Process-oriented guided inquiry learning in engineering

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Abstract

Process-oriented guided inquiry learning (POGIL) is a student-centered pedagogy. While it has been extensively used in the chemistry curriculum, its use in engineering has been limited. This paper describes the use of POGIL in the Introduction to Materials Engineering course. Assessment of its effectiveness shows that details of implementation can play a critical role. In particular, because of the student-centered aspect of the approach students can feel that they are not being "taught" and thus not take ownership of their own learning. By providing opportunities for students to check their understanding and reflect on their learning process performance is enhanced over a traditional lecture course.

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1. Introduction

Recently there has been an increasing awareness of the effectiveness of various types of active learning approaches. 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 (Prince & Felder, 2006). 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 cognitive models of learning (Prince & Felder, 2006; Svinicki, 2004). This paper discusses the implementation of one type of active learning, Process-Oriented Guided Inquiry Learning (POGIL), in the Introduction to Materials course. 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 (Farrell, Moog, & Spencer, 1999; Hanson & Wolfskill, 2000). POGIL was originally developed for the chemistry curriculum, but has now been extended to other fields such as biology and engineering.

This paper will describe assessment of POGIL worksheets developed for the one semester Introduction to Materials Engineering course as an example of how POGIL can be used in an engineering classroom. Worksheets have been developed that cover the typical topics of a one semester Introduction to Materials course. The effectiveness of the POGIL class was determined using a mixed methods study. This study addressed the following two research questions:
1. Does student performance improve in a POGIL class compared to a traditional lecture class?
2. How do students experience a POGIL class?

2. Methodology

The effectiveness of the POGIL class was determined using a mixed methods study. The lecture class was taught by the first author in the two years prior to implementing POGIL, after which he taught two sections of the POGIL class in two different semesters. The total sample consisted of 217 students in the control group, in which students were taught in a traditional lecture format, and 98 and 96 students in each of two different treatment groups, in which guided inquiry was applied. These two treatment groups were considered separately because of differences in implementation, as described below. Final course grades were used as the quantitative measure of student learning. For the qualitative data, three randomly-chosen student groups were audio recorded while working in the classroom, followed by individual semi-structured interviews with students from those groups. The interview questions were mainly focused on revealing how students were working in groups and developing their knowledge. After the course finished, additional data was collected by interviewing more students in order to gain additional insight. Segments of the transcripts were coded with short descriptive phrases, and these codes were then grouped into themes (Grbich, 2007).

3. Findings

The primary measure of effectiveness for this project was final course grade. Quantitative results show the following:
- There was no significant difference in course grade between the control group and the initial (fall '08) treatment group at $p<.05$.
- There was a significant difference in course grade between the control group and the second (spring '10) treatment group at $p<.05$, with the treatment group scoring higher.

In the first treatment group in fall '08, implementation focused on use of the worksheets. Students were provided the worksheets at the beginning of each class period, and they worked on it in groups throughout class. The

instructor did interact with groups and the entire class as necessary to address issues that arose, but no other feedback was provided. Based on the lack of improvement as seen in the quantitative data and the information obtained from the qualitative results (discussed below), additional opportunities for feedback were provided in the second treatment group in spring '10. For example, student response systems ("clickers") were used periodically throughout the class period to check student understanding, allow for student self-assessment of their learning, and help with the pacing of student progress throughout the activities. Another strategy implemented was the use of lesson objectives at the end of the class period. Although lesson objectives were provided in fall '08, they were not always mentioned in class. Reviewing these objectives at the end of the class period was used as a way to illustrate to the students what they had actually learned. Finally Scribe Reports were implemented in which students were required to respond online after class to a prompt 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." These prompts were intended to help students reflect on their performance and identify ways they could be more effective in their learning.

Three broad themes emerged from the open codes of the transcripts from the interviews. The first theme was that students did recognize the benefits of working in groups, such as promoting critical thinking, learning cooperative skills, gaining different perspectives, and retaining the content knowledge. The diversity of engineering majors in the same group provided opportunities for each student to contribute their own input, resulting in the group being able to solve the problems together. One student, Long (all names given are pseudonyms), described his group experience, "the group members kinda had diverse backgrounds, I mean some of us were chemical and other were more physics-based, so a lot of the questions we figured out ourselves." The students' understanding and learning were deepened and enhanced by group discussion. For example, Chris stated, "From our group session, well, they're interesting people and also, they can figure out stuff that I can't, so it is pretty helpful so I miss some stuff and then we can get together, figure it out." However, some students also reflected that group dynamics had an influence on the quality of group discussion. A good group rapport took time to establish. Once the students were more accustomed to getting into groups, they felt more comfortable working with others.

The second theme was that the use of worksheets increased students' levels of understanding of the content and their engagement. During group discussion, the students had to be actively involved in the problem solving process and interact with their group members rather than sitting and listening to lectures. One student, Sanjay, identified that the worksheets helped most in this guided inquiry class with the statement, "the questions on the worksheet were so, like common sense that they were like, 'Oh, why is he asking us this?' But it actually helped us better understand the concepts that he was trying to explain." Some students acknowledged the benefits of the worksheet to engage them better in discussion. Lamar stated, "Since we had the worksheets to guide us, the worksheets helped us to keep focused working in group."

The third theme was that the use of guided inquiry in this setting had minimal benefit due to the expectations of the students. Some students felt uncomfortable with not being told the answers to the worksheet questions and suggested that the instructor offer the answers to all the questions so they knew they were getting them correct. One student, David, shared his experience in guided inquiry learning, "Well sometimes yeah we do get to those questions where we can't find information or we don't know exactly what to put down so we talk about it for a little while and then we pretty much decide to wait till the professor stops, so we can make sure for right or wrong." Even though the instructor provided an active learning environment, students still expected to be fed knowledge by their instructor. Long expressed his concern in the interview, "I don't want the worksheet to completely take over and just feel like I'm – I'm never really getting taught by someone." A related issue is that some students did not seem to recognize the need to engage in critical thinking to answer the questions. However, other students seemed to recognize that they could use the worksheets to develop their own understanding of the material

This qualitative data points to the reasons behind the difference in performance between the two treatment groups. These results show that even in the initial treatment group the students did recognize the benefits of working in groups, such as establishing critical thinking, learning cooperative skills, and retaining the content knowledge. However, in this group there may have been minimal benefit due to the expectations of the students. Even though they recognized the benefits of working in groups, they were uncomfortable with not having an authority figure

provide the "correct" answers and felt that they had not been "taught" by the instructor. Thus, strategies were added to provide students' confidence in their own abilities, such as clicker questions and other activities as described above. According to one student in the spring '10 section," Sometimes you are not sure if you understood the concept, but if you get the right answer on the [clicker question], then you are sure you got it." Thus, while there was no change in the overall instructional strategy between the two treatment sections, the changes in implementation resulted in improved confidence in the students and improved performance.

4. Conclusions

This paper describes successful implementation of process-oriented guided inquiry learning in an engineering classroom. The goal of this class is to reverse the pedagogical roles of the instructor and the student, making students responsible for constructing their own understanding of the material and leaving the instructor to serve as the facilitator of this learning. While this paper provides one specific approach to accomplishing this goal, there are various other active learning approaches that may also be appropriate depending on the specific context of the class.

The results from the research study examining the effectiveness of this implementation suggest that a number of factors must be considered when implementing guided inquiry. The traditional classroom that students experience throughout their education sets up certain expectations that the guided inquiry instructor must be careful to manage. The primary expectation that seems to be revealed in this study is that students expect to be "taught" by an expert. Thus, it is important that appropriate feedback is provided so that students have a sense that the instructor is a part of their learning. Giving rationales and starting a whole-class discussion about the implementation of guided inquiry will help them make sense of their own learning and increase their awareness of being an active learner. At the same time, however, the instructor must be careful to guide the students in ways that still lets them discover the concepts on their own and promote their accountability. Thus, there is a delicate balance that must be maintained in order to make guided inquiry effective. For instance, providing students opportunities for self-assessment of their learning in class is a possible way to accomplish this.

Additional work is clearly needed to demonstrate how to best use guided inquiry within engineering, as well as to understand how learning occurs in the guided inquiry classroom. We are currently analyzing additional qualitative data in more detail using contructivist grounded theory (Charmaz, 2006), which will provide an in-depth understanding of the processes students used. We expect the theory that develops will be useful for developing more detailed guidelines for the use of guided inquiry.

Acknowledgements

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