Facilitating Problem-Based Learning with an Inverted Classroom

Dr. Gregory S Mason, Seattle University

Gregory S. Mason was born and raised in Spokane Washington. He received the B.S.M.E. degree from Gonzaga University in 1983, the M.S.M.E. degree in manufacturing automation from Georgia Institute of Technology in 1984 and the Ph.D. degree in mechanical engineering, specializing in multi-rate digital controls, from the University of Washington in 1992. He worked in a robotics lab for the Department of Defense for five years after receiving his M.S.M.E. He is currently an Associate Professor in the Department of Mechanical Engineering at Seattle University, Seattle, WA. His research interests are controls system and the use of technology to enhance engineering education. Dr. Mason is a member of the American Society of Engineering Education and the Society of Manufacturing Engineers. He is a licensed professional engineer.

Prof. Teodora Rutar Shuman, Seattle University

Teodora Rutar Shuman is an Associate Professor in the Mechanical Engineering Department at Seattle University. She has held titles of Paccar Professor and Department Chair, and is Affiliate Professor at the University of Washington. Her research includes NOx formation in lean-premixed combustion and electro-mechanical systems for sustainable processing of microalgae. Her work is published in venues including the Journal of Engineering Education, IEEE Transactions on Education, Bioresource Technology, Proceedings of the Combustion Institute, and Combustion and Flame. She is a member of the American Society of Engineering Education and the Algae Biomass Organization. Dr. Shuman serves as Program Chair for the ASEE Energy Conversion and Conservation Division this year.

She received a Dipl.Ing. degree in mechanical engineering from Belgrade University in 1992, an M.S.M.E. from the University of Washington in 1994 and a Ph.D. from the University of Washington in 2000.

Facilitating Problem-Based Learning with an Inverted Classroom

Abstract

In 2013, Seattle University was awarded a National 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 will use an Inverted Classroom (IC) to facilitate Problem-Based Learning (PBL). The instructional framework will be created through collaboration between faculty in mechanical engineering and psychology at Seattle University, and evaluated by academic partners from other institutions. To facilitate an IC, material traditionally covered in a lecture format will be moved outside of class time, developed for an on-line format, and made available in an online repository of learning resources. PBL will use authentic engineering problems co-developed with industrial partners from medical device, HVAC and process industries; problems will be evaluated by the academic partners. A variety of resources will be available to address the varied learning styles of the students.

The framework will be implemented in a Heat Transfer course that will be offered in traditional classroom (control) and IC-PBL (treatment) settings. Student self-directed learning and problem-solving skills in the two settings will be compared for their performance on design problems, exams, heat and energy concept inventory, and several rubrics.

This paper describes the process and accomplishments from the first phase of the grant, as well as the ongoing process in phase two.

Introduction

One of the challenges of modern engineering education is that programs must address not only technical topics but also prepare graduates to work on open-ended and ill-defined problems. At the pedagogical level these two goals can sometimes be in conflict. Technical education has traditionally relied on lecture and textbook type problems whereas teaching student how to address open-ended design problems requires an approach with less apparent structure.

One method for teaching problem solving is Problem Based Learning (PBL). In PBL, students are tasked with solving large open-ended problem that have been 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. Numerous 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]. This problem is exacerbated because new information and concepts are added to the field of engineering every year. Finding time to cover these new topics places increasing demands on class time and instructors are often hesitant to relinquish class time. This can limit the effectiveness and adoption of PBL in engineering classes.

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, as does PBL alone[12]. In addition, an IC can effectively address multiple learning styles by delivering the content in different formats[10]. 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, however, exist with the Inverted Classroom regarding student (a) preparedness for class, (b) attention span while watching online videos, and (c) misconceptions of fundamental principles [15]. Basic guidelines, by Zappe et al.’ and Rais-Rohani et al.[9], to overcome these challenges include (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.

The results from IC studies provide evidence that an IC can be used effectively to deliver traditional course content, even when class time is used for learner-centered activities. Furthermore, existing research points to the benefits of PBL[3,4]. Together, these 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 describes a project to implement PBL in an engineering course that is taught using an IC framework. The project, funded by the National Science Foundation, 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.

Project overview

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 will be 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 will be moved outside of the classroom. In-class time will be used primarily to solve authentic engineering problems supplied by industrial partners. The IC will be supported by experimental data, engineering reports, worked example problems, and vendor specification sheets, which will be available to students in a web-accessible repository of resources.

Specifically stated, the three project goals are to:

1. Develop and implement an instructional framework using an Inverted Classroom to facilitate Problem-Based Learning.
2. Evaluate the effectiveness of this instructional framework on student performance and attitudes.
3. Disseminate the new framework and teaching resources through publications, presentations, workshops, collaborations, and online portals.

Implementation

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

Phase I: Establishing a control for the study and developing curricula

During the first phase of the project, resources needed to support the proposed instructional framework will be developed and a baseline for testing the framework will be established.

The PBL activities will be developed with input from partners from various industries including an HVAC consulting firm, process engineering consulting company, and a medical device company. PBL activities will then be vetted by academic partners at Bucknell University and the University of Washington's Center for Engineering Learning and Teaching (CELT).

Learning resources, used by students as they solve the PBL activities, will include short screen-capture videos of the instructor explaining heat transfer topics. The videos will be created using PowerPoint with a Microsoft Surface tablet and Camtasia software. Additional resources will include vendor specification for heat transfer equipment used in the authentic problems, fluid and material properties, CFD tutorials, peer-reviewed research articles, example problems and lab reports, on-line quizzes, and homework. Resources will be posted on the university's learning management system (LMS), which provides support for rich content, such as videos, and is an ideal system for hosting the repository of learning resources and tracking usage. These resources will be designed with the input from our academic partners so that they can be directly used by other institutions.

In the first year of the study, the heat transfer will be taught as a traditional course. This will serve as the control for the study and provide a reference for comparison with an IC course taught in the second year. The heat transfer course provides students theoretical knowledge of conduction, convection, and radiation and practical skills necessary to design and analyze heat transfer systems, using a classical textbook[14]. 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 2 lists the course topics covered in the course.

Table 2: 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	

Phase II: Implementing the Treatment and Evaluation

In the second year of the project, the heat transfer course will be taught again by the same instructor. This time the course will be taught with an IC and PBL using the resources developed in Phase I. The course will be implemented in the following way:

1. Open-ended, authentic engineering problems, designed by faculty and industrial partners, and evaluated by academic partners, will be introduced in class to provide motivation and context for self-directed learning assignments. See Table 3 for an example of an authentic engineering problem.

2. Students will begin to solve the problems individually or in teams. The course instructor will facilitate a discussion among students and guide them to determine the knowledge they must gain and information they must gather to solve each problem.

3. Students will learn the needed fundamental engineering principles outside of class time through the Inverted Classroom by identifying and watching 8-12 minute videos and studying other materials in the learning resource repository. Initially, students will be guided on which on-line resources to use to master a particular topic. Eventually, they will be expected to search this repository to identify resources without guidance from the instructor. This scaffold approach will help to develop students' ability to self-direct their learning. An online quiz associated with each topic will encourage students to watch the videos and study other database materials in preparation for PBL sessions and quizzes and exams in class.

4. The open-ended authentic problems will be designed to build on and reinforce student knowledge acquired from the Inverted Classroom. The problems will be of incremental difficulty and scheduled to give students time to learn required theories and techniques outside of class time.

5. In-class activities will also include occasional mini-lectures, demonstrations, and questions/answer sessions to correct student misconceptions and build upon knowledge acquired from self-directed learning. In class quizzes/exams will be given periodically to assess the engineering fundamentals.

Table 3: An authentic problem with learning objectives and on-line resources

PBL Problem 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. The time temperature curve for cell death has been researched and follows an Arrhenius equation. 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. Peer-reviewed research article

Assessment goals

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. Research questions (goals), through the perspective of the Inverted Classroom and Problem-Based Learning, are:

1. Do students complete the same amount of material as in a traditional class?
2. Is student performance on traditional quizzes and exams the same or better? Additionally, do women and minorities perform as well or better?
3. Do students learn enough information outside of class to enable the IC?
4. Do students "invest in" (i.e., spend time on) the right information?
5. Do students generate solutions that are more workable and less error-filled?
6. Do students improve their problem-solving approach?

7. Do students feel more confident and efficacious in their engineering skills?
8. Do students believe that they have a better understanding of what working engineers do?
9. Are students more interested in, committed to, and positive about their studies and/or their future careers?

Assessment instruments to address each question are being developed during both phases of the project.

Project status

The project is currently in Phase I. A summary of project accomplishments to date follows.

1. The heat transfer course was taught in spring 2014 using a traditional format. This will provide the control for the study.
2. During the spring 2014 offering, detailed assessment data was collected on student performance and on what and when topics were covered. Student performance data includes student scores on all individual test and homework problem. These will be mapped to specific course topics, see Table 2, and used as a baseline for comparing student learning in the traditional course versus the IC-PBL framework.
3. Students' ability to solve open-ended problems, when taught using a traditional method, was evaluated using design problems and student interviews. This assessment tools was developed specifically for this projects. For this assessment, students were assigned an open-ended design problem. They were given a week to solve the problem. 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. This assessment was implemented twice in the traditional course – at week three and at week eight (in a 10 week quarter). In phase II this assessment will be repeated in the IC-PBL course. Data will be used to determine differences in students' ability to solve opened-ended problem.
4. Students in the traditional course completed the Heat and Energy Concept Inventory (HECI) test[15]. 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.
5. 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.

6. Learning resources, PBL activities and additional assessment instruments are in development.

Plans for Phase II

Phase II of the project will begin with implementation of the IC-PBL in the heat transfer course in spring 2015. Following the implementation and evaluation (described above) the faculty will disseminate learning resources, authentic problems, design problems, in-class demo's, as well as assessment tools through workshop(s), conference and journal publications.

Summary

The goal of this project is to develop an instructional framework that addresses students' ability to solve open-ended design problems and their knowledge of fundamental heat transfer topics. The framework will use an Inverted Classroom format to disseminate fundamental course concepts, freeing class time for Problem Based Learning activities. The project will study this new framework in the context of a junior level heat transfer course. Currently the project is in the first phase. The heat transfer course has been taught using a traditional format. This will serve as a baseline for the study. Learning resources, a description of PBL activities and assessment tools will be completed by June 2015. At that time initial results from the second phase of the project may also be available. The anticipated completion date for the project is the fourth quarter of 2015.

Acknowledgment

This work is sponsored by the National Science Foundation, Directorate for Education and Human Resources, TUES, Award Number 1245455.

References

1. Prince, M., *Does Active Learning Work? A Review of the Research*. J. of Eng. Educ. 93(3): p. 223-231, 2004.
2. Terenzini, P. T., Cabrera, A. F., Colbeck, C. L., Parente, J. M., & Bjorklund, S. A., *Collaborative learning vs. lecture/discussion: Students' reported learning gains.* J. of Eng. Educ, 90(1): p. 123-130, 2001.
3. Yadav, A., Subedi, D., Lundeberg, M.A., and Bunting, C.F., *Problem-based Learning in Electrical Engineering*, J. of Eng. Educ., 100(2): p. 253-280, 2011.
4. Prince, M. and Felder, R., *Inductive Teaching and Learning Methods: Definitions, Comparisons, and Research Bases*. J. of Eng. Educ., 2006. 95(2): p. 123-138.
5. Norman, G. and Schmidt, H., *Effectiveness of Problem-Based Learning Curricula: Theory, Practice, and Paper Darts*. Medical Education, 2000. 34: p. 721-728.

6. Zull, J., *The Art of Changing the Brain: Enriching the Practice of Teaching by Exploring the Biology of Learning.* 2002, Sterling, VA: Stylus Publishing. p. 148.

7. Matthew, R. G. S., & Hughes, D. C. *Getting at deep learning: A problem-based approach.* Engineering Science and Education Journal, 1994, 3(5): p. 234–240.

8. Zappe, S., Leicht, R., Messner, J., Litzinger, T., and Woo Lee, H. *"Flipping" the Classroom to Explore Active Learning in a Large Undergraduate Course.* Proceedings of 2009 ASEE Conference. 2009. Austin, TX.

9. Rais-Rohani, M., Walters, A., and Vizzini, A., *Emporium Based Redesign of Statics: An Innovative Approach to Enhance Learning and Reduce Costs.* 2010 ASEE Annual Conference and Exposition. 2010. Louisville, KY.

10. Lage, M., Platt, G., and Treglia, M., *Inverting the Classroom: A Gateway to Creating an Inclusive Learning Environment*. J. of Econ. Educ., 2000. 31(1): p. 30-43.

11. Mason, G., Shuman, T., Cook, K., *Comparing the Effectiveness of an Inverted Classroom to a Traditional Classroom in an Upper Division Engineering Course,* IEEE Transactions on Education, November 2013.

12. Roselli, R. J. and Brophy, S. P., *Effectiveness of challenge-based instruction in biomechanics*, J. of Eng. Educ., 2007. 95(4): p. 311-324.

13. Bland, L., *Apply Flip/Inverted Classroom Model in Electrical Engineering to Establish Life-long Learning*, Proceedings of the ASEE Annual Conference 2006. Chicago, IL.

14. Theodore L. Bergman, Adrienne S. Lavine, Frank P. Incropera, David P. DeWitt, *Fundamentals of Heat and Mass Transfer*, 7th Edition, Wiley, Hoboken, NJ (2011)

15. https://cihub.org/resources/heatandenergytransfer, accessed Jan. 2015