Development of a Combined POGIL and Flipped Classroom: an Action Research Project

Matthew DeMatteo
University of Cincinnati Blue Ash College

In the fall of 2012 an action research project was undertaken in an organic chemistry classroom with the intention of refining the Process Oriented Guided Inquiry Learning (POGIL) methodology employed in the course. The original goal of the project was to identify the strengths students identified within the POGIL activities, determine areas of improvement in the POGIL activities and subsequent lecture periods, and to evaluate how student perceptions of POGIL changed as the course proceeded. Instead of merely refining the use of POGIL activities, an unexpected method of instruction was discovered based on student feedback throughout the action research project. This new method of instruction made use of POGIL activities, elements of a flipped classroom model, and small-group practice sessions followed by whole-class discussions. This methodology radically transformed the classroom instruction to create a more learner-centered classroom based on the learning cycle model. Students responded very favorably to this new model of instruction. In general students reported negative initial perceptions of the POGIL methodology, but that throughout the course of the semester, those perceptions changed and became increasingly positive. Potential implications of the newly-developed model for instruction and student perceptions of the methodologies are discussed in more detail.

       Within the current educational landscape there have been many evidence-based calls to remove the traditional lecture as the dominant means of teaching. Lecture's utility is suggested to be limited to primarily the transmission of information and therefore may not be the most effective method of instruction in most learning environments where problem-solving and critical thinking skills are heavily required (Bligh, 2000). This has led authors to frequently point out the limitations of lecture and suggest that "telling is not teaching" (Spencer, 2006). As an alternative several approaches have been proposed and evaluated to remove lecture and replace it with other learning activities. Two particularly popular approaches have been Process Oriented Guided Inquiry Learning (POGIL)

and the flipped classroom. Both of these techniques replace normal in-class lecture time with other active learning activities. These techniques both rely heavily upon the benefits of social constructivism in that students engage in an active learning process with their peers to construct, evaluate, and apply their content knowledge in the classroom (Duit and Treagust, 1998).

Process Oriented Guided Inquiry Learning (POGIL) is one of the oldest organized methodologies available for the implementing inquiry in the chemistry classroom (Farrell, Moog, and Spencer, 1999). Within this pedagogy, students work cooperatively in self-managed groups to develop their understanding of chemical concepts. While the POGIL methodology was initially developed in chemistry, it has been extended into a variety of field including anatomy and physiology (Brown, 2010), and psychology (Vangas, *et al.,* 2013). During POGIL activities, students are presented with a model situation which they are led to explore. Students are then guided to develop generalizations based upon this model and apply these concepts to specific problems that they would typically encounter in a traditional classroom. This places the students in a more active learning environment that is expected to show improvement not only in student performance but also in their positive self-concept and views of chemistry. Some studies have shown improvement in student performance in the general chemistry (Moog and Spencer, 2008) and organic chemistry (Hein, 2012) classrooms. Other investigators, however, have observed mixed results from the implementation of POGIL (Chase *et al.,* 2013; Abdi-Rizak, 2008). It has been suggested that, as with most teaching methodologies, the style of adoption of POGIL may influence student learning in such an environment (Daubenmire *et al.*, 2015). For example, it has been shown that simple differences in how the professor interacts with students can have a significant impact on student learning. These findings encourage implementers to carefully consider the way POGIL is adopted in the classroom to maximize the potential benefit of its implementation. In light of this, the current study sought to focus on how students felt about the POGIL methodology and refined its implementation in the classroom based on student feedback.

A flipped classroom is defined as one in which content is delivered by some means outside of class, while students instead use classroom time to complete practice problems that apply the content knowledge they have learned outside of class (Bergman and Sams, 2012). This model of instruction was first reported by Mazur (1991). In most flipped classrooms

content knowledge is delivered through the use of technology in either the form of video recorded lectures or computer-based instructional systems. The distinguishing feature of this approach, however, is that students learn the basic concepts outside of the classroom rather through an in-class lecture on the topics while class time is used to learning activities that are active and social (Abeysekera and Dawson, 2015). This allows class time to be devoted to deeper engagement with the content. A frequent lure of the flipped classroom among teachers is that it provides them more opportunities for individualized instruction and insight into the areas with which students struggle (Herried and Schiller, 2013). Despite its popularity and the rapid pace with which this approach to learning has been adopted by instructors, very little research has been undertaken to evaluate the effectiveness of this approach to learning. Indeed calls have been made for specific types of research to further assess the flipped classroom approach to learning (Abeysekera and Dawson, 2015). Some studies have begun to appear evaluating the effectiveness of this approach and one, in particular, has shown positive gains in an advanced placement high school chemistry classroom (Schultz *et al.* 2014). As such, the flipped classroom shows significant potential as an educational methodology.

The goals of this study were to ascertain student perceptions of POGIL throughout the semester by qualitative means and use student input to refine POGIL implementation in the classroom. The information obtained in this study may also shed light on how student perceptions of the POGIL methodology changed throughout the course of a semester. It has been generally noted that student perceptions of the active learning strategies, such as POGIL, tend to be more negative initially due to the dramatic difference in teaching methodology compared to most college courses that rely more heavily upon lecture (Felder and Brent, 1996; Abdi-Rizak, 2008). In this action research project, the investigator sought to give the students a voice in how the course was modified to better suit their needs, experience the modifications, and further refine the course structure. Through the course of this study, student feedback led to the unanticipated adoption of a flipped-classroom model of instruction. Three basic questions were established to guide this study:

1. What strengths did students recognize in the implementation of the POGIL activities?

2. What recommendations did students have to improve the implementation of the POGIL activities?
3. How did students' perceptions of the POGIL methodology change as they continued to take part in the activities throughout the semester?

   In addition to the student perceptions of POGIL, their perceptions of the follow-up lecture/practice periods were also evaluated and modified in the same way throughout the semester.

Methodology

Action Research Design

   This study made use of an action research design (Kemmis *et al.,* 1988; O'Hanlon, 1996; Towns, 2000) to obtain information from students and make modifications to the course in the hopes of improving the course design and implementation. Action research is described as a cyclic process, as shown in Figure 1. It begins with the identification of potential deficiencies in the current teaching practices. Based upon these deficiencies, an initial plan is developed to seek to address the perceived deficit in the teaching practices. This plan is then implemented in the classroom and evaluated through some measures such as surveys, tests, or classroom observations. Data are then collected from these measures. It is compiled and reflected upon to revise the teaching strategies and develop a new plan for implementation in the classroom. The cycle then repeats through the implementation and evaluation of this new plan. This leads to a continuous system of evaluation and improvement of teaching practices.

Figure 1. The action research cycle.

Participants, Institution, and the Course

The participants in this study were 34 undergraduate students in an Organic Chemistry I class at the University of Cincinnati Blue Ash College (UCBA) in the fall semester of 2012. The students primarily consisted of adults ranging in ages from 18 – 50 seeking careers in science (biology or chemistry), pharmacy, medicine, or engineering.

UCBA is a regional two-year college of the University of Cincinnati. Students primarily graduate from the college with an associate's degree or transfer to the University of Cincinnati to either a four-year bachelor's degree or a professional program.

The course is the first semester of undergraduate-level organic chemistry intended for science majors of various types. The course met for a total of four 55-minute class periods each week. Three of these meetings were with the full class of 34 students, while the fourth meetings met with each half of the class separately. Students were also enrolled in a co-requisite laboratory class session that met for one four-hour class period once a week, however, this section was not necessarily taught by the same instructor as the lecture sessions.

Procedures

In this study, the initial deficiency in teaching practice was rooted in a prior case study performed in a similar class (unpublished results). In the prior case study statistically significant improvement was observed in student performance in organic chemistry as measured by both instructor designed and nationally standardized exams through the implementation of POGIL in the classroom. Student perceptions of the POGIL methodology, however, were fairly negative with a large portion of the class (11 of 19 students) strongly preferring the traditional lecture over the POGIL approach to learning. In light of this, the action research approach was used to seek to track student perceptions of the POGIL methodology and improve its implementation in the classroom throughout the course of the semester by making use of student input.

The semester was divided into a total of four units. Each unit consisted of designated chapters from the textbook. At the beginning of each unit, a plan of action was determined and implemented in the classroom. At the conclusion of each unit, students were provided with a short-answer questionnaire (see Appendix) that they completed and returned anonymously to the instructor. This questionnaire was modified

from one created by Towns, et al (2000). The instructor then analyzed and coded the student responses to the survey to determine common themes in the student perceptions and developed modifications to the plan of instruction. The new plan was then implemented and the cycle repeated for the subsequent units.

In the initial plan for the course, students were assigned to groups of 3 – 4 students each. These groups were assigned randomly at the beginning of the course. The groups were maintained for entirety of the first unit. Students engaged in POGIL activities in their assigned groups to introduce new topics 1 – 3 times per week. The activities used were from a published source (Straumanis, 2011) to ensure that they had been well reviewed and tested to conform to the POGIL methodology prior to implementation in this class. These served as the students' first introduction to the topics.

Throughout the activity, students were encouraged to make use of the following designated roles: facilitator, spokesperson, quality control, and process analyst. The facilitator's job was to keep track of the group's progress through the activity and read the questions aloud to the group so that all members could discuss and answer the questions together. The spokesperson was in charge of relaying any questions posed by the group to the instructor and was prepared to share the group's responses both to the instructor and to the class at large. The quality control specialist was to ensure that all papers in the group were consistent so that if the instructor picked up any paper from the group at the checkpoint, that paper would accurately represent the entire group's understanding. Finally, the process analyst was in charge of ensuring that all individuals participated in the discussion and clearly understood the group's responses. This individual also reported back to the group and to the instructor feedback on how the group operated and how it could improve.

As students worked through the activity, the instructor served as a facilitator and checked group responses at designated checkpoints in the activity. At the end of the activity, there were additional practice exercises that the students were to complete at home and bring back to class to be graded on the following day. In the subsequent class day an interactive follow-up lecture was led by the instructor to summarize and review the topics introduced in the previous POGIL activity. Students were encouraged to complete fill-in notes in class during this discussion. On the day following

a summary lecture, a short, approximately five-minute quiz was given at the beginning of class to evaluate student understanding of the topic.

Data Analysis
       All data that were collected from the questionnaire was compiled and coded to evaluate common trends in student responses. Coding was accomplished by analyzing the statements of students and categorizing among common themes noted by the researcher. The coded data were compiled into bar graphs to represent the frequency of various responses. The instructor then addressed these responses by developing and sharing the revised instructional plan with the class at the beginning of the next action research cycle. It should be noted that there was typically a one-week delay between retrieval of the information from the questionnaire and the revision to classroom instruction.

Student Initial Perceptions of Strengths
       At the conclusion of the first unit, students provided their perceptions of the strengths in both the POGIL activities and the follow-up lectures. When the collected data from the surveys was analyzed several common patterns were observed. Nearly all responses fit into one of only a few categories. The results of these survey responses are summarized in Figure 2 and Figure 3.
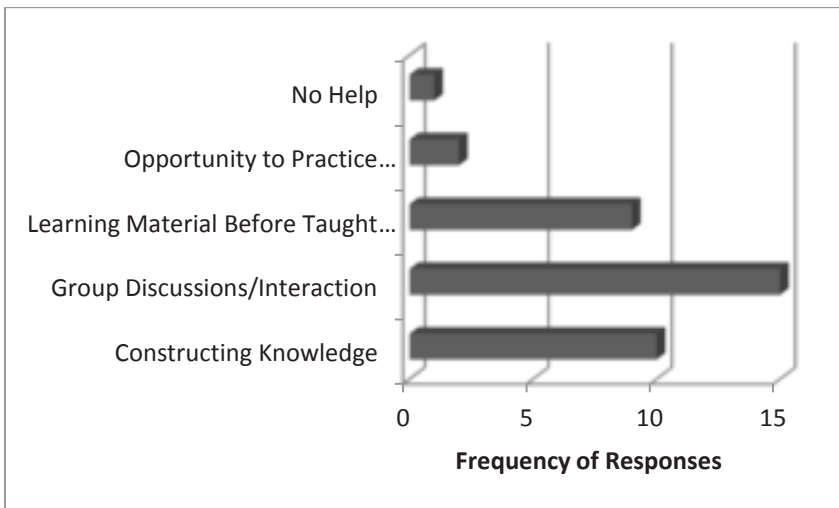

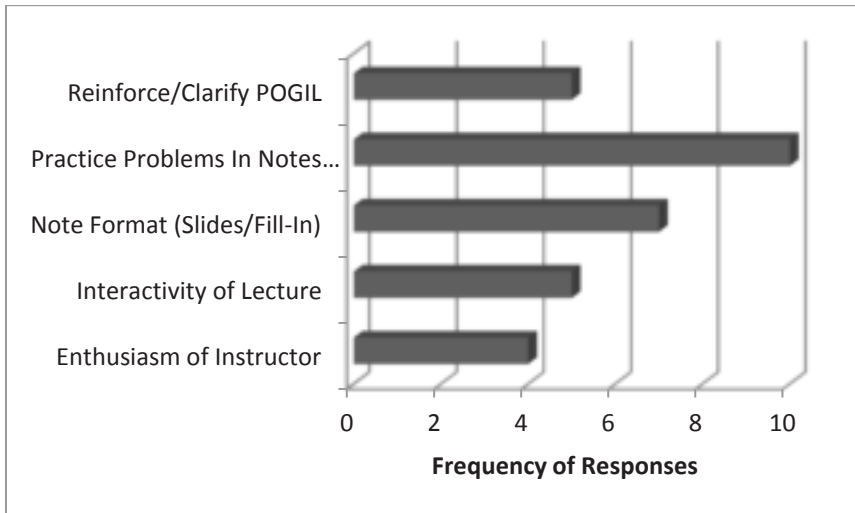*Figure 2.* Student perceptions of strengths in POGIL activities after unit 1.

Figure 3. Student perceptions of strengths in lecture after unit 1.

A large proportion of the class (15 of the 29 total responses) described the group discussions and interactions as strengths of the POGIL activities. An example of this is:

> "I have found that in the POGIL activity the act of explaining one's personal take on the lesson helps to shed light on misconceptions. Along with this many times students are forced to explain their understanding allowing them to better understand what they know because they can now explain it. This has happened to me many times."

By engaging in the activities, students felt comfortable sharing their understanding and asking questions of one another to attain a better understanding of the topic at hand. Many students expressed that by working in groups they were able to bring their different perspectives to bear on the topic at hand and attain a richer understanding than they might have had alone. They described how different group members could explain different parts of the activity to the rest of the group whenever they had difficulty arriving at an answer to a particular problem.

Another portion of the class (10 of the 29 total responses) described the process of knowledge construction as a strength of the POGIL activities. As an example of this:

> "The POGIL activities are most useful in the sense that they approach the topics in a 'building oriented' way. The strength of the POGILs is that they introduce a topic and layer onto it, allowing understanding to expand rather than memorization to occur."

Several students expressed views along these lines and pointed out that the POGIL activities introduced the topic before it was reviewed in lecture (9 of the 29 responses). As such, they felt that this provided them with a firmer foundation and made the material discussed in the subsequent lecture easier to comprehend. Some students also commented that the activities allowed them to find common patterns in the activity and use these to invent a concept for themselves rather than simply being told the concept from the start. The students indicated that this process made the material more comprehensible and the knowledge obtained longer-lasting.

Two of the 29 total responses viewed the POGIL activities as a means to practice the material discussed in class, while one student felt that the POGIL activities were of no help at all. These responses focused less on the value of the group dynamic or construction of knowledge.

When focusing on the lecture component of the class, numerous students (10 of the 29 responses) expressed that the practice problems embedded into the notes were a strength of the lecture. For example:

> "Also, I love how there are practice problems after each concept to test if we actually understood what was just taught. I really like how you don't just say 'try these' but actually walk us through the first example. That helps me build confidence for the material."

Students commented that alternating between discussing the topic and giving them a practice problem to work helped to solidify and test their understanding of the given topic. They explained that this allowed them to see how the concepts could be applied in problem solving.

Several students also pointed out that the note format of slides with fill-in notes was a strength of the lecture.

> "I really like having the guided notes. It allows me to pay attention to what is said more than keeping up with the notes."

The students seemed to agree that by having portions of the notes outlined as a skeleton with other portions to be filled in during class, they could pay attention and participate in the discussion without having to rewrite everything in their notes. At the same time they could still fill in the most important portions for themselves and make use of their understanding to help complete the notes. Students expressed that this was particularly valuable considering the large amount of content that was covered during each lecture period.

Along with the notes format, several students (5 of the 29) made explicit mention of the interactivity of the lecture as a strength. For example:

> ". . . the input of students allows for active involvement in the lecture so that we get to answer questions, and ask questions as a group."

Students noted that they were able to bring their own understanding to the lecture and have it clarified. In addition, they also found the lectures more enjoyable and engaging.

One final set of comments worthy of note is that 5 of the 29 students expressed that the lecture was beneficial in reinforcing what they had learned from the POGIL activities on the previous day.

> "The strength in the lecture is that they clarify or reinforce what we learned in the POGIL activities. For example, the acid-base-pKa activity seemed easier to understand after going over it in the lecture."

All of these student comments described value in having an initial exposure to the concepts through the POGIL activity which was then formalized through the lecture. In this way, the lecture served more as a clarification rather than an introduction to the topic at hand. Students felt

more comfortable discussing the material in the lecture because they had essentially learned it in the previous POGIL activity.

In general these initial strengths in the both the POGIL and lecture were expressed throughout the rest of the units and held constant throughout the course. Full details of these strengths in subsequent units are provided in the supporting information and only new additions will be discussed in the following sections.

Student Suggestions for Improvement and Revision to Class after Unit 1

At the conclusion of each unit, students provided feedback in the form of suggestions for improvement to the class. These suggestions for improvement were compiled, coded, and summarized to determine how to modify the class. The common suggestions for improvement at the conclusion of unit 1 are compiled in Figure 4. As Figure 4 shows, 7 of the 29 responses indicated that the largest improvement that could be made to class would be to add more problems and challenging examples into the lecture portion of the class.

Some students had suggestions with regards to the use of groups in activities. A total of 6 of the 29 responses made comments on group organization but these responses were divided with 4 students suggesting the group compositions be changed while 2 commented that groups should remain the same. A total of 5 responses suggested that the usage of roles should be encouraged in the groups. These comments indicated some frustration that group members were not making use of their designated roles and thus they felt that their group was not working as effectively as a whole.

Several recommendations were made to improve the work on the POGIL activities themselves. This included a request to hand in the POGIL take-home components after the summary lecture so that the students felt more comfortable with the material before they had to turn it in. Another suggestion was to complete more of the POGIL activities ahead of time. These students were concerned that they were having trouble finishing the activities in class and they would have preferred to a do a little more of the activity ahead of time rather than finishing up the end of the activity at home. These students expressed that they felt the end of the activity, rather than the beginning, tended to be more challenging and that they needed the instructor more when completing this portion.

Another set of students suggested that the POGIL activities should be scheduled on the designated recitation days when only half of the class met at a time. The concern students expressed here was that the instructor was more available to help groups on an individual basis on these recitation days than on days where the entire class met at one time. On final suggestion that was made was to have the summary lectures precede the POGIL activities. These students felt that they would be better prepared to complete the POGIL activities if they were more familiar with the concepts beforehand.
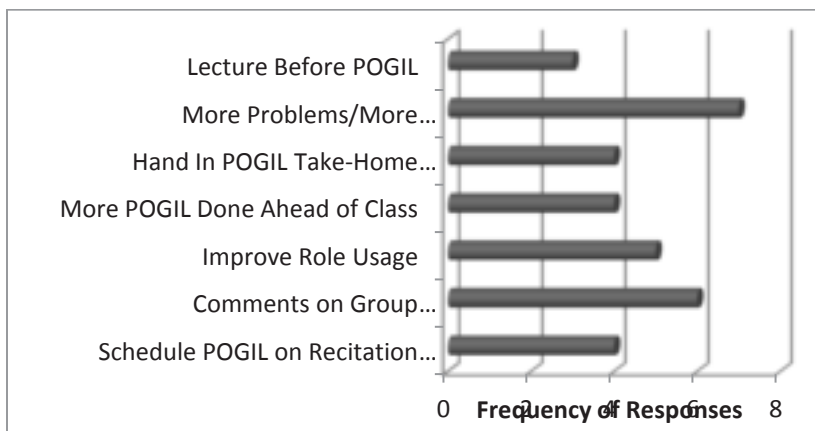

Figure 4. Student suggestions for improvement in the course after unit 1.

After unit 1, several modifications were made to address the common student suggestions for improvement. It should be noted that a conscious decision was made to discount the suggestion to lecture on the given topic before the POGIL activity covering that topic. This decision was made for two reasons. The primary purpose of the POGIL activities is to encourage students to construct their own knowledge based on model systems and their prior knowledge. By lecturing before the activity, the activities would instead become merely practice problems rather than inquiry activities. In addition, several students specifically noted the strength of using these POGIL activities to construct the knowledge prior to the summary lectures. As a result, it was decided that this was one suggestion for improvement that could not be accommodated. Instead the following modifications were made to the class:

- The lecture notes were shortened and more examples were embedded into the summary lecture days.
- Groups were changed and students were grouped heterogeneously to have students of a wide variety of ability levels based on their scores on the first unit exam.
- POGIL roles were encouraged through the implementation of a bonus point on quizzes where all group members scored 80% or above.
- The due date of the take-home portion of the POGIL activities was changed to the day following the summary lecture rather than on the same day as the summary lecture.
- More of the POGIL activities were assigned to be completed before class to help students finish the remainder of the activity in class.
- Where possible, POGIL activities were scheduled on the recitation days but progression through the content dictated that some of these activities might not be scheduled during recitation periods.

It is worthy of note that the heterogeneous grouping was used to ensure that all groups had the same potential to achieve the quiz bonus, as well as, to bring this difference in perspective to bear on the POGIL activities. It was emphasized that all students in a given group had a role to play in ensuring that every group member fully understood the content covered by the POGIL activity. These modifications were shared with the class and continued throughout unit 2.

Student Suggestions for Improvement and Revision to Class after Unit 2
       At the conclusion of unit 2, several of the same suggestions for improvement were made by the students in the course. The most common suggestions for improvement are categorized and summarized in Figure 5. By far, the suggestion most frequently proposed was to continue to provide more examples and more challenging example problems. The students expressed that they saw the key to their success in being able to apply the knowledge rather than simply understanding it. As such, they expressed that one of the most valuable resources they could have was more problems to practice in class. This accounted for 13 of the 28 total responses with statements such as:

"Maybe go over more problems you find more challenging so we understand them better as a whole."

"Even more example problems when possible. Those really help me to figure everything out."

Five students also commented that more should be done to encourage the usage of roles in POGIL groups. Three comments suggested that the POGIL should still be moved to only occur on recitation days. Another three students suggested that the pace of the material was too fast. It should also be noted that several students commented positively on the modifications made from the previous unit.
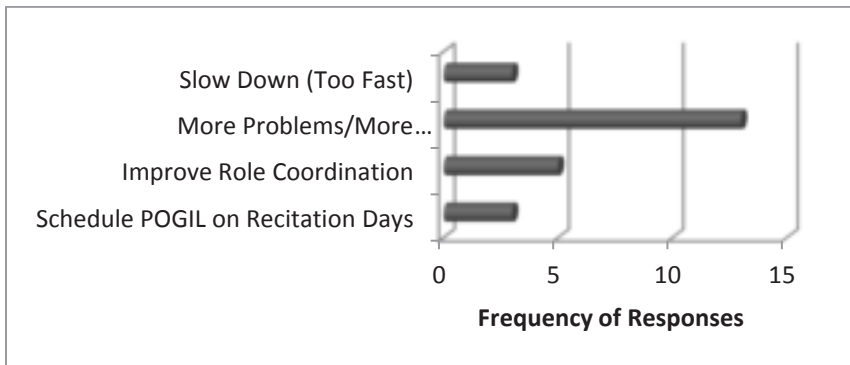

Figure 5. Student suggestions for improvement in the course after unit 2.

To address the suggestions made by the students, additional modifications were made at the conclusion of unit 2. Roles usage was continually emphasized by giving the students specific tasks that each role had to perform. For example, facilitators were asked to keep track of the time it took their group to complete a portion of the activity. Quality control was asked to specifically record the group's consensus on a question where answers could be more divergent. The process analyst was asked to record and share two strengths and two areas of improvement for their group as they worked together. Because of the nature of the class schedule, little could be accommodated to slow the pace of the course or to schedule POGIL activities only on recitation days. The major adjustment to the course, however, was that the notes were trimmed to the bare minimum and more example problems were worked into the course. The minimal

notes often took the form of recounting only the major points of the given topic and the common pitfalls but example problems were used more extensively to elaborate the key points. All of this was adjusted to incorporate the most common student suggestions for improvement of the course.

Student Suggestions for Improvement and Revision to Class after Unit 3

At the conclusion of unit 3, the investigator was surprised to note that the suggestions for improvement were nearly identical to those found at the conclusion of unit 2. Nearly all student comments could be categorized into the same categories observed for unit 2, with approximately the same frequency. This is summarized in Figure 6. Again, the most common suggestion was to increase the number and complexity of the example problems provided in class. The second most frequent suggestion was to slow down the pace of the class.
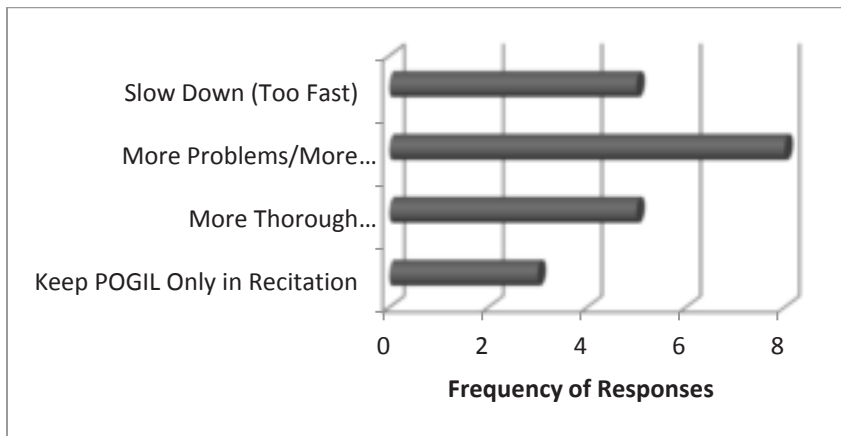

Figure 6. Student suggestions for improvement in the course after unit 3.

It was immediately apparent from the results of the unit 3 survey that the modifications of trimming the notes to the bare minimum and providing more example problems did not sufficiently meet the needs of the students. A new tactic was needed to address the prevailing concerns of the students. Because the student responses indicated no change when the notes were trimmed, it seemed possible that the students might be communicating that they had little trouble with the basic concepts of the course but were really struggling with the application. As such, it seemed

that the instructor was spending too much time elaborating on the basic concepts in class and not enough time helping them to apply the concepts. A completely new structure for the classroom was thus proposed and implemented that made use of a variation on the flipped classroom approach to learning. The implementation adopted in this study consisted of five basic stages:

1. The students would work through a POGIL activity in class on the first day of a cycle to explore and develop basic concepts of the topic at hand.
2. Students would be provided with "notes" worksheets to take home and fill out on their own based on the knowledge they had constructed in the POGIL activity, as well as, readings from their textbook. These would take the place of the regular in-class notes with interspersed practice.
3. Students would bring the completed "notes" worksheets to class where they would then be checked for completion and discussed very briefly. This would take up less than 15 minutes of class time.
4. Students would then work through additional "practice problems" individually and discuss them in small groups. Answers would then be shared in a whole-class discussion to elucidate problem-solving strategies, common misconceptions, and errors to avoid.
5. Students would be assessed on their comprehension of the topic in the following day by way of a short quiz at the beginning of the next class session.

This 5-stage approach was then repeated for subsequent topics throughout unit 4. Examples of the "notes" worksheets and "practice problems" are provided in the supplemental material. This approach was designed to allow significantly more time for the instructor to discuss application of the concepts with the students without sacrificing the development of clear notes for the students.

Strengths, Suggestions for Improvement, and Revision to Class after Unit 4
At the conclusion of unit 4 students again provided feedback on the perceived strengths of both the lecture and POGIL components of the class,

as well as, suggestions for improvement. Of the 34 students in the course, 24 provided feedback on the course modifications. It is worthy of note that prior to this unit this feedback had not changed significantly from one unit to the next. In fact, the perceived strengths, in particular, were virtually identical from one unit to the next. After the modifications made in unit 4, however, there were large changes in the students' perceptions of the benefits of the lecture component of the course.
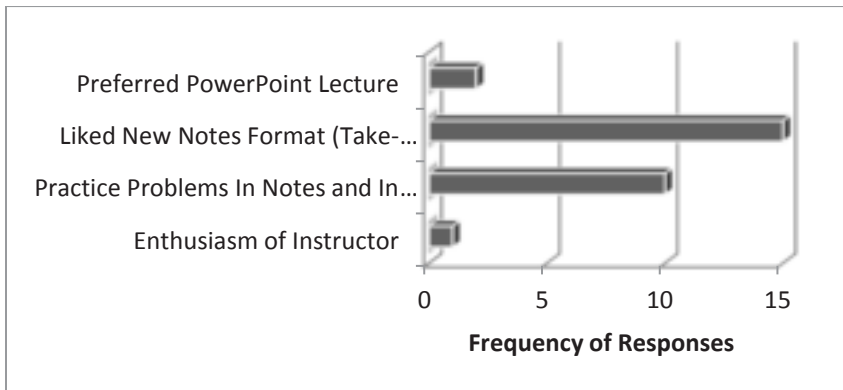

Figure 7. Student perceptions in the strengths in lecture after unit 4.

A summary of these perceptions is provided in Figure 7, which highlights several noteworthy points. Two students noted that they preferred the standard PowerPoint lecture format used in previous units and did not like the flipped classroom approach adopted for the lecture component of unit 4. In general, however, this was in sharp contrast to the rest of the class. A total of 15 of the 26 respondents specifically noted that the flipped classroom approach was a significant strength in lecture.

> "I love the new way of lecturing. It forces me to learn it
> before lecture, and then get to practice more in class. This is
> because the concepts aren't what is hard. It's better to be
> able to make the mistakes in class rather than on a test."

The above example response typifies that of most of the respondents. In general the students indicated that they found it beneficial to read and complete the notes outside of class and devote more class time to the application of those concepts in more challenging problems. Similarly, 10 students indicated that the practice problems both embedded in the

notes and in the subsequent problem-solving class period were very beneficial. Examples of these student comments include:

> "Lately lectures have been geared more towards practicing the concepts rather than learning them in class. This seems to be working. I found more benefit doing the harder problems in class versus taking notes."

> "I find it more effect [practicing] with the whiteboards because I feel it's equally important to understand what's wrong, why, and the reagents to use instead as it is to just know what to use for that type of reaction."

Several of these comments touted the benefits of working and discussing the problems in small groups during class in an environment where the students were free to make mistakes and obtain feedback to prevent similar mistakes in the future. This overwhelmingly positive reception to the course modifications was unexpected.
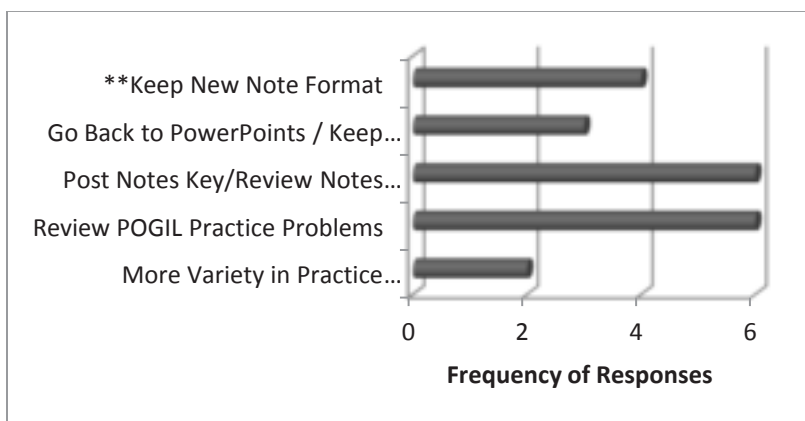

Figure 8. Student suggestions for improvement in the course after unit 4.

In a similar vein, the student suggestions for improvement to both the POGIL and lecture components of the class also changed dramatically from previous units. The student responses are summarized in Figure 8. These suggestions fell into four general categories, with some students providing no suggestions for improvement in the course. Although not a specific suggestion for improvement in the course, 4 students specifically

recommended that the new note format, wherein students complete the notes on their own outside of class, should be maintained.

> "Keep the format of chapter 10 notes. It forces us to look at the book, do homework, and leads us to be more prepared. That way when lecture comes, questions can be answered."

In contrast to this, 3 students recommended that the instructor either fully revert to the previous PowerPoint lecture style of notes or maintain at least some traditional lecture in the course.

> "The PowerPoints are better than the notes."

> "Maybe add one 'old style' lecture prior to the question sessions."

It is worth noting that students preferring some reversion to a more traditional lecture model for the course were in the minority. Six students recommended that the answer keys to the notes either be provided online or reviewed more thoroughly in class to ensure that all responses are correct.

> "Provide the answers to the questions in the notes. Maybe put some suggested answers to the notes online prior to class, but not answers to every part of the notes."

These students indicated that although they preferred completing the notes outside of class, they desired more confirmation that the notes they had taken were correct. In the unit 4 iteration of the course, the instructor only reviewed specific small portions of the notes and relied on questions from the students to guide any further review of the notes. Two students also recommended that the practice problem sessions be more varied.

> "Maybe do more variety of practice problems."
> "Don't do the white board practice problems every day."

These responses seemed to indicate that the practice problem sessions could become somewhat monotonous and that more variety would help to keep them engaged in the material. Six students recommended that some sessions be devoted to reviewing the take-home POGIL practice problems.

> "Go over in class the one or two issues most people ran into with the homework."

All of these comments indicated that the students preferred more class time be spent debriefing some of the take-home problems more thoroughly than the written feedback provided by the instructor.

Of particular note in these suggestions for improvement is that the prior suggestions for additional and more complicated practice problems in lecture seemed to be finally satisfied with this modification. In prior units, that suggestion for improvement had dominated the student responses but was nowhere to be found in the unit 4 reflections. Likewise, the student suggestions to slow down the pace of class were absent from the unit 4 reflections. This seemed to suggest that the modification made in unit 4 had the desired effect of addressing these specific student concerns.

Second Semester Continuation of Project

Although unit 4 was the final unit for the first semester of this organic chemistry class, modifications were carried through for the second semester of the course, as the majority of the students from the first semester continued into the second semester course taught by the same instructor. The modifications carried into the second semester of the course included:

1. Continued use of the flipped classroom model for instruction subsequent to POGIL investigation days.
2. The notes were briefly reviewed in their entirety at the beginning of each class period. This was later modified further to the posting of a protected pdf file on the course Blackboard site immediately following class.
3. The types of practice problems and the method of practice were changed on various days. Some days would involve a focus on synthesis or mechanism problems. Others would focus on predicting

the products. Likewise the method by which students would share their results was alternated between individual reporting, group reporting, and whole-class discussions to help keep the sessions more varied.

4. The take-home practice of the POGIL assignments was instead cut down to the most important components and incorporated into the in-class practice problem sessions to address student suggestions to review these problems more thoroughly.

Student feedback was continually collected throughout the second semester of the organic chemistry sequence, however, student responses for strengths in the course and suggestions for improvement became much more limited. Responses from the surveys indicated that students were fairly satisfied with the modifications to the course and had no significant suggestions for improvement.

Change in Student Perceptions of POGIL
The final aspect analyzed in this study was how student perceptions of the POGIL methodology changed over the course of the semester. This was measured in two ways.

1. Students were asked to describe their perceptions of the POGIL methodology at the conclusion of each unit.
2. Students were asked to describe for themselves at the conclusion of unit 4 how their perceptions of the POGIL methodology had changed over time.
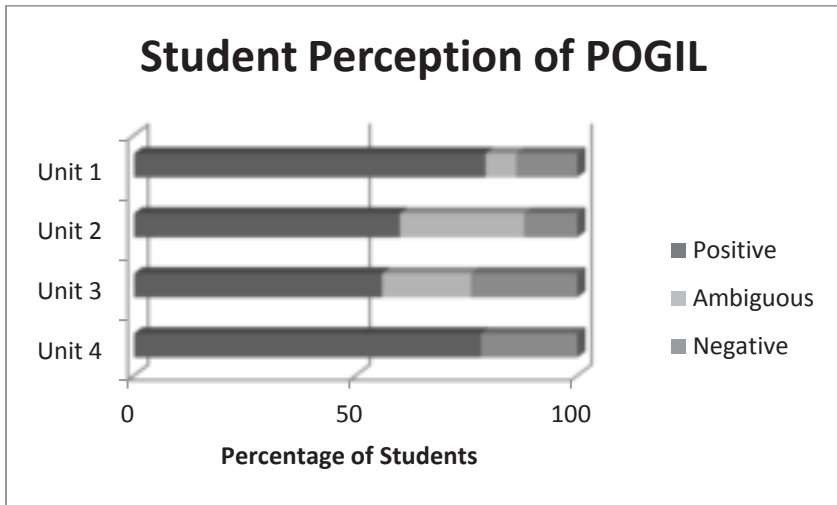
Figure 9. Student Perceptions of POGIL at Conclusion of Each Unit

Student responses of their perceptions were categorized as positive, negative, or ambiguous at the conclusion of each unit. The percentage of students reporting perceptions in these categories was then compiled and is shown in Figure 9. As this figure shows, the student perceptions of POGIL began fairly positively after the conclusion of unit 1 (79% reported positive perceptions of POGIL). It began to drop, however in units 2 and 3 (60% and 56%, respectively, reported positive perceptions). It then increased again at the conclusion of unit 4 (78% reported positive perceptions). Overall, however the perceptions of the POGIL after unit 1 were not notably different from those at the conclusion of unit 4 according to this measure. These data seem to suggest that student perceptions were fairly fixed and generally favoring POGIL by the conclusion of unit 1, with some students providing more ambiguous responses that could not clearly be associated with positive or negative perceptions during units 2 and 3. It is possible that this may be associated with more apprehension of the POGIL methodology during these units, however, this cannot be conclusively determined based on the data collected in this investigation.
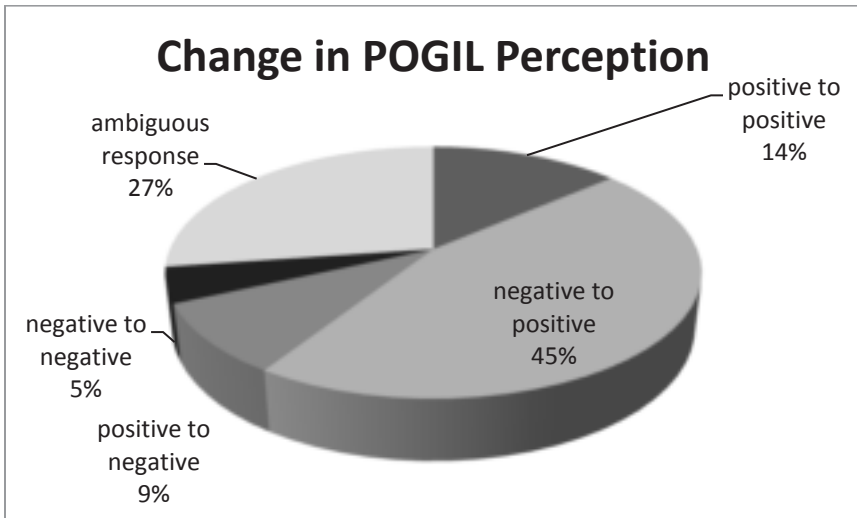
Change in POGIL Perception

Figure 10. Self-reported student change in POGIL perception at the conclusion of the course.

Students were asked to also report how they thought their perception of the POGIL methodology had changed from the beginning of the semester. After unit 4 the student responses were collected and categorized. Their responses are summarized in Figure 10. Nearly 45% of the students surveyed reported that their perceptions of POGIL were fairly negative in the beginning but had improved to become positive over the course of the semester. A smaller percentage of students (14%) reported that their perceptions of POGIL had begun positively and remained positive throughout the semester. Fewer students still (9%) reported that their perceptions of the POGIL methodology began positively at the beginning of the semester and became more negative as the semester proceeded. Only a very small minority of students (5%) reported that their perceptions had begun negatively and remained negative throughout the semester. It is worth noting that a significant percentage of students gave responses that were too ambiguous to definitely assign to any one category.

The data collected from these instruments suggest some possibilities for interpretation. The discrepancy between what the students reported at the conclusion of each unit and their overall reported impression of their change in perspective suggests that student perceptions of POGIL may have begun fairly negatively early in the course but had largely equilibrated at the conclusion of unit 1. This might be the best way to explain the fact that the

percentage of students reporting positive impressions of POGIL was largely the same in units 1 and 4 despite the fact that a very large percentage of students reported that their impressions of POGIL were initially negative and became more positive over time. This suggests that students require some time to settle into the routine of POGIL before they become comfortable enough with it to see it as beneficial but that it may not take as long as many instructors might presume. Students seem to adapt fairly quickly to new teaching methodologies when they are consistently used as the primary method of instruction in a given class. It is also worth noting that positive student perceptions of POGIL may ebb and flow over the course of the semester. This change in perceptions may correspond to the difficulty of the subject matter in the given unit and would require further investigation to identify the cause. Overall, the student perceptions of instruction should be viewed as encouraging to instructors interested in adopting the POGIL methodology, as the students in this study generally developed positive impressions of the method of instruction.

Theoretical Underpinnings and Implications for Instruction

Upon reflection on the instructional method adopted at the conclusion of this action research project (referred to as the POGIL/flipped classroom model), it appears that the success of this methodology may best be explained by its conformation to the Learning Cycle Model (Karplus and Their, 1967). According to Karplus' model, education begins with an exploration phase, in which the students explore scientific processes without any knowledge of the principles that underlie them. This creates a curiosity in the student and driving force to further understand the content. Once this "need to know" has been established, the students enter the concept invention stage. In this stage they are able to both arrive at conclusions of the foundational principles for themselves and/or are prepared to be provided with the required concepts to explain what was discovered in the exploration stage. Once these concepts have been invented, the students then enter into the application stage where they apply the concepts invented to new situations beyond those specific to the exploration stage.

The combined POGIL/flipped classroom model adopted during unit 4 of this study conforms strongly to this educational model. The POGIL activities serve largely as the exploration stage where students are presented with model systems and guiding questions to develop their

curiosity and their need to understand the organic chemistry concepts. Throughout the activities, the students also work to invent some of the concepts for themselves and subsequently apply them, but the concepts are generally not completely formalized in the minds of the students at the end of the activity. Because the students have undertaken this exploration through the POGIL activities and have some grounding in the concepts, they are then primed to formalize their understanding through completing the notes packets at home on their own. This formalizing of the knowledge they have attained serves as the concept invention stage of the learning cycle. With this formal knowledge base established, the students are then prepared to turn their attention to the application stage of the learning cycle. The in-class practice problems serve as an opportunity for the students to try their hand at applying the concepts to new situations.

The most noteworthy finding of this mapping of the POGIL/flipped classroom model on to the learning cycle is the discrepancy between where instructors typically spend their classroom time and where the students articulated they needed the most assistance. In a traditional lecture class and even in the POGIL classroom as initially conceived in this project, the instructor spends the majority of his or her time in the concept invention stage, ensuring that the students have a complete formal understanding of the concepts in the course. The POGIL/flipped classroom model, however, focuses the majority of the in-class portion on the exploration and application stages of the learning cycle. The concept invention stage then occurs primarily at home as the students read their textbook and complete their notes independently. The warm reception of the students to this model of instruction indicates that the areas students need the most support from the instructor is not in the traditional concept invention stage but rather initial exploration and final application stages.

Conclusion

The findings of this project provided insight into the student perceptions of a method of instruction and how student feedback could be used to revise classroom instruction into a more student-centered model. Students were able to ascertain several strengths of Process Oriented Guided Inquiry Learning. They noted significant advantages to being provided with the opportunity to construct knowledge on their own and to discuss the content with their classmates in a small group format. They recognized value in investigating the material prior to any formal

introduction of the concepts through either lecture or reading. These are the goals of any guided inquiry learning and the student perceptions reinforced that these goals were being met and recognized by the students.

Students report that their perceptions of Process Oriented Guided Inquiry Learning begin fairly negatively. This may be attributed to the fact that this methodology is in sharp contrast to the form of instruction that dominates much of their learning prior to this course, particularly within the sciences. In time the majority of students perceives positive benefits of POGIL and describes it as a superior method of instruction over a traditional lecture format of instruction. This change in perception, however, appears to occur fairly quickly (within the timeframe of one 4-week unit) and may fluctuate throughout the course of instruction.

Throughout the course of this project, the students provided several different recommendations to improve the classroom implementation of the POGIL methodology. These suggestions led initially to small modifications to the classroom but the persistent reevaluation of the classroom quickly led to a more significant change in the classroom instruction. A new methodology was developed that incorporated POGIL to explore the concepts and then a version of a flipped classroom approach for the subsequent concept invention and application stages. This POGIL/flipped classroom methodology was well received by the students and significant insight into where an instructor can make best use of his or her time to facilitate student learning. Traditional models of instruction lead instructors to spend the majority of their time helping students to invent concepts when students often recognize on their own that the areas in which they need the most support is in exploring concepts (analyzing data to ascertain patterns on which to base concept invention) and application of those concepts to new situations that differ from the exact context in which the concepts were originally developed. By focusing more on these areas where students have the greatest struggles, the instructor can be more effective in his or her use of class time to promote learning.

The study presented here qualitatively focused on student perceptions of the methodologies employed rather than a quantitative determination of the efficacy of these methods to student comprehension of the topic. While the student perceptions of the effectiveness of the methodologies employed is valuable, less subjective measures of that efficacy are required to ascertain whether the methodologies employed truly improve student learning compared to a traditional lecture model of

instruction. Further studies are currently in progress to assess the effectiveness of this combined POGIL and flipped-classroom model of instruction compared to the traditional lecture model. The effect of this model will be measured by student performance on several exams, as well as, student perceptions of their self-efficacy in chemistry. It is hoped that these further studies will give shed further light on this combined model of instruction and better evaluate its promotion of student learning.

References

Abdi-Rizak, M. (2008). Effects of Active Learning Variants on Student Performance and Learning Perceptions. *International Journal For The Scholarship Of Teaching & Learning*, *2*(2), 1-14.

Abeysekera, L., & Dawson, P. (2015). Motivation and Cognitive Load in the Flipped Classroom: Definition, Rationale and a Call for Research. *Higher Education Research And Development*, *34*(1), 1-14.

Bergmann, J., & Sams, A. (2012). *Flip your classroom: Reach every student in every class every day*. International Society for Technology in Education.

Bligh, D. A. (2000). *What's the Use of Lectures?* San Francisco: Jossey-Bass.

Brown, P. P. (2010). Process-Oriented Guided-Inquiry Learning in an Introductory Anatomy and Physiology Course with a Diverse Student Population. *Advances In Physiology Education*, *34*(3), 150-155.

Chase, A., Pakhira, D., & Stains, M. (2013). Implementing Process-Oriented, Guided-Inquiry Learning for the First Time: Adaptations and Short-Term Impacts on Students' Attitude and Performance. *Journal Of Chemical Education*, *90*(4), 409-416.

Daubenmire, P. L., Bunce, D. M., Draus, C., Frazier, M., Gessell, A., & van Opstal, M. T. (2015). During POGIL Implementation the Professor Still Makes a Difference. *Journal Of College Science Teaching*, *44*(5), 72-81.

Duit, R., & Treagust, D. F. (1998). 1.1 Learning in Science-From Behaviourism Towards Social Constructivism and Beyond. *BJ Fraser & K. G. Tobin (Eds.), International Handbook of Science Education*, 3-25.

Farrell, J. J., Moog, R. S., & Spencer, J. N. (1999). A Guided Inquiry General Chemistry Course. *Journal Of Chemical Education*, *76*(4), 570-74.

Felder, R. M., & Brent, R. (1996). Navigating the Bumpy Road to Student-Centered Instruction. *College Teaching*, *44*(2), 43-47.

Hein, S. M. (2012). Positive Impacts Using POGIL in Organic Chemistry. *Journal Of Chemical Education*, *89*(7), 860-864.

Herreid, C. F., & Schiller, N. A. (2013). Case Study: Case Studies and the Flipped Classroom. *Journal Of College Science Teaching*, *42*(5), 62-67.

Karplus, R., & Thier, H. D. (1967). *A new look at elementary school science: Science curriculum improvement study*. Rand McNally.

Kemmis, S., McTaggart, R., & Retallick, J. (2004). The action research planner.

Mazur, E. (1991). Can we teach computers to teach. *Computers in Physics*, *5*(1), 31-38.

Moog, R. S., Creegan, F. J., Hanson, D. M., Spencer, J. N., Straumanis, A., Bunce, D. M., & Wolfskill, T. (2008, September). POGIL: Process-oriented guided-inquiry learning. In *ACS Symposium Series* (Vol. 994).

O'Hanlon, C. (1996). *Professional development through action research in educational settings*. Psychology Press.

Schultz, D., Duffield, S., Rasmussen, S. C., & Wageman, J. (2014). Effects of the Flipped Classroom Model on Student Performance for Advanced Placement High School Chemistry Students. *Journal Of Chemical Education*, *91*(8), 1334-1339. doi:10.1021/ed400868x

Spencer, J. N. (2006). New Approaches to Chemistry Teaching. *Journal Of Chemical Education*, *83*(4), 528-535.

Straumanis, A. R. (2011). *Organic chemistry: A guided inquiry for recitation, volume 1* Belmont, CA: Brooks/Cole, Cengage Learning.

Towns, M. H., Kreke, K., & Fields, A. (2000). An Action Research Project: Student Perspectives on Small-Group Learning in Chemistry. *Journal Of Chemical Education*, *77*(1), 111-15.

Vanags, T., Pammer, K., & Brinker, J. (2013). Process-oriented guided-inquiry learning improves long-term retention of information. *Advances In Physiology Education*, *37*(3), 233-241. doi:10.1152/advan.00104.2012

Biographical Information

Dr. Matthew DeMatteo (Matthew.DeMatteo@uc.edu) is an Assistant Professor of Chemistry at the University of Cincinnati Blue Ash College, where he teaches organic chemistry. His current research interests are focused on the application of active and inquiry-based learning techniques in both the chemistry classroom and lab. This includes process-oriented guided inquiry learning (POGIL) and the flipped classroom approach. He received his Ph.D. in physical organic chemistry in 2007 and his M.Ed. in 2008 from the Ohio State University. Prior to his work in higher education, he worked as a chemistry teacher at Oak Hills High School in Cincinnati, Ohio.

University of Cincinnati Blue Ash College
9555 Plainfield Rd.
Blue Ash, OH 45236