ASSESSING PROBLEM-BASED LEARNING IN AN ENGINEERING CAPSTONE COURSE

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Abstract

North Dakota State University (NDSU) was the recent recipient of a Bush Grant for providing support and training for NDSU faculty. As part of that grant, the "Faculty Institute for Excellence in Learning" (FIEL) was created. The author was selected as a FIEL "Fellow" and subsequently submitted a proposal and received funding to apply a problem-based learning approach to the departmental capstone course. During the summer of 2001, the capstone course was revised and restructured to meet the primary objective of the course. The basic philosophy, format, evaluation and assessment of the course came into question. The contents of this paper, 1.) describe some of the philosophical questions that had to be addressed, 2.) provide an overview of problem-based learning, 3.) explain the revised course content and delivery systems, and 4.) provide an explanation of the techniques used to evaluate student work and provide course assessment.

Introduction

The Department of Civil Engineering and Construction at North Dakota State University consists of two divisions, the Division of Construction Management and Engineering and the Division of Civil Engineering. Prior to 1998, the Department had three separate capstone courses for each degree program (construction engineering, construction management, and civil engineering). During the Spring Semester of 1998, a single overall departmental capstone course was created. The intent was to provide a true "capstone" experience, where students in each degree program could combine their skills to achieve the successful completion of a project. The primary objective of the capstone experience is to combine all aspects of the planning, design, and construction phases of a project into meaningful education experience which mimics "real-world" design and construction practices. Students are required to use all of the knowledge and skills that they have acquired throughout their educational experience to develop the documentation required for actual project construction (design drawings, cost estimates, project schedules, quality and safety plans, etc.). The intent of the capstone experience is to integrate the engineering and management disciplines into a single comprehensive educational experience.

Philosophical Questions

A number of meetings were held to determine the exact role and function of the capstone experience. Initially, fundamental philosophical questions had to be addressed by the faculty. For example, what should be the overall structure of the course and how is this tied to the course objectives?, what is the basic instructional format?, what are the purpose and function of the group and class meetings?, what is the role of the instructional staff?, should and will the expertise of other faculty be required?, what is the role of guest / industry speakers?, and is there a need for faculty advisors for each group? Along with the discussion that followed these questions, the issues of evaluation, assessment and information access were also discussed. For example, how will the student work be evaluated and by whom?, how will information be accessed by the students (Blackboard Course-Info, www, share directory)?, how will course assessment be accomplished?, how will previous course assessment be incorporated into subsequent course offerings?, and how can the assessment be tied to the Annual Departmental Assessment Report and the ABET & ACCE reports? After much discussion, it was determined that the basic approach that should be used in the capstone course would incorporate problem-based learning.

Why Problem-Based Learning [1][2]

In June of 1994, the Wingspread Conference brought together state and federal policy makers, and leaders from the corporate, philanthropic, higher education, and accreditation communities to discuss “quality” in undergraduate education. The discussion that took place was based on the assertion that there exists a substantial need for improvement in American undergraduate education in order to meet the needs of today's business and industry.

The conference developed the following list of important characteristics of quality performance of college and university graduates:

- High level of communication skills.
- Ability to define problems, gather and evaluate information, develop solutions.
- Team skills (the ability to work with others).
- Ability to use all of the above to address problems in a complex real-world setting.

Problem-based learning (PBL) techniques help students develop the above skills necessary in order to succeed in their post college careers. Students in PBL courses are challenged to "learn to learn" so that they can achieve their highest potential in their chosen professions. Students work cooperatively in groups, seeking solutions to "real world" problems by asking and answering their own and their peers' questions. In helping to teach each other, students achieve a high level of comprehension of the concepts of the course.

PBL - Roles and Procedures

PBL is an instructional method characterized by the use of “real world” problems as a context to learn critical thinking, problem solving skills, and acquire knowledge of the essential concepts of the course. Arguably, there is a gray area between problem-based learning and other forms of cooperative or active learning due to the facts that they share certain common features and hybrid approaches are formed as course instructors adapt methods for particular situations. However, in PBL the problem comes first, which contrasts with teaching strategies where concepts are presented in a lecture format followed by "end-of-chapter" problems [3]. In PBL, students working in small groups must identify what they know, and more important, what they don't know and must learn in order to solve a problem. The scope and nature of the problem preclude simple answers. Students must go beyond the textbooks to collect information and knowledge from a variety of resources. The primary role of the instructor is to act as a facilitator for the overall group process and stimulate and direct learning. The basic features of PBL are:

- Learning is initiated by a problem, which are based on real-life, open-ended situations.
- Students work in small permanent groups with access to an instructor.
- Students identify and locate the resources required to solve the problem.
- Learning is active, integrated, cumulative, and connected.

Typically, a class is divided into groups of approximately four or five students. These are usually permanent groups whose membership remains constant throughout the semester. At the purest level of PBL, the groups define the "learning issues" that they believe are at the core of each problem. The groups then decide how to divide their labors to resolve these issues.

The basic features of PBL were incorporated into the course delivery system for the Capstone Course, as described below.
The Problem: “An anonymous benefactor has offered to provided a sum of $700,000 to be used for the construction of a Regional Science Center located in the Fargo-Moorhead area. Several sites are currently being considered for the Center. One in particular looks quite promising. It is located on 23rd

Avenue SW, between the Red River Zoo and 45th Street SW. This particular site has the recommendation of the Fargo Department of Planning and Development, since the Regional Science Center is an appropriate use of the land and will conform to the Southwest Area Growth Plan. In addition, the construction of the "green space" parkway and possible pedestrian paths could be integrated into the proposed plan for the Center. It is anticipated that the current land owner (who is not the anonymous benefactor) will donate this parcel of land for the Center. Thus the entire $700,000 will be used for actual construction of the Regional Science Center, as well as, the associated on-site facilities." It is anticipated that the Regional Science Center will consist of the following: Science Center Building, Access Road, Parking Facilities (for guests and staff), Pedestrian / Bike Trails (tied into the SW Area Parkway System), Potable Water System, Sanitary Sewer System, Storm Water Management System, Landscaping Plan (using the fundamental concepts of Xeriscape).

The Groups: For the capstone course, students were assigned to groups of five or six students per group. Since there were fifty-eight students in the course, we used eight groups of five students and three groups of six students for a total of eleven groups. For each group, we tried to achieve a balance of construction and engineering students within each group. There were, at a minimum, three engineering students and two construction students per group. The student groups were responsible for developing the "learning issues" that they believed were fundamental for completing the problem. In addition, they had to define what information was needed for the problem, where they could find it, and how were they to properly use that information in the context of the problem. Initially, they were not aware of the information that could be accessed through Blackboard Course Info.

In order to promote effective group work, several team building and communication exercises were incorporated into the initial phases of the course. Student groups had to develop the deliverables and grading criteria for each status report, oral presentation, and the final project. Once the student-based deliverables and grading criteria for the status reports and final project were formulated, they were distributed to the faculty members who were responsible for evaluating student work. Faculty members then had the opportunity to review and comment on the deliverables and grading criteria. Faculty members were invited to the class to present the revised deliverables and criteria and to offer any comments, suggestions, or answer any questions.

Resources: The basic project information provided by project participants (City of Fargo Engineering and Planning Department) and included typical information that is available to the engineering firm (architectural CAD drawings, a geotechnical report, very basic project specifications, a plat map, and a topography map). All of this information was in electronic format and could be accessed by the groups using Course Info. The information was centrally located in order to minimize repeated, and possibly disruptive, contact between student groups and industry professionals.

The role of the instructional staff was to act as an agent of the owner. They had decision making capabilities with regard to project definition and scope. Other faculty assumed the role of project consultants, for both the student groups and the owners (the instructional staff). Student groups assumed the role of design/build firms who were responsible for the complete design and construction of the facility.

TABLE I
Basic Course Outline

Introductions and Team Formation	Week 1
Team Building Exercises	Weeks 1&2
Project Requirements and Resources	Weeks 2&3
Basic Work Plan, Preliminary Cost and Time Estimates	Weeks 3-6
Site Layout/Design and Constructibility Reviews	Weeks 6-8
Building Interior and Exterior Design	Weeks 9-12
Overall Engineering Design, Revised Cost & Time Estimates	Weeks 12-14
Final Report	Week 15

In order to check student progress, a number of written status reports were required to be submitted throughout the semester. Additionally, two oral presentations were scheduled for each group as well as a final written report. Peer evaluation of group members also contributed to the student grade, as indicated in Table II.

TABLE II
Grading Criteria and Basic Deliverables

Status Report No. 1 (Work Plan, Cost Estimate, and Project Schedule)	10%
Status Report No. 2 (Site Layout/Design and Constructibility Reviews)	10%
Midsemester Oral Presentation	10%
Status Report No. 3 (Building Interior and Exterior Design)	10%
Status Report No. 4 (Final Design, Final Cost and Time Estimates)	10%
Final Oral Presentation	10%
Final Project	30%
Peer Evaluations	10%
TOTAL	100%

Evaluation and Assessment

The basic starting point for assessing student learning begins with asking two basic questions: 1.) what should students know and be able to do at the end of the semester?, and 2.) what evidence will indicate that they have reached these goals? The basic tools that were used for assessing knowledge in the capstone course were the status reports, the oral presentations, and the final projects. For the capstone course, evaluation of the student work (status reports, oral evaluations, and the final project) was performed by select faculty who had expertise in given areas (structures, geotechnical, cost estimates, schedules, etc.).

The actual deliverables and the grading criteria for the status reports and the final project were developed in class by the student groups, with input from the faculty. The faculty members that graded each of the status reports and final project used the formatted versions of the student-based deliverables for their evaluation of student work. Appendix A illustrates the grading sheet that was used for Status Report No. 1 (Work Plan, Cost Estimate, and Project Schedule). Appendix B contains the evaluation form used to evaluate team members. The final course evaluation form is found in Appendix C. Our assessment practices follow ABET guidelines, as follows. Initially the Capstone Learning Objectives must be identified, followed by the ABET Learning Objectives. Both are linked through Objective Mapping.

Capstone Learning Objectives: The specific "Learning Objectives" of the Capstone course were developed from a student perspective during the Fall 2001 semester. They were modified slightly, by the students, for the Spring 2002 semester, as listed below.

1. Think critically and be able to design, analyze, and solve complex, real world problems.
2. Locate, evaluate, and properly use appropriate learning resources.
3. Work cooperatively and effectively in a small group setting.
4. Demonstrate versatile and effective communication skills, both verbal and written.
5. Use the knowledge and intellectual skills acquired in this course to assist me in continual and lifelong learning.

ABET Learning Objectives: The A-K objectives of the ABET criteria are to prepare civil and construction engineers who will have:

A. an ability to apply the knowledge of mathematics, science, and engineering.
B. an ability to design and conduct experiments, as well as to analyze and interpret data.
C. an ability to design a system, component, or process to meet desired needs.
D. an ability to function on multi-disciplinary teams.
E. an ability to identify, formulate, and solve engineering problems.
F. an understanding of professional and ethical responsibility.
G. an ability to communicate effectively.
H. the broad education necessary to understand the impact of engineering solutions in a global and societal context.
I. a recognition of the need for, and an ability to engage in lifelong learning.
J. a demonstrated knowledge of contemporary issues.
K. an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Objective Mapping: The purpose of objective mapping to match the *Capstone Learning Objectives* (1-5) with the *ABET Learning Objectives*(A-K) in the form of a matrix.

TABLE III
Objective Mapping

		ABET Learning Objectives										
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
Capstone Learning Objectives	**1**	_	_	_		_			_		_	_
	2		_			_						_
	3				_		_					
	4							_				
	5									_		

The next phase of assessment should indicate how we assess and measure each of the ABET Learning Objectives. We have to identify the following: 1) Curricular Practices, 2) Outcome Indicators, 3) Performance Target, 4) Assessment Schedule, and 5) us Improvement Methods for the Capstone course.

Curricular Practices: The basis question is, what do we do in a particular course that helps meet each of the ABET Learning Objectives? For the Capstone course, this includes the following: Written Reports, Oral Presentations, Participation in an Extracurricular Workshop, and Evaluation and Assessment Forms.

Outcome Indicators: Next we had to indicate what methods and deliverables we use to measure our curricular practices. For the Capstone course the following outcome indicators are used: Written Reports - Status Reports 1-4, Final Project , Oral Presentations, Workshop Participation, and Evaluation and Assessment Forms.

Performance Target: The purpose of the Performance Target is to determine our goals for each of the outcome indicators. For each outcome indicator, the following targets were used for the Capstone course.

TABLE IV
Performance Targets

Outcome Indicators	**Target Min. Group Standard**	**Target Class Average**
Status Report No. 1	80 pts. (100 pt. scale)	85 pts.
Status Report No. 2	80 pts. (100 pt. scale)	85 pts.
Status Report No. 3	80 pts. (100 pt. scale)	85 pts.
Status Report No. 4	80 pts. (100 pt. scale)	85 pts.
Final Project	85 pts. (100 pt. scale)	90 pts.
Midterm Oral	85 pts. (100 pt. scale)	90 pts.
Final Oral	85 pts. (100 pt. scale)	90 pts.
Engr. Workshop	Required participation	90%
Form Work	Submittal of all forms	100%

Assessment Schedule: The purpose of the Assessment Schedule is to determine the points in time when progress is checked (evaluated) for the outcome indicators. For the Capstone course the following Assessment Schedule is used.

TABLE V
Assessment Schedule

Outcome Indicator	Date
Engineering Workshop	Sat. February 2
Status Report No. 1	Thurs. January 24
Status Report No. 2	Thurs. February 14
Midterm Oral Presentation	Tues. Feb. 26 & Thurs. Feb. 28
Status Report No. 3	Thurs. March 7
Status Report No. 4	Thurs. April 4
Final Project	Thurs. April 18
Final Oral Presentation	Tues. April 26 & Thurs. April 28
Form Work (Evaluations)	Tues. April 30 & Thurs. May 2

Continuous Improvement Methods: After mapping the outcome indicators versus the ABET learning objectives, outcome performance must be measured and documented, as shown in the matrix on the following page. Additional performance measures for the capstone course come directly from the course evaluation forms (refer to the supplemental document). Performance measure allows for continuous improvement at the course level through documentation of the results and then finally attempting to answer the following basic "Assessment Questions":

1. What did we find out?
2. Did we learn anything and what will we do differently next time?
3. How will we modify our curricular practices, indicators, targets, and/or assessment schedule?

What did we find out? The interim "status reports" were tremendously beneficial for keeping the students on track. At the end of the semester there was no mad rush to get the work completed. The students had time to reflect on their work, finalize the written report, and prepare for the final oral presentations.

Did we learn anything and what will we do differently next time? The students have an intense desire for quality faculty input concerning their work. A superficial response or evaluation is taken more negatively by the students than no response at all. We (as a faculty) have to develop tools and techniques that allow for quality response to student work with a minimal time commitment form the faculty. This is a classic "Catch 22" situation. It takes time to complete a comprehensive review of student work but we have severe time limitations. We have to determine a proper balance between student needs and available faculty time. It was anticipated that the role of technical consultants (by the faculty) would be less of a time commitment that their previous role as "group advisor." However, it appears that most groups went to other sources of information to get answers to their questions. This is not necessarily a bad thing, in fact we encourage this type of initiative. We want our students to be able to research "outside" sources and collect and analyze information that is relevant to the topic at hand. At this time it is not clear of the future role of faculty in the capstone course, specifically related to the technical aspects of the project.

The Course Info site worked very well for transmitting information to students and to contact students (via e-mail) concerning various aspects of the project. Starting with the Summer 2002 semester, ITS will be upgrading to Blackboard 5.5.1. We will be transferring the course to Blackboard and we will be taking advantage of some of the new and improved features.

How will we modify our curricular practices, indicators, targets, and/or assessment schedule? This question will remain unanswered until we review all of the course documentation, evaluation, and assessment. However, we (the course instructors) feel that indicators, targets, and assessment

schedule are reasonable and seem to be well suited for the capstone course. Not all student groups achieved the minimum (or average) performance target for each course deliverable. The performance targets may need adjustment, but without sacrificing quality or lowering out standards. We may just need to develop better evaluation tools. Curricular practice is another issue, however, the PBL approach that was used this seemed to create more student engagements and involvement in the course and also within their respective groups.

Benefits

Based primarily on the response of the students, we can confidently state that the primary benefits of the PBL approach for the capstone experience are that:

1) PBL more realistically reflects actual design and construction practices.
2) PBL promotes the concept of teamwork.
3) PBL assists in improving student communication skills.

For the capstone course, construction management students increase their exposure to design activities, while civil (and construction engineering) students increase (or supplement) their knowledge in the area of project management. This approach, in the long, may help to mitigate the actual or perceived adversarial relationships that can often occur between engineers, construction managers, and contractors.

References

[1] Allen, D., Introduction to Problem-Based Learning (PBL), a workshop organized by the Faculty Institute for Excellence in Learning, August 21, 2001.

[2] Duch, B., Groh, S., and Allen, D., The Power of Problem-Based Learning - A Practical "How To" for Teaching Undergraduate Courses in Any Discipline, Stylus Pub., April 2001.

[3] Rhem, J., Problem-Based Learning: An Introduction, a featured article in the National Teaching and Learning Forum, Vol. 8, No. 1, 1998.

[4] Kaufman, D., Felder, R., and Fuller, H., Accounting for Individual Effort in Cooperative Learning Teams, ASEE Journal of Engineering Education, pp. 133-140, April 2000.

Appendix A

STATUS REPORT NO. 1
Work Plan, Cost Estimate, and Project Schedule

Introduction (5 pts)_____
- Who are you?
- What do you do?
- What is your background?

Project Objectives (5 pts)_____
- What are you going to do?
- How are you going to do it?
- How long is it going to take?
- How are you going to measure the progress?
- What are the project costs?

Plan of Work and Work Breakdown Structure (10 pts)_____
- Detailed description of your work plan.
- WBS with code numbers.

Constructibility Review (10 pts)_____
(site conditions and restrictions; sequence of work as planned; allowances for space and access; etc.)

Cost Estimate (40 pts)_____
- QTO and costs for all resources
- Computerized version of the cost estimate

Project Schedule (30 pts)_____
- Summary Table of Scheduling Information
- Computer Generated Project Schedule

ê **Total (100 pts)**

_____

Appendix B

PEER EVALUATION OF GROUP MEMBERS

Your Name: _____ Group No. _____

Please write the name of all of your other group members (do not include yourself) and rate the degree to which each member fulfilled his/her responsibilities in completing the assigned tasks. The possible ratings are as follows:

Excellent Consistently went above and beyond -- tutored teammates, carried more than his/her fair share of the load

Very Good Consistently did what he/she was supposed to do, very well prepared and cooperative

Satisfactory Usually did what he/she was supposed to do, acceptably prepared and cooperative

Ordinary Often did what he/she was supposed to do, minimally prepared and cooperative

Marginal Sometimes failed to show up or complete the assigned tasks, rarely prepared

Deficient Often failed to show up or complete the assigned tasks, rarely prepared

Unsatisfactory Consistently failed to show up or complete the assigned tasks, unprepared

Superficial Practically no participation

No Show No participation at all

These ratings should reflect each individual's level of participation, effort, and sense of responsibility, not his/her academic ability.

Name of Group Member	**Rating**
_____	_____
_____	_____
_____	_____

Your Signature: _____

Appendix C

COURSE EVALUATION FORM

At the conclusion of this semester, please answer the following questions. *If necessary, use the back side of this sheet for any additional comments*.

1. On a scale of 1 to 10, how would you rate your overall experience in working with your group? _____.
   Explain:

2. Overall, how would you assess or rate the work that your group did? (Was it your best effort? Could you have done better? Were you happy with your work? Did you have serious time constraints? Were the objectives of the course unclear?)

3. Were faculty consultants response to technical questions helpful in attaining solutions?
   Explain:

4. Did you like the way in which class meeting time was used? If not, how would you suggest that class time be used?

5. What did you like best about this course?

6. What did you like least about this course?

7. Overall, what did you think of the course and what suggestions (general or specific) do you have for improving the course?