approach step-by-step, rather than immediately giving students the answer. This provides a model of logical thinking for students to follow in solving problems.

Student Interactions

When addressing student questions individually, novice preceptors performed little to no assessment of students' background knowledge. When a student asked a question, the preceptor typically entered into an informative explanation without first determining what the student already knew. These types of explanations are helpful in getting students to arrive at a correct answer, but may not address the underlying confusion or misconception that led to the student's question.

In interacting with students on a larger group scale, novice preceptors acted as presenters of information. On some occasions, preceptors asked for input from the students such as "what did you get for this value?" but rarely engaged in dialogues with the group. Novice preceptors also sometimes called on individual students to provide their explanations to the group. After an explanation was given, the preceptor usually confirmed the validity of what the student said and summarized the explanation or reiterated key points.

Intermediate

Quantitative Problem Solving

Intermediate preceptors displayed many of the same characteristics as novice preceptors in their approaches to quantitative problems. The focus remained on getting students to derive a correct answer, though intermediate preceptors were much more efficient at doing so. They showed more confidence when explaining the solution to a problem and spent less time figuring out how to solve the problem. Rather, they were able to quickly identify a successful approach and guide the students through the necessary steps to solve the problem. When showing how to solve a stoichiometry problem, one preceptor began by outlining the steps necessary to obtain an answer. The preceptor explained that first, a unit conversion was necessary from grams to moles using the molar mass. Next, a molar ratio should be used from the balanced chemical reaction in order to arrive at an answer. Following this explanation, the preceptor showed the calculations to get the correct answer.

In general, there was still a heavy reliance on identifying what equations should be used, though intermediate preceptors emphasized the relationships among variables rather than immediately plugging in numbers. Intermediate preceptors also stressed the importance of units in solving equations and how the units of different variables were related.

Conceptual Knowledge-Building

Intermediate preceptors were very efficient at interpreting questions and were able to immediately identify what concepts were important in a given scenario. Their knowledge of chemistry concepts appeared more readily accessible to them, and explanations came quickly. Basic chemistry skills such as drawing Lewis structures and writing electron configurations appeared effortless and intuitive. In explaining more challenging conceptual questions, intermediate preceptors built explanations that relied on a set of applicable factors, however their explanations were more fluent and practiced than those of novice preceptors.

Preceptors at this level drew connections between different concepts and articulated them to the students. For example, one preceptor explained the relationship between solubility of ionic compounds and their respective melting points by using Coulomb's law, which expresses the electrostatic force between charged particles. These types of explanations also show a continued focus on rules and patterns that can be applied to different situations. When intermediate preceptors were asked deeper-level questions by students, the preceptors often did not have an explanation immediately ready and had to stop and think about their response. Intermediate preceptors were able to build explanations in response to students' questions based on their own conceptual knowledge after taking time to consider the question.

Student Interactions

Similar to novice preceptors, intermediate preceptors did not focus on assessing student knowledge in their interactions. When working through problems in front of a large group of students, they often asked the students to supply answers. Typical questions were "what value did you get here?" and "would this value be greater or less than?" which reflect lower-level reasoning skills. By asking these questions, preceptors involved students more in the process of problem solving, but these questions do not place a high cognitive demand on either students or preceptors. When students supplied answers, the intermediate preceptors typically confirmed the accuracy of their statements and occasionally provided clarification, but did not elaborate on concepts.

Expert

Quantitative Problem Solving

In helping students solve quantitative problems, expert preceptors shifted focus from deriving a correct answer to interpretation of the answer. The importance of equations, units, and other procedural elements of algorithmic problem solving were still stressed, but at this level more time was spent understanding what a numerical answer meant within the context of chemistry concepts. For example, in solving a problem that asked how many photons of light of a particular wavelength were required to produce a certain amount of energy, a preceptor explained why it did not make sense to have an answer that was not a whole number of photons and related this to the concept of energy quantization. This more sophisticated explanation reflects a deeper level of understanding of underlying concepts behind problems.

Conceptual Knowledge-Building

Expert preceptors gave more sophisticated explanations of concepts, which were longer and more detailed than explanations given by novice and intermediate preceptors. In general, more time was spent on explaining an individual problem by the expert preceptors compared to less experienced preceptors. Experts also elaborated more on student responses, rather than simply restating them, and gave deeper explanations in response to student questions. While working on a problem that asked students to determine molecular geometries, a student correctly identified the molecule OF_2 as bent, then asked why this was the case. The preceptor responded by explaining that the geometry of molecules is due to the repulsive force between negatively charged electrons, which causes regions of electron density to be distributed so that they are as far away from each other as possible. The preceptor also emphasized that this was not because the electrons "don't like each other," which is a common explanation given by students. The explanation given by the expert preceptor modeled the type of reasoning and chemical thinking that students should use to justify their answers to conceptual questions.

In many instances, expert preceptors guided students through explanation building through a series of questions and engaging in dialogue. When interacting with students, expert preceptors did less talking than novice and intermediate preceptors and allowed students to contribute more of their own ideas. Expert preceptors provided support and helped students build their own explanations by prompting them with questions or supplying some useful information. This strategy gave students the opportunity to construct their own understandings rather than relying only on explanations given by preceptors. Both strategies of giving explanations and building them alongside students were used with frequency by expert preceptors, suggesting a greater flexibility in what strategies they employ.

Student Interactions

Expert preceptors identified student misconceptions and took steps to correct them. These misconceptions were identified through questions asked by students as well as responses given by students to preceptor-initiated questions. In one instance, several students asked a similar question about the relationship between kinetic energy and potential energy. This led the preceptor to recognize that many students held the erroneous idea that kinetic and potential energy were inversely related. This misconception was addressed by the preceptor, who gave an explanation to the whole group of students about the relationship between these two forms of energy.

While expert preceptors asked students some of the same low-level reasoning questions as novice and intermediate preceptors, they also asked more higher-level reasoning questions. Questions such as "why does this happen?" and "what effect does that have?" forced students to think more deeply about concepts and reflect on their own understanding. This also served as a formative assessment strategy to indicate to both students and preceptors how a student's learning was progressing.

Discussion

The observations made in this qualitative study provide great insight into how general chemistry preceptors interact with students in a PLTL model. The preceptors observed in this study all displayed strong knowledge of fundamental chemistry concepts and how to apply them to solve problems. In addition, they were enthusiastic in their interactions and motivated to help students learn. These results are consistent with observations of peer leaders in PLTL programs nationwide (Lewis, 2011). A wide variety of teaching strategies were observed, suggesting that preceptors have flexibility in the way they interact with students to facilitate learning. The characterization of preceptor teaching strategies led to a model (Figure 1) that expresses how preceptors grow as both learners and teachers as they gain experience.

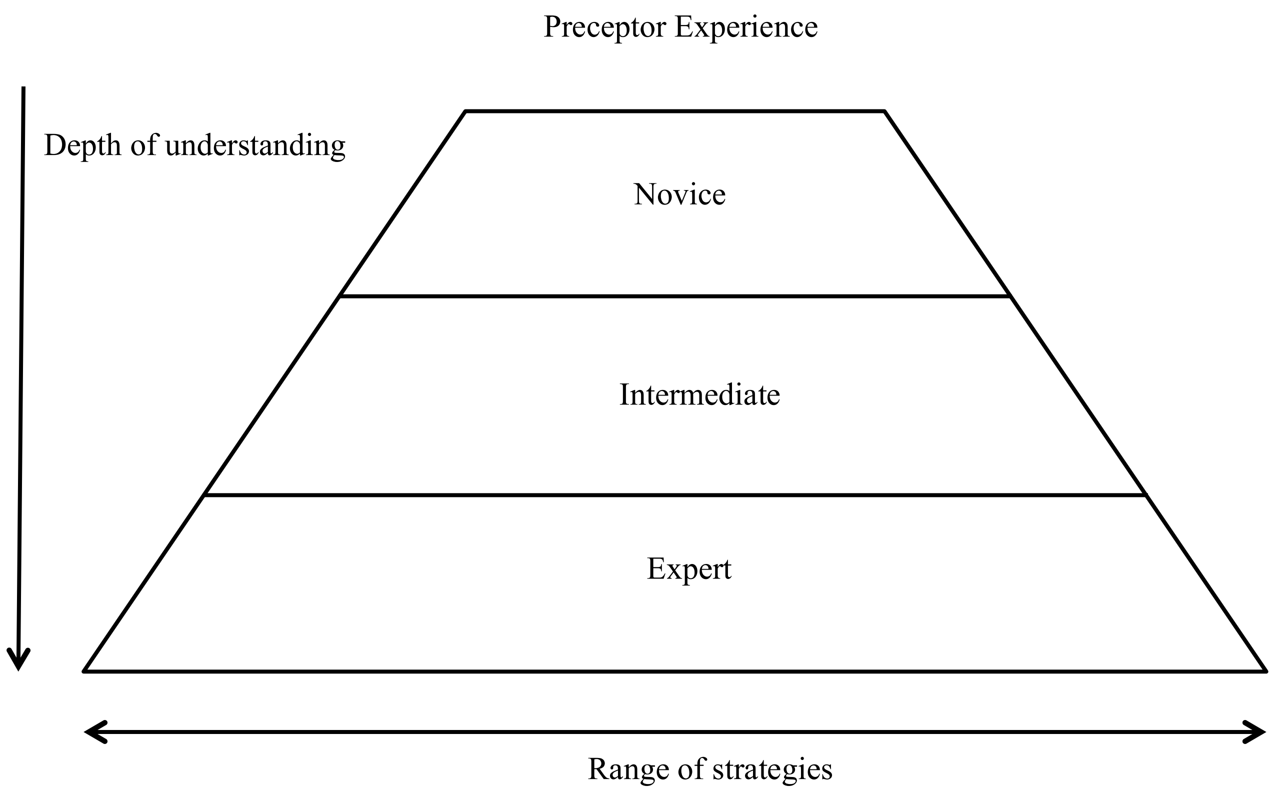

Figure 1. Conceptual understanding deepens and the range of teaching strategies used by preceptors increases as a preceptor gains experience.

Several important themes emerged from observing and characterizing the teaching strategies used by preceptors. As a preceptor gained experience, their interactions with students became more sophisticated and they employed a wider range of teaching strategies. The strategies used by more advanced preceptors suggest growth in both content knowledge and teaching abilities in chemistry, which is often referred to as pedagogical content knowledge (Tien, *et al.*, 2004).

The level of sophistication in preceptors' explanations shows an evolution in the depth of their thinking that comes through more exposure to the material and further training in chemistry. This supports current research in learning progressions, which suggests that it takes much more time than previously thought to learn a complex scientific discipline such as chemistry (Sevian, *et al*., 2012). Conceptual understanding develops over multiple exposures to ideas, and this progression takes place over a long period of time (Driver, 1989). Learning progressions in chemistry and other scientific disciplines describe how understanding of a topic changes, becoming increasingly more sophisticated with more exposure to that topic (Sevian, *et al*., 2012). While preceptors' content knowledge was not directly evaluated in this study, observations of how preceptors interact with students provide insight into the depth of their understanding.

Novice preceptors, having recently completed general chemistry, possess an understanding of chemistry that is likely only slightly greater than that of students in the class. Novices tend to approach problem solving from the perspective of a student, often working alongside the student to derive a correct answer. Preceptors' understanding appears to grow through a second or third year of exposure to the material, and taking more advanced chemistry classes also broadens their knowledge base. The act of building explanations and explaining their own thinking process allows preceptors to reflect on their understanding. This reflective process is called metacognition, which is cited as an essential component of expert-level knowledge in any field (Bransford, *et al*., 2000).

As preceptors gain experience, a shift occurs in how they approach problem solving. Novice preceptors are focused on guiding students to a correct answer, viewing that as the ultimate goal. By contrast, more advanced preceptors emphasize interpretation of an answer and what it means in the context of underlying chemistry concepts. An understanding of the procedural elements of problem solving in chemistry is important for students to develop, and the structured approaches modeled by preceptors are excellent at facilitating this. However, the ultimate goal of education in chemistry is for students to gain more enduring understandings about how core chemistry concepts can be applied in a variety of relevant contexts. This also reflects the goals of the Chemical Thinking curriculum, which envisions chemistry as a way of thinking organized around a set of essential questions (Talanquer and Pollard, 2010). These aims should guide how preceptors interact with students around problem solving. Observations made in this study suggest that this is not something inherently grasped by new preceptors, but rather a skill that develops through experience. In light of this finding, we propose that a focused training program for new preceptors would enable them to better help students in developing a deeper conceptual understanding of chemistry.

Preceptor Training

Currently, preceptors in Chemical Thinking receive very little formal training. Novice preceptors learn to teach by observing the professor and more experienced preceptors. The results of this study support the idea of implementing a training program to help preceptors develop tools to interact more effectively with students. For PLTL programs nationwide, peer leader training has often been described as superficial, focusing mainly on aspects of organization and management of student groups (Gosser, *et al.*, 2010). However, some PLTL programs have introduced training for peer leaders that focuses more on pedagogical training and direct application of research on how people learn to facilitate student learning (Tien, *et al*., 2004).

Successful training programs exist where peer leaders learn about educational theories behind PLTL by reading selected research literature on the subject. This gives peer leaders a greater understanding of how students learn in PLTL and how to most effectively facilitate learning. Both conceptual and quantitative problem-solving strategies are also stressed in this type of training. Peer leaders are taught to make their thinking visible when modeling problem solving to students. Leaders are then shown how to guide students through problem solving by providing scaffolding and encouraging students to explain their thought process. This strategy teaches students to adopt a structured approach to problem solving that increases their confidence and success in solving problems. Peer leaders are able to directly apply their new knowledge of pedagogy and problem solving to facilitate student learning (Tien, *et al.,* 2004).

Many PLTL programs in general chemistry have peer leaders enrolled in a separate semester-long course that provides pedagogical training (Hockings, *et al*., 2008; Lewis, 2011). Because of institutional constraints, our training program is envisioned as a single session that would take place at the beginning of the semester, supplemented by group meetings with the professor throughout the semester. Prior to attending the training, new preceptors will be required to read selected research literature on PLTL, peer learning, and problem solving to provide them with background knowledge in pedagogy. During the training, which will be led by the professor and advanced preceptors, these ideas will be discussed with the goal of establishing concrete strategies that can be used by new preceptors to facilitate student interactions. Rather than providing new preceptors with a list of effective strategies, it is our goal to have the preceptors come up with this on their own through group discussion and reflecting on their experiences as students as well as what they have read. We want preceptors to better understand that their role is not necessarily as a teacher, but rather as a coach to guide students and help them develop their skills and confidence in learning chemistry. This training program will enable them to be more effective in that capacity.

Conclusion

Previous research indicates that students' understanding of chemistry concepts develops over time with multiple exposures to ideas (Sevian, *et al*., 2012). The present study shows how the teaching strategies of preceptors develop with experience, as evidenced by interactions with students. In order to be an effective chemistry teacher, one must possess both strong content knowledge and teaching skills specific to the discipline (Tien, *et al.,* 2004). Both of these aspects grow through experience, but we propose that the development of teaching skills can be accelerated through targeted training.

Based on observations of preceptors' interactions with students, we hypothesize that the level of explanations given by preceptors reflects the depth of their conceptual understanding. More research is needed to better understand how specific teaching strategies and interactions with students are linked to the growth of conceptual understanding. Learning is an active process and knowledge is socially constructed through verbal dialogues and interaction around meaningful problems (Vygotsky, 1978). With this concept of learning, it seems only natural that teaching would lead to greater understanding, but little work has been done to characterize this process within the framework of the PLTL model in chemistry. One proposed investigation is a longitudinal study that follows the evolution of individual preceptors as they gain experience to see how both their understanding of chemistry concepts and use of teaching strategies change. A more complete understanding of the teaching and learning processes that occur within a PLTL model will enable chemical educators to structure peer-learning programs that effectively facilitate student learning.

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