AC 2012-4503: DEVELOPING AND IMPLEMENTING GUIDED INQUIRY MODULES IN A CONSTRUCTION MATERIALS COURSE

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Developing and Implementing Guided Inquiry Modules in a Construction Materials Course

Introduction

In recent years, leading engineering research and accreditation agencies have called for engineering education to become more reflective of real-world engineering practice. The National Academy of Engineering (NAE) suggests better alignment of engineering curricula and academic experiences with the challenges and opportunities graduates will face in the workplace, emphasizing the importance of student-centered education and student learning outcomes that are focused on performance characteristics needed in future engineers[1]. The Accreditation Board of Engineering and Technology (ABET) has set standards for engineering curricula to focus on the skills needed to integrate future engineers into the real world[2]. As advised by ABET, higher education programs in the engineering discipline are expected to (1) create opportunities for students to adopt a systems approach capable of considering short and long-term environmental, societal, political, regulatory, and economic issues while identifying, defining, and devising solutions to real-world, open-ended problems; (2) take a research-based, inquiry-based approach to actively engage students in the learning process; and (3) facilitate development of interpersonal skills such as teamwork, technical writing and public speaking to communicate with technical as well as nontechnical audiences[3].

Guided inquiry methods encourage students to apply problem-solving skills, generate and evaluate alternative solutions, periodically assess progress toward the solution, and extract general principles from specific solutions; students can then make sense of new information and regularly assess their own knowledge and skill levels, thus promoting the development of meta-cognitive skills[4]. These methods portray the teacher as a facilitator or guide, providing only the materials and problems for students to investigate and devise their own procedures to solve the problem[5]. From this type of instruction, both student and instructor become critical in the teaching and learning process; a cycle of guidance, problem solving and collaboration that continues among students and between students and instructor that allows greater understanding than traditional lecture and learning.

Project-based Resources for Introduction to Materials Engineering (PRIME) modules are a recent instructional approach in engineering disciplines. Within the context of modern engineering applications, the PRIME modules address the fundamental concepts of materials science. By integrating the fundamental concepts with advanced technologies, the PRIME modules enable students to recognize the connection between the academic and real world engineering issues, thus motivate them to learn on their own6[6, 7]. Douglas and colleagues have implemented PRIME modules in courses related to understanding professional ethics within the engineering discipline[8]. These engineering educators assert that such an instruction style incorporates effective educational pedagogies, including active learning and team based projects that excite students about materials by relating them to modern technologies. Module instruction is geared towards student learning outcomes, as well as interaction and communication within the engineering discipline.

While PRIME modules were developed in one area of engineering, they were designed to be flexible enough to be used in many different engineering courses with differing amounts of time devoted to the material. PRIME modules are structured so that topics are repeated between modules for context purposes only. This exposure to fundamental topics in different contextual settings allows students to view principles from different perspectives and to form a higher level of understanding[6, 7]. Moreover, these modules offer specific opportunities for students to critically think through open-ended problems that need precision and application of concepts which combine conceptualization, design, and building, while providing opportunities to enhance communication and hands-on problem solving skills[9].

The research described in this paper was to successfully develop, implement, and test guided inquiry modules into Construction Materials, a required Civil Engineering Technology course at this University, taught every spring semester. In the present research study, the duration of a single module varied, but typically covered more than one class period, and usually one to two weeks of class time. The authors hypothesized that instruction using guided inquiry modules (treatment) would result in greater perceived learning gains and better performance on exams than through traditional lecture instruction (control).

The focus, guided by recent findings and developing pedagogical research, was on an active learning, team-based approach to education. The project deployed two important components: 1) adaptation and translation of a successful research result for new instructional strategies; and 2) demonstration of student learning improvement based on an active learning approach. These project components were designed to accomplish six objectives:

- Increase student learning;
- Increase student engagement;
- Enhance faculty-student interaction;
- Improve student cooperation;
- Promote active learning; and
- Improve student performance on course learning objectives.

In each module, this study moved students away from the traditional educational setting involving passive listening and lectures given by learned professors from platforms. On the contrary, students were encouraged to work in teams to complete worksheets (in the form of guided inquiry modules) that guide them through the process of learning, actively engaging them in processing information, as well as routinely utilizing and developing important skills such as teamwork, communication, and critical thinking. This research also examined how students perceived learning gains and effectiveness of the two instructional approaches they experienced; providing insight into student perceptions of learning toward improving pedagogy within engineering courses.

Research Setting

Modules were developed for each of the six primary topics comprising the major blocks of instruction for the course: Aggregates, Asphalt, Concrete, Iron and Steel, Wood, and Masonry. The modules were developed iteratively with frequent interaction between the two researchers particularly as the program envisioned both researchers executing three each modules as an instructor for each course section (A and B). Guided inquiry modules stand independent from each other and address each separate block of instruction. The modules shared a common format and generally included:

- Background information on the topic
- Learning objectives
- Active in-class exercises
- Solutions

Both sections (A and B) used traditional lecture-based instruction and instruction using guided inquiry modules in an alternating fashion (see Table 1 below). Section A received the guided inquiry module treatment during the first half of the course, while Section B received the guided inquiry module treatment during the second half of the course. This design allowed for comparison of treatment versus control groups, acknowledging significant threats to internal validity due to lack of random assignment and two different instructors teaching the two sections.

Table 1. Implementation of Instructional Approaches

Module Topics	Assessment	Treatment (Module)	Control (Lecture)
Mid-semester Analysis			
Aggregates	Pre-/post-test quizzes 1		
Asphalt	Pre-/post-test quizzes 2		
Concrete	Pre-/post-test quizzes 3	Section A	Section B
	Midterm Exam		
	Mid-semester Course Assessment		
End of Semester Analysis			
Iron and Steel	Pre-/post-test quizzes 4		
Wood	Pre-/post-test quizzes 5		
Masonry	Pre-/post-test quizzes 6	Section B	Section A
	Final Exam		
	End of Semester Course Assessment		

It should be noted that the in-class exercises also tended to follow a recognizable format involving vernacular associated with the particular block of instruction followed by a variety of problems testing both understanding of abstract concepts and factual areas of knowledge as well as applications involving mathematical analysis and interpretation. Each of the guided inquiry modules for Construction Materials typically covered about two weeks or ten (10) hours of classroom instruction for each topic. However, the inherent flexibility of this methodology allow each module to be tailored to the specific topic so that the classroom time for more complex topics such as concrete was appropriately extended.

A total of 81 students from two sections participated in the study. Participants included 7 female and 74 male students; 9 freshmen, 23 sophomores, 28 juniors, and 21 seniors. Among the 72 non-freshmen, 34 were transfer students. Section A contained 40 students, while Section B had 41 students. While the two sections were roughly balanced by gender and transfer student composition, Section B was more balanced by class rank. Among the 65 students who self-reported race/ethnicity on the course assessment, 59 indicated Caucasian descent.

Analysis

Student participants were asked to provide feedback both at mid-semester and end of semester to assess the instructional approach, as well as their perceived learning gains based on that approach via a two-page ten-item questionnaire created by the researchers, based on the SALG (Student Assessment of Learning Gains) survey (www.salgsite.org). Students rated items on a five point Likert-type scale, from 1=no gain or not helping at all, to 5=great gains or helped a great deal. The questionnaire included open-ended comments on the instructional approach and understanding of class content based on the instruction received to this point. A questionnaire similar to the midterm course assessment was administered to students at the end of the course. This questionnaire included a set of questions asking students to indicate which of the two instructional approaches was more effective for their learning, rated on a five point scale from 1=lecture, 3=about the same, 5=module.

Student scores on midterm and final exams were also used as measures of student learning. These tests were the same tests used for the previous five iterations of the course and provided an excellent source for comparative statistics to assess student performance given the implementation of the new instructional techniques in the research program. Each of the exams was comprehensive covering three respective blocks of instruction. Questions tended to adhere to multiple choice and matching formats in assessing student performance.

The data analyses for this study involved both descriptive statistics and group comparisons (t-tests and Chi-square tests of independence) to determine any statistically significant differences between the two course sections on exam scores, and perceptions of learning gains. Instructor and treatment effects were not able to be simultaneously investigated due to the study design. Results were considered statistically significant if $p < .05$ for all analyses conducted.

Student Perceptions of Knowledge Gain and Value of Module Instruction

At midterm, a course assessment was conducted to study the relationship of student perceptions to instructional approach received. Chi-square tests indicated that perceived learning gains were independent of type of instruction for the main concepts, relationships between concepts, and concrete and asphalt topics (see Table 2). However, perceived learning gains in aggregates was dependent on instructional approach ($\chi^2(4,51)=12.86$, $p=.01$). Frequencies of student responses indicate that students in the treatment group were more likely to perceive "great gain" than those in the control group for aggregates.

The treatment group had more favorable perceptions of learning based on instructional approach and pace of class than the control group at midterm. Chi-square tests indicate that perception of the degree to which type of instruction ($\chi^2(3,51)=8.65$, p=.03) and pace of class ($\chi^2(4,51)=15.56$, p=.004) helped learning was dependent on type of instruction received, with the treatment group expressing more positive perceptions.

Table 2. Results of Chi-Square Tests of Independence of Topics and Course Aspects from Instructional Approach for First Half of Semester (Section A Treatment Group)

Perceived Gains and Contributions to Learning	χ^2	N	Df
Perceived Learning Gain			
Main concepts	4.19	50	3
Relationship between concepts	5.86	51	4
Aggregates	12.86**	51	4
Asphalt	5.16	51	2
Concrete	4.85	51	3
Perceived Contribution to Learning			
Instructional approach	8.65*	51	3
Linking of topics, activities, and assignments	5.15	51	3
Pace of class	15.56*	51	4

*p<.05, **, p<.01, ***p<.001

For the end-of-course assessment, students were asked about their perceived gains in understanding course content and specific topics covered in the second half of the semester. Chi-square tests indicated that perceived learning gains on the main concepts, the relationships between concepts, iron and steel, wood, and masonry were not dependent on type of instruction received for those topics in the second half of the semester (see Table 3).

Table 3. Results of Chi-Square Tests of Independence of Topics and Course Aspects from Instructional Approach for Second Half of Semester (Section B Treatment Group)

Topic or Course Aspect	χ^2	N	df
Perceived Learning Gain			
Main Concepts	1.05	73	2
Relationship between concepts	0.71	73	2
Iron and Steel	3.74	71	4
Wood	2.95	73	3
Masonry	4.62	72	3

*p<.05, **, p<.01, ***p<.001

When asked on a continuum about which instructional approach was more effective in encouraging participation, and providing discussion, activities, and teamwork opportunities that encouraged learning, responses from students in both sections indicated that a significantly larger proportion viewed the module instruction as more effective (see Table 4). Interestingly, when comparing the two sections, perception of effectiveness of the instructional approaches was dependent on group. The treatment group (Section B) was more favorable toward module instruction on every statement (see Table 4).

Table 4. Student Perceptions of the Two Instructional Approaches and Chi-square Tests of Goodness of Fit (all students) and Independence (Section A vs. Section B)

	Frequency						
Which instruction approach…	Module 5	4	3	2	Lecture 1	Chi-square Goodness of Fit	Chi-square Independence
Did you participate most often?	37.0	20.5	32.9	5.5	4.1	$\chi^2(4,73)=33.51$ p=.000	$\chi^2(4,73)=18.03$ p=.001
Provided an atmosphere that encouraged participation?	28.8	23.3	32.9	11.0	4.1	χ2(4,73)=21.45 p=.000	$\chi^2(4,73)=13.10$ p=.011

Provided discussion and activities in class that helped your learning during the course?	30.1	27.4	27.4	6.8	5.5	$\chi2(4,71)=22.31$ $p=.000$	$\chi^2(4,71)=15.10$ $p=.005$
Provided teamwork opportunities that helped your learning of the material covered in the course?	42.5	23.3	23.3	5.5	4.1	$\chi2(4,72)=36.61$ $p=.000$	$\chi^2(4,72)=18.62$ $p=.001$

Conclusions

Findings from this study are expected to contribute to the growing research on instructional approaches that educators, specifically in higher education, seek in order to improve student learning gains within their classes. After implementing the two instructional approaches in this first phase of the two year study, student perceptions strongly support the notion that module instruction provides a class structure that is effective for learning gains. Specifically, practical and statistical significance of the research findings include:

- In both sections, grades improved tremendously from midterm to final exams, learning gains which are commonly expected by educators and students during a course. While comparison of the midterm and final exam scores yielded no statistically significant differences, Section A scored higher in both instances, regardless of being under the treatment condition.
- Students receiving guided inquiry module instruction performed significantly better on the initial topics of Aggregates and Asphalt; however, there were no statistically significant differences between treatment and control conditions for the other topics.
- An assessment of student perceptions on components of the type of instruction received suggests that students in the treatment group perceived certain aspects of the class (instructional approach, pace) as more positive than those in the control group. These results support the investigators' hypothesis that students would respond more positively to instruction using guided inquiry modules.

Statistically significant differences suggest that within the guided inquiry module instruction group, greater learning gains were perceived based on the type of instruction alone regarding the effectiveness of the two instructional approaches, specifically in (1) encouraging student participation and discussion, (2) providing teamwork activities, and (3) creating an atmosphere conducive to learning. Guided inquiry module instruction offers an engaged atmosphere of discussion and hands-on opportunities and is more student-centered than teacher-directed, all of which may give students motivation to learn, and therefore, demonstrate greater learning. Supporting this assumption, student responses to the assessments in this study verify the notion that module instruction has its intended effect: an engaging, active, motivating, and comfortable environment to learn, and therefore, a feeling or atmosphere wherein one is able to succeed.

The use of guided inquiry module instruction is a means to meet both the professional needs desired in the field of engineering graduates as well as the criteria set by engineering accreditation agencies. PRIME module instruction, a specific guided module instructional approach recently implemented by engineering educators, is a more student-centered, active learning environment when compared to a traditional lecture, passive learning environment. The current study suggests promising results as well as considerations when implemented in future courses. Implementation of the PRIME modules in a Construction Materials course has shown that students are more engaged and therefore more prepared for the engineering field through the active learning and hands on activities within the course modules. Results of student perceptions and learning outcomes provide reasons to believe, and support, that guided inquiry module instruction is a more successful approach toward student understanding of course concepts and skills than traditional lecture instruction.

With the variety of learning environments offered in higher education settings, an instructional approach that offers both active and cooperative learning along with facilitation rather than direction from the instructor will be more inviting and motivating to both traditional and nontraditional students. Such a motivation will then lead to greater participation by students in the classroom and greater learning outcomes; combined with the knowledge of students entering the classroom can further that learning. As more educators in the engineering discipline begin to instruct and draw out student experiences through the guided inquiry instructional approach, the likelihood exists that more students will seek out and continue toward the engineering profession. As shown in the current study, the increase of student learning outcomes and engagement is encouragement to the engineering discipline that the implementation of PRIME modules guided inquiry instruction benefits the engineering field overall. Used previously in engineering ethics courses and most recently in Construction Materials, steps toward preparing engineering graduates more effectively can be furthered as future engineering educators continue such an instructional approach in their own courses.

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