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FACILITATING PROBLEM-BASED LEARNING WITH AN INVERTED CLASSROOM

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Abstract. *This paper presents motivation, implementation, and preliminary results from a research project sponsored byaNational Science Foundation (NSF) grant titled "Facilitating Problem-Based Learning with an Inverted Classroom."The objective of this project is to develop an instructional framework that promotes self-directed learning and enhances problem-solving skills in undergraduate engineering students without sacrificing knowledge of fundamental engineering principles. The instructional framework uses an Inverted Classroom (IC) to facilitate Problem-Based Learning (PBL). To facilitate an IC, material traditionally covered in a lecture format is moved outside of class time, developed for an on-line format, and made available in an online learning management system. PBL uses engineering problems co-developed with industrial partners from aerospace, medical device, HVAC and process industries. The framework is implemented in a Heat Transfer course that is offered in traditional (control) and IC-PBL settings. Student self-directed learning and problem-solving skills indicate improvement in IC-PBL over traditional setting.*
Keywords: *Problem-based learning, inverted (flipped) classroom*

1. INTRODUCTION

One of the challenges of modern engineering education is that programs must address not only technical topics but also prepare graduatesfor real engineering practice. More often than not, engineering practice means solving open-ended and ambiguous problems in rapidly changing technical environment. Furthermore, industry is looking for graduates who require little-to-no on-the-job training in order to boost their profits. These trends present new challenges for engineering education and may require adoption of novel teaching methods.

One method for teaching problem solving is Problem Based Learning (PBL). In PBL, students are tasked with solving large open-ended problemsduring class-time and under supervision of instructor. Problems are crafted so that the students must address and learn technical content from the course. PBL has been shown to be an effective framework for teaching engineering fundamentals within the context of open-ended problems. Studies [1,2] show improved learning when classroom instruction is problem-based as well as an improved ability to solve open-ended problems [3].

PBL has two notable drawbacks. First, PBL students often perform poorer than those taught in a traditional class when tested using standardized tests on fundamental engineering principles [4]. This is especially true for self-paced and self-directed PBL activities [5]. This problem is usually overcome by creating a PBL environment that is structured, assessed, and supported [6]. Second, extra class time is necessary for solving open-ended problems, which leads to a reduction in the total number of concepts covered in a course [7].

An inverted (or flipped) classroom can free class time with minimal effect on content and so provides a promising framework for PBL instruction. In an Inverted Classroom (IC), lecture material is moved outside of the class, freeing in-class time for learner-centered activities. Course content is delivered through a variety of mediums including screen-capture videos, simulations, interactive problem solving and other online materials [8,9].

The Inverted Classroom approach has been shown to be an effective delivery method in several studies [10,11]. The IC does not negatively affect student performance on traditional class and standardized tests [12]. IC can promote self-directed learning and help develop professional problem solving skills because the format teaches the student to find and

interpret the information needed to solve problems [13].

Challenges with the Inverted Classroom can be overcome by (1) requiring an online quiz before class to ensure preparedness, (2) keeping videos less than 30 minutes, (3) fixing student misconceptions by spending the first 10 minutes of class answering questions or holding mini-lectures, and (4) using multi-media for online content to engage students [8,9].

Those results suggest that an IC and PBL could be successfully integrated to improve student self-directed learning and problem-solving skills without sacrificing a strong understanding of fundamental engineering principles.

This paper is a continuation of a paper presented at the 2015 ASEE Annual conference in the NSF Grantee's Poster Session [14]. The new material includes implementation details and preliminary results obtained after applyingindustry-supplied PBL assignments in a heat transfer course that is taught using an IC framework.The project, funded by the National Science Foundation [15], began in 2014 and is expected to conclude at the end of 2015. The remainder of this paper describes the project and progress to date.

Projectoverview

The goal of the project is to improve self-directed learning and students' problem-solving skills while maintaining the number of engineering concepts taught in a course and student understanding of fundamental engineering principles. This is accomplished by using an IC to facilitate PBL. This instructional framework is being implemented in a Heat Transfer mechanical engineering course. Screen-capture video lectures, tutorials, and classic homework-style example problems is moved outside of the classroom. In-class time is used primarily to solve authentic engineering problems supplied by industrial partners. The partners supply problem statements, documentation, experimental data, and vendor specification sheets. Course materials are available to students in a web-accessible Learning Management System (Canvas) [16].

Two essential project goals are to:

1. Develop and implement an instructional framework using an Inverted Classroom to facilitate Problem-Based Learning, and
2. Evaluate the effectiveness of this instructional framework on student performance and attitudes.

2. IMPLEMENTATION

The instructional framework was developed and then tested in a Heat Transfer course. The framework is loosely based on Bloom's Taxonomy. By inverting the classroom, knowledge and comprehension is attained through videos and other on-line resources outside of the classroom; application, analysis and synthesis is attained through PBL using authentic, open-ended engineering problems. The project is being implemented in two phases.

Phase I: Establishing a control for the study

In the first year of the study, the heat transfer was taught as a traditional course, using a classical textbook [17]. This serves as the control for the study and provides a reference for comparison with an IC-PBL course. Heat Transfer is taught in the junior year over a 10-week quarter. The course is taught in three 65-minute classes per week with a 90-minute laboratory session once per week. Table 1 lists the topics covered in the course.

Table 1: Heat Transfer Topics

Conduction	Convection	Radiation
Conservation of energy	Newton's law of cooling	Planck's law
Conduction rate equation	Convective heat transfer coefficient	Wein's displacement law
Heat diffusion equation	Boundary layers	Blackbody radiation
Boundary and initial conditions	External flow	Radiation geometry
1-D, steady-state conduction	Internal flow	Surface properties
Conduction with thermal generation	Natural (free) convection	Radiation exchange
Extended surfaces: fins and pins	Heat exchangers: Basic design	
2-D conduction	Heat exchangers: LMTD method	
Transient conduction	Heat exchangers: Effectiveness/NTU method	

During Phase I, detailed assessment data was collected on student performanceon all individual exam, quiz, and homework problems. These will be mapped to specific course topics, see Table 1, and used as a baseline for comparing student learning in the traditional course versus the IC-PBL framework.

Two open-ended design problems were assigned, one early and the other late in the quarter. Students were given a week to solve each. The instructor acted as the client for the problem and so did not provide any technical assistance. At the end of the project each student gave a five minute presentation to a panel of three faculty members. They were graded, using a rubric developed specifically for this assessment.

Students in the traditional course completed the Heat and Energy Concept Inventory (HECI) test [18]. This test is designed to evaluate the following four concepts: a) temperature vs. energy, b) temperature vs. perceptions of hot and cold; c) factors that affect the rate vs. amount of heat transfer; d) thermal radiation. Data from this assessment will be compared with test results from students in the IC-PBL course and used to determine differences in student's understanding of basic heat and energy concepts.

Three original assessment tools were developed and applied end-of-term to: a) discern students' understanding of real-world engineering activities. b) measure students' interest in, commitment to, liking in, and identification with engineering programs and careers, and c) measure students' confidence and efficacy in their engineering skills. Data from this assessment will be compared with test results from students in the IC-PBL course.

Phase II: IC-PBLImplementation

In Phase II of the project, the heat transfer course was taught again by the same instructor. This time the course was taught with an IC and PBL. The course was implemented in the following way:

1. Open-ended, authentic engineering problems, designed by faculty and industrial partners, and evaluated by academic partners, were introduced in class to provide motivation and context for self-directed learning assignments. See Table 2 for an example of an authentic engineering problem.
2. Students were given 4 to 5 class periodsto solve the problems in teams. The course instructor facilitated a discussion among students and guided them to determine the knowledge they must gain and information they must gather to solve each problem.
3. Students learned the needed fundamental engineering principles outside of class time through the ICby identifying and watching 8-12 minute videos and studying other materials on Canvas. This scaffold approach is expected to help to develop students' ability to self-direct their learning. An online quiz associated with each topic encouraged students to watch the videos and study other database materials in preparation for PBL sessions and exams in class.
4. In-class activities include occasional mini-lectures, demonstrations, and questions/answer sessions to correct student misconceptions and build upon knowledge acquired from self-directed learning. In class exams were given periodically to assess the engineering fundamentals.
5. Detailed assessment data was collected on student performance on all individual exam, quiz, and homework problems.
6. Other assessment tools included the HECI and the same original end-of-term assessment tools as those applied in the traditional setting (see above). Additional assessment tools were developed to evaluate project performance and student problem-solving skills.

Table 2: A PBL with learning objectives and on-line resources

PBLProblem Statement	Cells and tissue are sensitive to heat and will die if they become too hot. The time for 90% of cells to die at 46degC is approximately 10 hours while at 70degC is approximately 1 minute. Some medical devices capitalize upon this fact and attempt to selectively heat tumor tissue to inactivate the malignant cancer cells.If a tumor that is 2 cm in diameter is heated with electrical energy, emanating from a probe in the center of the tumor that is 2 mm in diameter, how much electrical power is needed to inactivate (90% cell death) the tumor? **Industrial Partner:**Spiration Inc. (d.b.a. Olympus)
Objectives	Student will be able to: 1. Identify necessary inputs to the systems 2. Research and understand appropriate Arrhenius curve for the system 3. Research thermal properties for cells 4. Conduct an energy balance on the system 5. Determine power needed to inactivate the cells 6. Compare times to inactivate the cells for different inputs 7. Calculate heat transfer to surrounding tissue 8. Compare calculated results to experimental data supplied by industrial partner
On-line Resources	Video Topics: 1. Conservation of energy 2. Conduction with thermal generation 3. Transient heat transfer Support Information: 1. Example problems 2. Experimental data

3. PRELIMINARY FINDINGS

A key component of this project is the research measuring the effect of the teaching framework on student self-directed learning and problem solving, understanding of fundamental engineering principles, and knowledge of and attitudes towards the engineering profession. The data analysis has only just begun, so the following findings are only preliminary at this time:

- Using the IC-PBL format, the instructor was able to cover the same amount of content as using a traditional format.
- Students in the IC-PBL performed better on exams than those in the traditional course, although these results have not been adjusted for potential differences in the class populations.
- Students in IC-PBL performed better on open-ended design problems. That is, they presented solutions that were more realistic.
- The IC-PBL format needed to be administered carefully. It's easy under this format to overwhelm students with work.

4. CONCLUSIONS

The goal of this project is todevelop an instructional framework that addresses students' ability to solve open-ended design problems and their knowledge of fundamental heat transfer topics. The framework uses an IC format to disseminate fundamental course concepts, freeing class time for PBL activities. The project studies this new framework in the context of a Heat Transfer course. Learning resources, a description of PBL activities and assessment toolswas completed in June 2015. Preliminary results indicate that students in IC-PBL learn deeper and can solve open-ended problems better than those in traditional settings. The anticipated completion date for the project is the end of 2015.

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