Use of guided inquiry as an active learning technique in engineering

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Abstract*: The purpose of this study is to examine the effectiveness of using guided inquiry in an Introduction to Materials class at a large research university. Throughout the course, the instructor, as a facilitator, guided students by providing an active learning environment and probing them with questions. A comparison was made between lecture and guided inquiry sections, both taught by the same instructor. The Materials Concept Inventory (MCI) was used as a pre-test/post-test to measure students' learning; student satisfaction and self-assessment of learning was measured by the Student Assessment of Learning Gains (SALG). Measures of learning showed no significant difference between these two sections. From surveys and interview data, we found that students did recognize the benefits of being active learners, but they felt uncomfortable without having an authority figure provide the "correct" answers. More implications and challenges of using this guided inquiry in engineering will be discussed.*

Context

Active learning techniques are being used with increasing frequency as a means to engage students in their own learning. The use of active learning in the classroom spans a continuum, ranging from the occasional use of problems for students to solve, to the extensive use of discussions, problems, or other activities in a class. Guided inquiry falls at the extreme end of this continuum. In a traditional class, students acquire knowledge by coming to the classroom, listening to instructors' lectures, and taking notes. In a guided inquiry 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). This approach replaces a traditional teacher-centered model with a new student-centered model. This approach has not been used within engineering, although elements of the approach exist within other approaches such as cooperative and collaborative learning(Demetry & Groccia, 1997; Felder, 1995; Felder, Felder, & Dietz, 1998; Haller, Gallagher, Weldon, & Felder, 2000; Terenzini, Cabrera, Colbeck, Parente, & Bjorklund, 2001; Wankat, 2002), problem-based classes (Deek, Kimmel, & McHugh, 1998; Harmon, et al., 2002; Maskell, 1999; Polanco, Calderon, & Delgado, 2001; Wankat, 2002; Woods, et al., 1997), and guided design (Wankat, 2002).

The guided inquiry approach used in this study is modeled after work done in the chemistry curriculum. Several studies conducted on implementation within chemistry have shown the effectiveness of this approach (Farrell, et al., 1999; Hanson & Wolfskill, 2000). Several common, and important, outcomes observed in all of these assessments of implementations are: more students successfully complete the courses; student mastery of content is at least as high as for traditional instructional methods; and students generally prefer the approach over traditional methods. However, whether these outcomes will also hold true when guided inquiry is implemented in engineering courses is unknown. Also, there have been no studies examining how student learning occurs within a guided inquiry classroom. Thus, the purpose of this study is to examine the implementation of guided inquiry within engineering. The particular setting is the Introduction to Materials course at a large public research institution.

Research questions

The specific research questions for this study are:

1. Do students who are in a guided inquiry class have a better understanding of materials concepts than students in a traditional lecture class?
2. Do students who are in a guided inquiry class feel like they have a better understanding of materials concepts than students in a traditional lecture class?
3. How do engineering students construct knowledge in a guided inquiry classroom?

The first two questions are addressed through a quantitative study in which comparison is made between sections taught by the same instructor using traditional lecture and guided inquiry. The third question is addressed through a constructivist qualitative study in which students from the guided inquiry class were interviewed during the semester in which the guided inquiry class was taught and shortly after the semester was over.

Theoretical Frameworks

The guided inquiry approach is based on a cognitive model of learning (Svinicki, 2004). This model describes learning as occurring when 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. The guided inquiry approach is designed so that students must actively process information in order to complete the worksheet.

As will be discussed below, some of the results of this study can be understood in terms of the Reflective Judgment Model described by King and Kitchener (1994). Their model of reflective judgment is a stage model describing the epistemic beliefs of learners, that is beliefs regarding the nature of knowledge and how conclusions are to be justified. The model is based on empirical research, in which they found that the epistemic beliefs of learners could be classified into seven stages. These stages can be further grouped into the following three categories:

- Pre-reflective thinking: Knowledge is obtained either by direct observation or from people in authority. This knowledge is certain and is not to be questioned. Of particular relevance for this project is that "[p]eople who hold these assumptions do not differentiate between well- and ill-structured problems, viewing all problems as though they were defined with a high degree of certainty and completeness (p. 16)."
- Quasi-reflective thinking: Learners in this category accept that some knowledge may be uncertain, but judgments regarding this knowledge are individualistic and idiosyncratic. "While they acknowledge differences between well- and ill-structured problems…they are often at a loss when asked to solve ill-structured problems because they don't know how to deal with the inherent ambiguity of such problems (p. 16)."

- Reflective thinking: Knowledge is constructed based on its context. Judgments are based on an evaluation and interpretation of the evidence, and some judgments may be evaluated as more reasonable than others.

Methodology

In order to determine the effectiveness of this approach, a comparison was made between lecture class sections and guided inquiry class sections, both taught by the same instructor. These sections were taught over the course of several years, and the treatment group was taught in a semester after all the control sections had been taught. The Materials Concept Inventory (MCI) was used in a pre-test/post-test design to measure students' learning. The MCI is a thirty item, multiple choice instrument designed by Krause, Tasooji, and Griffin (2004) to assess students' level of conceptual knowledge in an introductory materials science class. In order to assess students' beliefs about their learning, student satisfaction and self-assessment of learning were measured using the Student Assessment of Learning Gains (SALG) (Seymour, Wiese, Hunter, & Daffinrud, 2000). The SALG is an online instrument designed to focus on how the pedagogy of the class affected students' learning gains, as opposed to issues of teacher performance or the extent to which students "liked" the class. The total sample consisted of 217 students in the control group, in which students were taught in a traditional lecture format, and 98 students in the treatment group, in which guided inquiry was applied.

In order to better understand the ways in which learning occurs within a guided inquiry classroom, a qualitative study was also conducted. 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 theoretical sampling was conducted by interviewing more students in order to gain additional insight. Interviewees were selected based on their SALG surveys and voluntarily participated in the interviews. Qualitative data analysis is still ongoing.

Findings

Table 1 shows demographic data for the control and treatment groups. The two groups are equivalent, except for the total number of credits completed. Table 2 shows the results from the various quantitative measures of performance. The control group actually shows a greater gain in MCI score than the treatment group, although the actual difference is small and probably does not represent a real difference in performance. Crosstab analysis of the letter grades (not shown) shows no difference between the two groups in the numbers of A, B, C, or DFW grades earned, in contrast to what has been found previously in the chemistry curriculum (Farrell, et al., 1999; Hanson & Wolfskill, 2000).

Table 1: Demographic data.

	control group	treatment group
GPA	3.2	3.3
SAT verbal score	590	590
SAT quantitative score	681	660
credits completed*	81	98

*Significant at p<.05

Table 2: Performance measures.

	control group	treatment group.
course average	79	81
MCI pre-test*	12.15	13.55
MCI post-test	13.37	13.83
MCI gain*	1.26	0.08

*Significant at p<.05

Selected SALG results are shown in Tables 3 and 4. In general, students from the lecture class felt more confident in their ability to understand the material and that the class activities were more beneficial. The only areas in which guided inquiry students have a higher score on the SALG were items related specifically to mechanical aspects of the guided inquiry class, namely the use of the worksheets and working with peers in class. In particular, it is interesting to note that lecture students felt more confident in their abilities of problem-solving and finding trends in data, even though those are specific aspects that are emphasized in the design of the worksheets.

Table 3: Selected SALG results. Items ask to what extent each of the characteristics of the class helped learning.

	control group	treatment group
activity sheets*	3.16	4.02
group work	3.01	3.30
information on how classwork, reading, or assignments related*	3.61	3.10
quality of contact with teacher*	3.94	3.48
working with peers in class*	3.19	3.64
working with peers out of class	2.58	2.93
way in which materials was approached*	4.33	3.36

*Significant at p<.05

Table 4: SALG results on the extent to which students feel they understand various topics or can perform skills as a result of the class.

	control group	treatment group
phase diagrams*	4.24	3.94
mechanical properties*	3.92	3.41
crystal structures	3.89	3.67
diffusion	3.79	3.77
kinetics*	3.74	3.37
corrosion*	3.89	3.28
problem-solving*	3.28	2.98
finding trends in data*	3.13	2.74
critically reviewing data	3.22	3.05
working with others*	2.59	3.19

*Significant at p<.05

Preliminary examination of the transcripts for the interviews suggests that students did recognize the benefits of working in groups, such as establishing critical thinking, learning cooperative skills, and retaining the content knowledge. However, 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 know they are getting them correct. Even though the instructor provided an active learning environment, students still expected to be fed knowledge by their instructor. As stated by Long (all names given are pseudonyms), "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. For example, Carol stated that "sometimes, we would get stuck and we would end up just sitting there because we had no idea and we would just have to wait for him to come around or to say, or we'd ask other groups but we would try and look up the answers in the book." However, other students seemed to recognize that they could use the worksheets to develop their own understanding of the material. According to Jason, "it [the worksheets] helped us figure out the material without having to hear it from someone… he [the instructor] directed us towards the answer and then we could figure it out on our own."

The differences in how students viewed the class may be related to their epistemic assumptions as described by the Reflective Judgment Model. Take, for example, the contrasting statements of Carol and Jason. Carol's statement seems to place her within the category of quasi-reflective thinking; when faced with an ambiguous problem she has difficulty understanding how to approach it. In contrast, Jason may be operating closer to reflective thinking; he accepts the ambiguity of the problem and recognizes that it is possible for him to justify a "best" answer on the basis of the data provided.

Recommendations

Overall, the use of guided inquiry in this context showed no benefit to student performance, and students were less satisfied with the class. We consider three possible reasons for these results:

1. There may have been minimal benefit due to the expectations of the students. Even though they recognize the benefits of working in groups, they are uncomfortable with not having an authority figure provide the "correct" answers. This may be due to the students being at the lower stages of the reflective judgment model, where they see knowledge as uncertain and thus have difficulties with being able to answer ambiguous questions. Strategies to develop confidence among the students in their own abilities, as well as ensuring the classroom activities are carefully tailored to account for different levels of epistemic beliefs about knowing are needed in order to make guided inquiry work effectively.

2. Previous work on "inquiry-oriented" instruction in mathematics has shown that undergraduate students taught using inquiry methods score the same as students taught using a traditional method on procedural questions, while they score significantly higher on conceptual questions (Kwon, Rasmussen, & Allen, 2005; Rasmussen & Kwon, 2007; Rasmussen, Kwon, Allen, Marrongelle, & Burtch, 2006). The performance measures used in this study (course grade, MCI) tended to be more procedural or knowledge-based in nature, which may have masked conceptual gains associated with processes such as identifying trends in data, critical thinking, etc.

3. Use of guided inquiry in large classes requires special approaches not needed with smaller classes. For example, it has been recommended that student response systems ("clickers") be used periodically throughout the class period (POGIL, 2005). This and other activities can be used to check student understanding, allow for student self-assessment of their learning, and help with the pacing of student progress throughout the activities. Activities such as these were not used in this implementation, which may have contributed to students' sense of feeling "lost".

Going forward, a number of questions remain. First, analysis of the qualitative data using grounded theory (Charmaz, 2006; Strauss, 1987; Strauss & Corbin, 1998) will provide a more detailed understanding of how students approach the guided inquiry class than is given here. The difference in effectiveness found in this study compared to what has been found previously in chemistry suggests that there are differences either in the way it has been implemented in chemistry or with the attitudes and expectations of chemistry students. Given that this engineering implementation was modeled after the chemistry approach, future work will focus on students. Specifically, interviews will be conducted with chemistry students at institutions where guided inquiry has appeared to be successful. There are also plans to incorporate the Reasoning About Current Issues Test, which is a measure of Reflective Judgment.

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Conversely, can active learning techniques help students acquire a level of knowledge equivalent to or greater than that acquired through the traditional formats while they stimulate student interest and help them develop critical thinking skills? In the following section, we describe two experiments designed to examine these questions. A number of important criteria guided the selection of these activ-ities.Â The activities described here addressed issues that instructors can use traditional methods to teachâ€”a discussion section in the caseof multiculturalism and a lecture in the case of opinion polls. Fourth, both activities were collaborative.Â Few would question the importance of public opinion as a guide to political action in a democratic state.