AC 2011-101: STUDENT CONSTRUCTION OF KNOWLEDGE IN AN ACTIVE LEARNING CLASSROOM

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Student Construction of Knowledge in an Active Learning Classroom

Abstract

Recently there has been an increasing awareness of the effectiveness of various types of active learning approaches. Research has shown that while there may be differences depending on the type of method chosen, the experience of the instructor, and the characteristics of the students, in general active learning techniques result in improved student outcomes, particularly when deep learning is the goal. In addition to the empirical research showing improvement on various learning outcomes, the use of active learning is also supported by cognitive models of learning. Despite the clear evidence for the effectiveness of these approaches, there is less understanding of how student learning occurs in an active learning classroom. This study begins to address that issue by conducting a qualitative study. The specific context for this study is a second semester general chemistry course at a small liberal arts college in the Rocky Mountain region of the US. In this class, Process-Oriented Guided Inquiry Learning (POGIL) was used. In a POGIL class, the instructor does not lecture. Rather students work in teams, typically of four students, to complete worksheets. The worksheets contain three components: 1) Data or information as background material; 2) Critical thinking questions, which are designed to lead the students to understanding the fundamental concepts represented by the data, and 3) Application exercises, which provide the students with practice in solving problems using the concepts they have derived. The instructor's role is to guide the students, walking around the room and probing them with questions to check their understanding. The research question that guided the study design was: How do students construct knowledge in a POGIL classroom? This question was addressed from a constructivist perspective in order to emphasize the role of the individual in constructing understanding. Data was collected using individual semi-structured interviews with 11 students, conducted at the end of the semester. The interview questions were focused on identifying aspects of the class that helped or hindered their learning. Blog entries written by the students throughout the semester were used to help tailor the interview for each student and were used as a secondary source of data. Interviews were transcribed verbatim and then analyzed by first creating codes that summarized and organized the data and then sorting these codes into primary themes. The primary themes identified through the analysis are: time to adapt; conceptual understanding; developing concepts for themselves; working in groups; opportunities to practice; and ownership of learning. The rich description from this study provides insight into how students actually go about learning in an active learning environment, providing opportunities to adjust that learning environment to better meet their needs and enhance the effectiveness of these approaches.

Introduction

"Teaching and learning are correlative or corresponding processes, as much so as selling and buying. One might as well say he has sold when no one has bought, as to say that he has taught when no one has learned (p. 29)."[1]

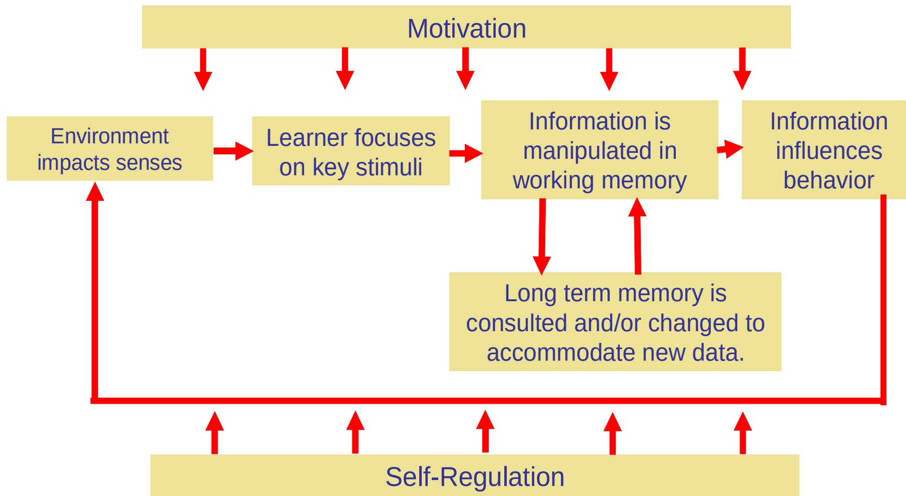

Figure 1: Schematic diagram illustrating the cognitive model of learning.

Although the lecture mode of teaching is often considered the "traditional" approach, the quote above from John Dewey illustrates that "innovative" approaches to learning have been proposed for over 100 years. Nevertheless, recently there has been an increasing awareness of the effectiveness of various types of active learning approaches. Within engineering specifically, a number of active learning approaches have been developed, including cooperative and collaborative learning,[2-7] problem-based classes,[2, 8-12] and guided design.[2] Prince and Felder have provided a comprehensive review of the effectiveness of various types of active learning methods, both within engineering and in education more generally.[13] Their review shows that, while there may be differences depending on the type of method chosen, the experience of the instructor, and the characteristics of the students, in general active learning techniques result in improved student outcomes, particularly when deep learning is the goal.

In addition to the empirical research showing improvement on various learning outcomes, the use of active learning is also supported by models of learning based on constructivism.[14] Dewey describes learning as an individual process, "a term denoting the various ways in which things acquire significance for the individual (p. 46),"[15] which occurs at least partially when learners "…think about what the teacher tells them and interpret it in terms of their own experiences, beliefs, and knowledge."[16] Vygotsky emphasizes the social construction of knowledge, that it is through our interaction with the world and others that we develop an understanding of important concepts.[17] Vygotsky's focus was on children, and he describes the development of speech in children as moving from entirely social (interacting with others) to egocentric (talking for oneself) to inner speech (thinking). The beginning of this development is always social interaction with others. Vygotsky's concepts have since been extended to adult learning.[14]

Specific cognitive models have also been developed that described the way information is processed during learning.[13, 18] Figure 1 illustrates one of these models. The key point to note in this model is that information is actively manipulated in the mind of the learner within the context of the existing structure of the learner's long-term memory. The learner has essentially three options: 1) The information can be accommodated into the existing structure. The traditional lecture approach assumes that this always occurs; 2) The new information does not fit into the existing structure, and a state of disequilibrium occurs. At this point the structure of long-term memory needs to be changed to accommodate the new information, or 3) The new information is rejected and long-term memory is left unchanged. Thus, prior learning and existing misconceptions are key elements that affect learning. These biases can act as a "filter" and affect how students accommodate new knowledge into long-term memory. One of the goals of constructivist models of learning is to provide opportunities for students to confront their misconceptions directly so as to repair them.

One practical application of how to apply the constructivist approach is through the learning cycle model.[19-21] In this model there are three phases of learning. The first is the exploration phase, in which the learner manipulates data or information. This results in the second phase, which is concept invention or term introduction. In this phase the learner uses the data to develop general rules or concepts. Finally is the application phase, in which the learner applies the concepts developed to new situations. This learning cycle models both the scientific research process, and the way young children learn about their world. In traditional teaching, the exploration phase is skipped, and teaching begins with concept invention. In contrast, studies have shown that learning occurs better when the concept invention phase comes later in the sequence.[20, 22-23] This approach is most powerful when the learners themselves invent the concepts (rather than having it told to them). This educational approach is the basis for constructivism. In a constructivist approach the roles of the instructor and students are quite different from a traditional class.[24]

One particular approach that applies the learning cycle model is Process Oriented Guided Inquiry Learning (POGIL). Despite several studies that show the effectiveness of POGIL,[25-26] there is little known about how student learning occurs in a POGIL classroom. The purpose of this study is to examine the ways individual students learn within this collaborative environment. Therefore, this study was undertaken to answer the following research question: How do students construct knowledge in a POGIL classroom? The focus was on the specific aspects of the class that they used for learning. This study does not address issues of the course design or implementation; these issues have been discussed in other papers.[25-26]

This study was conducted in a freshman chemistry class for two reasons: 1) Chemistry often serves as a "gatekeeper" course for engineering, and thus improved success in chemistry may help to retain students in engineering and improve performance in later chemistry-related courses, and 2) Other than work by the author, POGIL has not been used in engineering.[27-28] Thus, there is little opportunity to examine student learning using POGIL in engineering. Insights gained from this chemistry course may help in development of this and other active-learning approaches in engineering classes.

Research Design

Epistemology and Theoretical Perspective: Although the pedagogical approach used is collaborative, the interest in this study was on how individuals learned to succeed (or not) in the class, and the beliefs and experiences that led to the ways in which they approached learning. Thus, this research was conducted from a constructionist epistemological view. As described by Crotty, constructionism describes meaning as being created through shared interactions between people and the world;[29] meaning does not exist independently of human thought, but the meaning ascribed to the world by us is based on how we interact with the world. Within constructionism there are a number of theoretical perspectives that describe the philosophical assumptions of the methodologies that might be used. In this study a constructivist perspective was taken, which focuses on the meaning-making of individuals. Note that this use of the term "constructivist" is distinctly different from its use to describe pedagogical approaches, although the philosophical base is somewhat similar.

The use of a constructivist perspective implies that knowledge is constructed by individuals based on their individual beliefs and experiences. Thus, an understanding of those individual experiences is a key aspect of the research process. As described by Charmaz, a constructivist study "assumes that any theoretical rendering offers an *interpretive* portrayal of the studied world, not an exact picture of it (italics in original, p. 10)".[30] A constructivist study seeks to explore in depth the experiences of a small number of individuals in order to obtain a full understanding of multiple aspects of that experience. Unlike quantitative research, which uses large numbers of participants in order to statistically generalize the sample to the population from which it was taken, qualitative research specifically focuses on a comparatively smaller number of participants in order to describe their experiences from multiple angles and in great depth.

Another important aspect of the constructivism is its recognition of the researcher as an instrument of the research. Charmaz says that "no researcher is neutral because language confers form and meaning on observed realities. Specific use of language reflects views and values…We may think our codes capture empirical reality. Yet it is *our* view: we choose the words that constitute our codes. Thus we define what we see as significant in the data and describe what we think is happening (italics in original, p. 46-47)."[30] What is important is not that we get the codes "right", that it matches someone else's codes, but that the description rings true, that it has good "fit" with the data. As such, the concept of inter-rater reliability has no meaning in a constructivist study. Codes are situated in time, within a particular context, and based on a particular researcher's construction, and thus there are multiple possible interpretations of the data.

Constructivism as a theoretical perspective guided the research design in several ways. The focus of the study was on the ways in which individuals make meaning within the context of the classroom. Data collection was therefore conducted using individual interviews to gain an understanding of the ways in which the participants learned to succeed within the class. Data analysis focused on identifying those elements of the interviews which reflected individual beliefs and meaning.

Study Context: In a POGIL class, the instructor does not lecture. Rather students work in teams, typically of four students, to complete worksheets. The worksheets contain three components: 1) Data or information as background material; 2) Critical thinking questions, which are designed to lead the students to understanding the fundamental concepts represented by the data, and 3)

Application exercises, which provide the students with practice in solving problems using the concepts they have derived. The instructor's role is to guide the students, walking around the room and probing them with questions to check their understanding.[25-26] The POGIL approach has primarily been used within the chemistry curriculum,[31-34] with recent development of materials for engineering.[27-28]

This study took place in the second semester general chemistry course at a small liberal arts college in the Rocky Mountain region of the US. The instructor begins the semester by rotating students through different groups each week. After several weeks the groups are set for the remainder of the semester based on observation by the instructor as to which students work well together. In class the students work within groups to answer the worksheets. After class one student acts as the scribe and completes an online report that answers questions such as "What was a strength of your group's performance today?" or "Identify two things that your team might do to work more effectively and efficiently." Students also complete weekly blogs that address specific questions about concepts learned in the course or approaches to learning.

Participants: A total of 17 students were enrolled in the course. All students were invited to participate, and 11 students agreed. Students were given an incentive of $20 in cash for participating and all signed an informed consent form approved by the University of Florida Institutional Review Board. Students were asked to provide their major, year in school, and self-reported college GPA; since most of the participants were freshmen, this GPA may only represent a single semester of classes. Demographic characteristics of the participants are given in Table 1; all names are pseudonyms. As noted in Table 1 all participants had GPAs of 3.0 or higher; since students volunteered to participate there may have been some self-selection bias resulting in only the better students participating and the data may not include students who had more negative views of the class.

Table 1: Demographic characteristics of participants.

Name	Sex	GPA*	Major	Year
Michael	Male	3.7	Biology	Freshman
Susan	Female	3.6	Biology	Freshman
Christy	Female	3.4	Neuroscience	Senior
David	Male	3.9	Chemistry/Physics	Freshman
Lisa	Female	3.5	Nursing	Sophomore
Anna	Female	3.4	Environmental Sciences	Freshman
Cheri	Female	3.5	Undecided	Freshman
Tom	Male	3.4	Biology/Pre-Med	Freshman
Brett	Male	3.0	Engineering	Freshman
Patty	Female	3.9	Chemistry	Freshman
Marty	Male	3.9	Chemistry	Freshman

*Self-reported college GPA. For freshmen this GPA is for only a single semester of classes.

Methodology: The data was analyzed using thematic analysis to identify the primary themes articulated by the participants that were related to the research question. Thematic analysis is used to provide a broad descriptive overview of a particular topic. It is important to note that thematic analysis is a rigorous method with specific data analysis techniques;[35] it is more than simply reading the transcripts and identifying themes that appear as you are reading. Tonso points out that "what separates qualitative data from mere anecdotes is the systematic way data are gathered and analyzed. In contrast, anecdotal information, which also comes from real-life experiences, lacks the rigor of qualitative research."[36]

Methods: Data was collected using semi-structured interviews that occurred on campus with the students at the end of the semester. Prior to the interviews, interview guides were prepared for each participant. These guides consisted of two components. First were general questions that were asked of all students. Questions focused on aspects of the class that would illuminate the issue indicated by the research question. Examples of interview questions are, "Tell me how your group works together to complete the worksheets," "How do the homework or other things you do for class other than the worksheets help you learn?" and "How does working in a group help or hinder your ability to learn the material?" In addition to these questions, specific questions were developed for each student by reading their blog entries. For example, Susan had mentioned in her blog the benefit of a phase diagram simulation. Asking her about that during the interview provided further insight into how hands-on activities benefited her learning. In addition to the planned questions, additional questions were asked during the interview to explore additional topics that arose. In some cases these led to questions that were added to the interview guides for the remaining students. Each interview lasted 20-30 minutes and was digitally recorded.

All interviews were transcribed verbatim by an external transcriptionist. Analysis was conducted by coding each significant statement in the transcript with a brief descriptive tag. These codes were generated by asking of the data questions such as "What is this an example of?" or "How did learning occur in this instance?" Codes were generated without reference to any theoretical construct, published literature, or prior codes, as is the practice in constructivist research, in order to allow the voices of the participants to be heard. A typical transcript thus resulted in 50-70 individual codes. After initial coding, codes were grouped into themes by identifying those codes which addressed similar issues, with reference to the original data as necessary. Throughout this process analytical memos were written to more fully describe individual codes, to capture initial thoughts on themes, and to identify potential themes to be explored in other transcripts.

Findings

The primary themes identified through the analysis are: time to adapt; conceptual understanding; developing concepts for themselves; working in groups; opportunities to practice; and ownership of learning. Each of these themes is described in more detail below.

<u>Taking Time to Adapt to an Active Classroom:</u> All but one student talked about the time it takes to adapt to this style of teaching. Students were initially hesitant about how guided inquiry would work, and in some cases were specifically antagonist against it. For example, Tom stated that "I didn't like it at all. I just wasn't used to it and our first test I didn't do well on whatsoever," and Patty stated "When I first went into it like the very first day of class I can remember I was just like this is horrible." Several commented that this is because they were used to lecture style classes, and didn't see how they could learn using guided inquiry. According to Patty, "all

through high school I just wanted it just to be told to me." The preference for lecture could be reinforced by the success they had had with it. This view was exemplified by Michael who said "That's just me, how I've always been taught and how I've always succeeded." For all of these students it was a process of getting used to the class to appreciate it. In some cases it was a gradual process, and they could not identify anything specific that changed their perception:

I think it was just a lot of not like trial and error, but just adapting and just getting used to it. Like I don't, can't really remember like making a conscious change like I need to do this from now on. I think it just kind of slowly came to me that and I slowly got used to like having to relate everything and not being presented with it right up front. And having to like think through everything on my own so. (Tom)

In other cases they were able to identify specific incidents that caused them to undergo the change:

We actually had a blog, last semester's blog, because I had the same professor. It was about what we didn't like about the, about the learning style which is learning-centered as opposed to [teacher]-based learning. We actually wrote a blog on that and then I just sat back and thought about it and I was like ha, it actually helps one learn better than the lecture. And that's when my attitude changed. I mean I didn't have, it was just like, I was like we should maybe have more lectures but then I was like oh, I was just content and started appreciating it. (Marty)

Acceptance of this approach to learning was an important factor in making it effective. Regardless of initial feelings towards the class, when students opened their minds to the possibility of learning in this class it became in essence a self-fulfilling prophecy and learning improved. As pointed out by Marty, "if you just sit there and you're like 'God, I wish we had lectures, it's just a complete waste of time,' you'll be missing a lot of points rather than that person who just sits there, he has a clear mind, this is how we learn…So after you change your perspective how you feel about your learning style, it just helps you progress like you're ready to move on."

<u>Recognizing Importance of Deep Conceptual Understanding:</u> Students talked about the importance of understanding not just "what", but also "why". By this they seemed to mean that it was important to not just be able to use equations mechanically, but to understand where that equation comes from. The importance of this was that it allowed them to adapt their use of the equations or concepts to new problems that were different from what they had seen before. The structure of the worksheets allowed students to work step-by-step through the development of concepts, which allowed them to answer test questions that involved more than "plug and chug":

When you get a lecture you just kind of know how to do the steps whereas with the [worksheets] that she gives us, she gives us a concept and we have to work through it and it makes sense why like the equation works the way it does, where all the factors come into the equation. And then she gives us problems on the test where we have to use that equation and the concepts that we learned in the [worksheet] to solve that problem. It's not exactly like the [worksheet] like so here's your equation, solve it. It's like asking you a question in which you have to remember the equation and how to get the equation and which numbers go into the equation. (Lisa)

This deep conceptual understanding also allowed students to remember equations. Rather than having to rely on rote memorization, they could recognize a situation where a particular equation would be useful:

Instead of going here is my equation this is how I do it, it's more like oh, so that's why we have this equation. And maybe the why helps to remember because then you go oh, what do I need to use, how does this work. (Christy)

This conceptual understanding went beyond equations as well. For a variety of different concepts, having the deep understanding allowed students to go beyond memorization and to apply the knowledge across different contexts:

Knowing how everything works is very important like why… different boiling points are different rather than just how to figure out if they're different or not. And I think that's very important because if you know like different chemical structures in this point, I don't know, know why that they affect the boiling point the way they do. You can better apply it to other things like if the boiling point is raised then the vapor pressure has to decrease. (David)

<u>Recognizing Importance of Developing Concepts for Themselves:</u> This theme, along with Working in Groups, was mentioned most often by the students. It was important for the students to develop the concepts for themselves, rather than just being told. This led to the conceptual understanding described above. Anna pointed out that "Because if we think of it ourselves then it's, I feel like it's more permanent. Like if we come up with a conclusion by ourselves whereas if she tells us, we're like oh yeah, that sounds right like that's right. And we hear it. But until we can apply it ourselves or until we come to it ourselves it's not as permanent." In order to develop this understanding, it was important that the worksheet not require large conceptual leaps. According to Christy "They do it in a step-by-step basis instead of going one big concept blah. It's more like little step, how does this work, little step how does this work, add them together, oh, okay."

Another advantage of learning the concepts for themselves was that they remembered the material for a longer period of time; Anna specifically compared her experience in a General Chemistry 1 lecture class the previous semester with this class:

Last semester I had a different teacher and her tests were multiple choice and they were really easy and I have a lot like, I took AP Chemistry in high school so I already had a lot of the background knowledge that I needed so really the class was just kind of like glossing over what I already knew. And if I heard her say it in class like I could recall it on the test. It was just multiple choice. But then looking back I'd be like oh, well I don't really know that that well. Like I know the basics of it but I don't really understand it whereas this semester it's a lot more difficult this way and, because I'm teaching myself and it's a lot more work. Like I put in a lot more time this semester but her tests are a lot harder. Like there's no multiple choice. It's all essay, like it's all writing and concepts and large mathematical problems and I'm like integrating them. So it's a lot harder to do really, really exceptionally well because if I don't get, like there's no way to check myself so if I don't know something it's like completely up in the air. So her tests are definitely harder. But walking away from it if I know 80% of what I was *supposed to learn from this class it's really well compared to like the 90% of like glossing over the chemistry that I got from the first semester.* (Anna)

Because he was actively learning during class, Brett felt that in some ways this class required less work outside of class time.

Because it makes us think more about it and you know, and then I feel like when I figure it out for myself I understand it better and I don't just forget it when I walk out of the classroom… I have to go back less, I have to study less for this class than I do my other classes where the teachers lecture so. (Brett)

Brett's experience in this regard, however, is different from other students, such as Anna (see quote above) who felt that the class required more work (see additional themes below). Another advantage of developing the concepts for themselves was that if they didn't remember an equation or relationship, they were able to re-develop it because they remembered the process they had used.

I've sat in other lectures of chemistry and I mean you may know the information for a week or two but once you stop using it you seem to like lose the information. And with this because you kind of like learned how to do it, you at least know how to make the connections again. So although you may not remember it three weeks from now but if you can at least get to the same spot you can usually make the same connections and get the right answer…I guess it's kind of like driving to a place and you're just given like one way to go whereas if you learn the problem solving you can take different detours and go around it which may be shorter or take you longer but as long as you know how to do it I think that's the important part. (David)

One concern, however, was that in some cases students could develop the wrong understanding. For some students this was problematic because they said it was difficult to "erase" the wrong understanding. Tom was one student who had a problem with this, saying "the biggest thing that I find with it is that if your group isn't sure about a problem and say you do learn it wrong or think you've figured it out but it's not correct, then it takes awhile…it's hard to kind of erase that and replace it with the new and correct [information]." Brett exemplified the concerns over what could happen if this incorrect understanding was not caught.

That was where our whole group thought we had the right answer on one of the problems in the [worksheet]. And so when, so we just moved on and when I went back and studied that I studied you know, it was wrong by one variable or something like that and so when I took it on the test I got the answer wrong or I did the process incorrectly and then but then when I got the test back I went back in my notes and I was like wait a minute, I did this right. And then I asked her [the instructor] and she was like 'oh and the thing in your [worksheet] is wrong.' So that was frustrating for me. (Brett)

<u>Recognizing Benefits of Working in Groups:</u> Working together in groups came through as one of the most significant attributes of the class. The benefits were that they could "bounce ideas off each other" (Tom), teach each other, and rely on each other when they didn't know what to do. The way in which the group helps learning was described by Susan:

And we'll basically just start like, we all like read the information and then if anyone's confused on the information we'll be like okay I didn't understand what this meant. Someone else will clarify it and then we just kind of approach the problem. Like each one of us kind of throws out a brainstorming idea and like okay, yeah, that makes sense and then from there we'll try to approach it this way and I'm like a lot of times it'll be like one person's like well I think it's like this. Another person's like well I think it's like this and we'll try different ways and like okay, I'm wrong because of this or whatever. (Susan)

Teaching someone else was also seen as a way to enhance a student's own learning, as pointed out by Marty who said "Because when you help the other person anyway the content sticks better to your mind."

Several students said that when they tried to complete the worksheets on their own it was much harder because they couldn't interact with others. That group interaction was seen as a critical part of the learning process, as expressed by Cheri who said "[Completing the worksheet is harder on your own] because you don't have the group to confer with and come up with an answer and argue which I think the arguing factor is pretty important…because then you understand why everybody else came up with their answer or why, what their thought process was. I think that's pretty good information to know like how other people are going about thinking about it."

It was interesting that several students talked about how it was difficult when one student wasn't in the mood to work in the group. Rather than feeling that they could just let that student slack off, they seemed to feel some sense of responsibility to make sure that group member learned the material, and if that student wasn't willing to participate that day it was frustrating:

If you're going to have one of those off days it's just better for you not to come and try to work it out on your own because I think it's pretty frustrating when someone doesn't want to cooperate I guess and they're just kind of sitting back and letting everybody else do it and kind of being like well I don't get it but I don't want to try, you know. That's just frustrating for a group to have to deal with that because I know for me I try to help people but if you don't want to be helped it's kind of like well, I might as well not waste my time. (Lisa)

Students differed on whether or not they thought it was important to have a group that all was at the same ability level or at different levels. The varying opinions are exemplified by David and Marty:

And if you're working with people much above your level or much below your level it does hinder it a lot because it'll move either too quickly or move too slowly for you. And so you don't learn at the appropriate speed but as we got later into the semester she [the instructor] designed the groups according to our abilities and that helps a lot. (David)

Because when you kind of stick people with the same abilities in the same group pretty much there'll be no learning because it'll just be like rushing through like the [worksheets] and just all right, we know the answers. You don't delve much deeper. But when you're helping a person with like not as able as you are then they'll ask you like this really simple questions and then *you'll kind of think about it and you'll be like, huh, actually I've never thought of that. So why is it this way? And so it's just like a way of encouraging more of like critical thinking and the group work and also it's just like balancing the entire class so that everyone can learn so that it's just not like if you put like the people's abilities in the same group and then the other guys in another group they'll be like at a disadvantage because the other guys would be moving way faster, they'll be moving way slower and maybe they wouldn't be learning as much.* (Marty)

<u>Importance of Opportunities to Practice Outside of Class:</u> Students felt it was important to have opportunities to practice outside of class. The worksheets were seen as where you learned the concepts, but there was not adequate time in class to actually apply those concepts. According to Anna "Generally I feel like I get like a glossing, like a gloss over during class and like it gets, like I get the ideas and the general concept but I definitely have to look at it again before it's like in my head." The homework was the opportunity to practice applying the concepts, which allowed for better learning and retention. Many of the students commented on this:

I think it [homework] just reinforces it in your head. Like you've learned it once or gone through it once and then reinforcing and [the homework] just kind of cements it and just makes it like stronger learning like better learned I guess. (Tom)

The repetitive practice, it's also, you know, goes back to helping concepts really stick in your head. (Brett)

And honestly like doing them just once for me isn't enough like if I go back and study for a test usually I go back and just rework the [homework] problems because it's, yeah, you need to be able to repeat the thing over and over again until you really do understand it I think…You have to kind of create a plan, tell a story, like approach the problem on your own. And so I think just practicing doing that in itself can translate to other completely different problems on the test. (Susan)

<u>Taking Ownership of Learning:</u> Several students talked about a switch in their approach compared to a lecture class. They felt it was important to take responsibility for your learning much more in a POGIL class than a lecture class. This responsibility took several forms: making an effort to do reading or approach the instructor when needed; spending much more time outside of class, and doing that on a regular basis rather than cramming. Lisa compared the amount of work needed in this class to the amount needed in a lecture class, noting that it takes more work but that work leads to a deeper understanding:

Because you leave the class feeling like you barely understand what's going on and then it's up to you to go and actually research more and read and work through problems and actually do more work than whereas in a lecture you can just sit there and watch, or watch the teacher work the problems out on the board and give you a study guide with all your notes and this is what you need to know. So it takes more time but I think if I had more time it would be a lot better to learn it because you learn concepts that you can apply instead of just learning facts and spitting them back out on tests. (Lisa)

Discussion and Conclusions

The findings show that students found a number of ways to be successful in the class. Whether it was through group interactions or practice through homework, the students developed the strategies needed to learn the material. Interestingly, they consistently recognized that, despite the additional work needed, they were benefiting from that extra work. They saw the advantages of learning concepts deeply, in a way that could be applied to other situations, rather than shallow learning that only applies to the context in which the material is learned.

The findings point to the power of the constructivist model of learning. In this setting, the learners recognized the benefits of social construction of knowledge. When Susan said "Like each one of us kind of throws out a brainstorming idea and like okay, yeah, that makes sense and then from there we'll try to approach it this way," she was talking about the initial social interaction. This social interaction led ultimately to what Vygotsky called inner speech,[17] or as Anna put it "Because if we think of it ourselves then it's, I feel like it's more permanent."

We also see evidence that the students recognized the way in which application of the learning cycle impacted their learning.[19-21] When Lisa said that "she gives us a concept and we have to work through it and it makes sense why like the equation works the way it does, where all the factors come into the equation" she was talking about moving through the learning cycle, from exploration to concept invention. And because of this learning cycle the students were able to move into the application phase where they truly could apply those concepts in new situations. This was contrasted with lecture classes, in which students saw the application phase as being limited; in that setting they could apply the concepts in the same way as presented in class, but could not move to new applications.

We also see in the data elements of Vygotsky's zone of proximal development.[17] The zone of proximal development is the difference between a student's capabilities and the level that can be reached when trying to learn new material, and thus represents the range of difficulty over which optimal learning occurs. A student who is taught within this zone stretches her capabilities, while she becomes frustrated if she is asked to perform beyond this zone. When David said "she [the instructor] designed the groups according to our abilities and that helps a lot," he was talking about working within his zone of proximal development. We also see in the findings that this zone varies with individuals. For example, David's zone was narrower than Marty's, and so he was seeking group members that were closer to his own level.

The students in this study have themselves identified an important distinction in education, the difference between training and learning. When Christy said "Instead of going here is my equation this is how I do it, it's more like oh, so that's why we have this equation," she was echoing von Glasersfeld who pointed out that recognizing this difference would "sharpen the distinction between training and learning. It would help to separate the acquisition of skills, i.e. patterns of action, from the active construction of viable conceptual networks, i.e. understanding. Hence it would encourage educators to clarify the particular goals they want to attain (p. 135)."[14]

The findings here point to the power of the learning cycle in developing the deeper understanding required for "learning", and provide guidance as to what students see as needed to support that learning. The learning cycle is not the only approach to develop effective learning, but the findings here show that when it is applied it can result in deeper learning than a lecture class. In addition, while the findings were obtained in a POGIL classroom, they point to broader implications for pedagogical design. There are a number of similar approaches based on constructivist models of learning, including collaborative and cooperative learning, problem-based learning, and guided design. For any of these approaches, ensuring that the classroom is "turned", so that responsibility for teaching by the instructor becomes responsibility for learning by the student, is likely to lead to the same kind of deep learning observed here.

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