Assessing Challenge-Based Instruction in Biomedical Engineering

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Abstract

As part of the NSF funded Engineering Research Center (ERC) VaNTH (Vanderbilt, Northwestern, University of Texas, and Harvard/MIT) we have revised courses in the Biomedical Engineering Department at Northwestern University. Various changes were made in the course content and structure to create opportunities for students to engage in solving realistic challenges faced in actual biomedical engineering practice. In addition, the classroom environment was restructured to support collaborative and reflective learning, and provide opportunities for students to practice skills expected in engineering practice. For example, students presented their findings, defended their positions, and debated with fellow students and faculty instructors their conclusions; such interactions allowed development of core engineering competencies. This paper provides an overview of the challenges and learning activities that were developed for three specific courses that have been implemented at Northwestern. We focus on the assessments used to measure student understanding of the scientific concepts, as well as the development of engineering skills. Studies were conducted in the domains of bio-optics and biotechnology over a one-year period. This paper describes how our assessment of the classes evolved over the year to build on lessons learned from previous classes.

Introduction

As part of the VaNTH ERC Northwestern faculty have revised various courses to enhance the learning experience of students. The VaNTH engineering faculty recognize that courses should embed the subject matter in a practical context, foster the development of practical skills such as oral and written communication and teamwork, as well as teach the underlying scientific principles. The reason for embedding learning in context is based on a theoretical as well as practical stance. Learning and instructional theories explain that providing real-life contexts increases students' interest, provides opportunities for students to apply their knowledge, and prepares students for situations they will encounter after graduation[1,2]. From a practical perspective, ABET has compelled engineering schools to re-examine their curricula and to make appropriate changes to align learning outcomes with the new criteria. Two relevant ABET criteria that have influenced our course revisions are that students should 1) 'understand the impact of engineering solutions in a global and societal context' and 2) have the 'ability to communicate effectively'[3].

The overall mission of the VaNTH ERC has also guided our work. Briefly, our task is to 'innovatively provide students of the next generation with knowledge in bioengineering so they may address some of the most demanding issues facing our society'[4]. In order to prepare students to face this challenge we need to provide them with the necessary skills and knowledge to undertake such a profound endeavor. As such we are revising our courses to provide opportunities for students to practice engineering skills, become familiar with current biomedical engineering problems, and wrestle with consequences of engineering solutions to these problems.

The VaNTH ERC has been structured such that faculty, or domain experts, work together with learning scientists, learning technologists, and assessment experts to redesign and evaluate courses. We work together as an interdisciplinary team to create innovative course materials and design appropriate evaluation plans. We follow an iterative design process in that we implement changes, collect feedback, and use these data to inform the design of the next course and evaluation. This paper describes three courses and assessment plans that have been implemented at Northwestern from Winter 2001 to Fall 2001. The three courses fall under the domains of bio-optics and biotechnology. This paper provides an overview of each course, the changes that were implemented, and the assessment plans used. The course revisions and assessments were designed based on the principles described in the How People Learn (HPL) framework[5]. The following sections provide background on the HPL approach and describe how our revised courses align with this educational framework.

Background on How People Learn

In 1999, National Academy Press published a book commissioned by the National Research Council (NRC). The book, *How People Learn*: *Brain, Mind, Experience, and School*, was the product of a two-year study that reviewed findings from the education and cognitive science literature. Based on this review, the book distills the main principles that can be derived from the past thirty years on research of the science of learning. These four principles have implications for how we structure the classroom setting to provide the most productive learning experience for students. The HPL framework suggests that the classroom environment be 1) learner-centered, 2) knowledge-centered, 3) assessment-centered, and 4) community-centered[5]. We have used these four principles to guide how we restructure courses within the VaNTH ERC.

A learner-centered environment recognizes the knowledge and skills students bring to the classroom. Students are not blank slates: they enter the classroom with a rich repertoire of ideas about how the world works. Students use this intuitive knowledge to make sense of new information and ideas. The implication for instruction is that the classroom setting should recognize students enter with prior knowledge and a productive learning environment should build on these initial ideas to produce a more robust and integrated understanding[6, 7].

Most engineering classrooms are knowledge-centered in that the topics covered are clearly defined and outlined. However, other aspects of knowledge-centered include highlighting why it is important to learn the material and demonstrating what expertise looks like. These aspects of knowledge-centered provide context for students and motivate the importance for learning the subject matter. Furthermore, a knowledge-centered environment reinforces integrated learning and the development of expertise rather than rote memorization or superficial understanding.

An assessment-centered environment not only evaluates understanding at the end of the course but also provides continuous opportunities to gauge learning. On-going assessment enables students to make their thinking visible and to uncover any persistent misconceptions. The principle of assessment-centered suggests that formative assessments should be implemented to provide students with opportunities to revise and improve their thinking, help students see their own progress over the course, and help faculty to identify problems that need to be remedied. These assessments differ from traditional exams in a couple of ways. One, exams are given at discrete time intervals and typically do not ask students to review and evaluate their thinking process. Responses to exam questions may reveal student misconceptions but typically questions are not written in such a way as to elicit conceptual understanding. Rather, many exam questions are procedural in nature such that success consists of identifying the correct set of equations and performing the appropriate mathematical analysis. Second, misunderstandings identified on exam responses need to be diagnosed and remedied. If this feedback loop is not closed then the exam does not serve the purpose of formative assessment. Often, the pace of the course is so fast that by the time the exams are graded and returned the course has moved on to other topics, and the learning opportunity is missed.

The idea that a learning environment should be community-centered recognizes that learning and teaching takes place in a social context. That is, a classroom consists of faculty and students, the course is situated within a particular engineering department, and the subject matter is based on the achievements of past and present engineers and scientists. Each of these aspects of community influence, either implicitly or explicitly, the accepted norms of classroom behavior and engineering practice. Once we recognize the influence of community we can better capitalize on the untapped potential that can be realized from each of the individuals that make up the community of practice. For example, classroom activities should advocate the intellectual camaraderie that promotes asking questions, building on each other's knowledge, and collaboration necessary to solve complex problems. Community extends beyond the classroom as well. Faculty can collaborate with each other to restructure courses so that these types of behaviors become standard classroom practice.

This section provided an overview of the principles that guide the development of new course materials within VaNTH. The following section provides a brief background on the classes we restructured at Northwestern, and reviews specific changes that align with each of these principles.

Background of Courses

Three courses were revised at Northwestern as part of the VaNTH project. This section discusses the main topics covered for each of the courses, the materials that were developed for the class, and how these materials align with the principles of the HPL framework. Table 1 provides details of these three courses.

Course	Quarter	Students	Domain	Professor
BME 338: Interaction of Laser Radiation with Tissue	Winter 2001	11 total; 5 female, 6 male	Bio-optics	Joseph Walsh
CE 495: Microbial Ecology of Bacterial Biofilms	Spring 2001	6 total; 5 female, 1 male	Biotechnology	Matthew Parsek
BME 395: Bioprocess Technology	Fall 2001	11 total; 4 female, 7 male	Biotechnology	Gülnur Birol

Table 1. Details of VaNTH courses taught at Northwestern University.

Bio-optics

Some of the main concepts addressed in the bio-optics course were light absorption and emission, propagation of light in tissue, measurement of optical power and energy, and various optical models for light propagation in tissue such as Beer's Law and Monte Carlo. The general class structure incorporated a combination of lectures, laboratory experiments, and student presentations. One unique aspect of the Winter 2001 offering was the inclusion of laboratory experiments. The experiments were included in the class as a way for students to test hypotheses, collect, analyze and synthesize data, and engage in an iterative investigation of the different models of light propagation. Students worked in teams on the different experiments and were responsible for submitting laboratory reports as well as preparing presentations for the class.

After each experiment was completed students gave presentations to the class on their findings. These discussions served as a way for students to share information, grapple with inconsistencies among the data, and highlight any misunderstandings. Students stated their hypothesis and defended their position based on evidence. The presentations and experiments align with the HPL framework in several ways. By creating classroom activities that allow students to interact with each other and share and discuss ideas, we form a community of practice that advocates intellectual debate. Knowledge is shared and developed through interactions among faculty and students to form a more community-centered classroom.

The sharing of information also provides an opportunity for students to make their thinking visible and to uncover any possible misunderstandings. Once this knowledge is shared ideas can be refined and misunderstandings can be diagnosed and remedied as they are revealed. In this way, there is not a time lag between when a student provides a response and when (or if) appropriate feedback is given. This makes the classroom more assessment and learner-centered.

The experiments and class activities were also embedded in a practical real-life challenge. Students were presented with a challenge at the beginning of the course and the challenge served to provide context for completing the experiments and to motivate students. The challenge in the bio-optics class was to 'determine a way to continuously measure blood oxygenation in the brain non-invasively'. This is a relevant and current issue in medical diagnosis of stroke patients. Students completed various assignments and experiments to help them determine a solution to this practical challenge. The challenge-based approach helps to accomplish the overall mission of VaNTH by familiarizing students with current biomedical engineering problems and providing opportunities for students to propose and defend engineering solutions to these problems.

The challenge-based approach and the revised course activities not only align with learning theory, but also address several core competencies of engineering practice as well as ABET criteria. Students are given opportunities to solve actual engineering problems and develop skills required in engineering practice. For example, students practice oral and written communication skills, work in teams to solve an engineering problem, conduct experiments, and analyze and interpret data[3].

The assessments used in the bio-optics course served multiple purposes. First, assessments were implemented to collect feedback about the revised course materials. We implemented periodic questionnaires, videotaped student presentations, interviewed faculty and students, and administered multiple 'thought questions' to gauge student understanding and knowledge development. These assessments tell us if we accomplished our goals and provide data to inform future revisions of course materials.

Second, formative assessments such as the 'thought questions' enable students to make their thinking visible and to reflect on what they know, or don't know about the subject matter. These assessments bring misunderstandings or gaps to the forefront and make students aware of their thought processes.

Third, traditional assessments were implemented in order to assign grades. These assessments included homework, lab reports, an independent project, and final exam.

Biofilms

Similar to bio-optics, the biofilms course posed a real-life challenge and students were expected to solve this challenge as part of the class activities. Many of the key concepts of the course were embedded in the challenge assignment. Some of these concepts included gradients, differences between biofilms and liquid culture communities of bacteria, and where biofilms are found and how to control them. The biofilm challenge is given in fig. 1.

Your team has been hired by Patriot Chemical Co. to investigate a problem they are having with their water distribution piping in their paper processing division. They historically have had severe corrosion problems associated with pipes in this system. They traditionally replace the piping- which results in severe financial loss while the system is down. Patriot is hiring your team to discover the source of the problem and provide a feasible solution that will avoid future need to replace piping. The goal of this exercise is to determine the nature of the problem and to come up with a solution as quickly and cost-effectively as possible. The plant foreman has recently noticed rust in the effluent of the system. This is usually an early indication that the pipes are beginning to fail.

We have designed this exercise to simulate as close to a "real life" scenario as possible. Initially there will be very little information for you to work with. Using your creativity and knowledge of microbiology/engineering your team can develop a trouble shooting flow chart and dissect the problem. There is more than one way to go about getting the right answer. I will act as your liaison between Patriot and any commercial labs/services you will require to generate information crucial to solving this problem. Depending upon the information/tests you solicit, the response time will vary in accordance with the nature of the information requested. Any costs associated with requested lab tests/information will be given as estimates to your group prior to your requesting it.

Part I) What could be the cause the problem?

Part II) How would you propose to fix it?

Background: As you investigate this challenge you need to consider multiple factors. First, the company has indicated they would like an accurate as well as cost-effective solution. In addition, they require a thorough justification of your recommendation. This requires you to draw on the knowledge presented in this class as well as information you obtain through research, data collection, consultations, etc.

Figure 1. Biofilms challenge, winter 2001.

The professor of the course served as the 'liaison' between the students and Patriot Chemical Co. If students needed information about the plant or data regarding the corrosion they would contact the professor who would then provide them with the data they requested. Students worked in teams and every two weeks gave a progress report presentation to the class. Similar to the bio-optics course, the presentations and assignments aligned with the HPL framework to make the classroom environment more learner-, assessment-, and community-centered. In addition, the challenge problem embedded learning in an actual engineering context and allowed students to practice core competency skills such as teamwork and communication.

Various assessments were also implemented in the bioflims class. In order to collect feedback about the new challenge assignment we administered pre and post-tests, questionnaires, videotaped student presentations, interviewed faculty and students, and administered multiple 'thought questions' to gauge student understanding and knowledge development. These assessments are similar to ones used in the bio-optics course and help us determine if we accomplished our goals and how the materials could be refined.

The biofilms course also included traditional assessments in order to assign grades but there is one substantial difference between this course and the bio-optics course. In contrast to the bio-optics course, the challenge assignment was assigned 20% of the course grade. Other graded assessments included midterm and final exams and class participation.

Bioprocess Technology

Faculty at Northwestern and Vanderbilt Universities collaborated to outline the structure of the bioprocess technology course. The course included a series of three challenges that aligned with various topics of the course. Two challenges were originally developed at Vanderbilt and a third challenge was developed at Northwestern. This course is unique in that it is a result of cross-institutional collaboration to embed the same VaNTH-developed materials in multiple courses at multiple universities[8]. An example of one of the bioprocess challenges is given in fig. 2.

> The Board of Directors of Microbaway Antibiotics, Inc. has just voted on allocating funds towards construction of a new production facility to be used for the production of penicillin, a highly profitable antibiotic. As members of the Microbaway Antibiotics, Inc. product development team, it is your task to develop a mathematical model describing the microbial kinetics of penicillin production. This model will be used to maximize penicillin production at the new plant prior to production.
>
> You will need to review production data in order to generate your model. Anne T. Biotic, a fermentation expert from SporeTech Pharmaceuticals, will help you run some experiments at one of SporeTech's penicillin production facilities, PenSim. Anne will provide you with the initial operating conditions from the last several production runs as a starting point in your analysis (we are also planning to run our plant at these operating conditions). Microbaway's management has requested that a preliminary report defining and assessing the kinetics of penicillin production be presented at the manager's meeting next week. This report should include the proposed model of the relationship between biomass, nutrients, penicillin and/or others as they are related, any assumptions, simplifications etc. It is very important that you substantiate your proposed model via simulation results and support your findings.
>
> After the development of this initial report, your team will need to test your proposed model based on a set of experimental data that will be provided to you by the fermentation expert. This will allow you to validate/invalidate your model. Your team will need to generate another report for presentation at the quarterly Director's meeting to take place in Maui, Hawaii, in November.

Figure 2. Example of one challenge used in Bioprocess Technology, fall 2001.

Topics addressed in this challenge include microbial kinetics, stoichiometry of growth and product formation, biomass formation and substrate utilization. Similar to the bio-optics and biofilms courses students worked in teams to solve the challenge and engaged in class discussions to report their ideas, progress, and solutions. Similar to the other courses, class assignments and activities were structured to align with the HPL framework.

Multiple assessments were also used in the bioprocess technology class. Again, the assessments used a combination of traditional measures such as homework and exams, as well as formative assessments such as thought questions and reflection activities. Since this course included materials developed at a different institution we collected data on these specific materials. We administered surveys and a technique called 'muddiest points'. For muddiest points, students were periodically asked what they found confusing or what should be changed. These assessments allow us to compare student data across campuses and uncover any implementation issues.

Evolution of the Courses and Assessments

As previously discussed, we used various assessment methods to inform our work. Table 2 summarizes several VaNTH-related research questions and the corresponding assessments used to answer these questions. Our research seeks to explore how specific course revisions affected student learning and understanding. As such we collected data to serve multiple purposes. One, our assessments measured student learning in the course. Assessments such as pre and post-tests, reflective thought questions, and interviews captured students' understanding and ability to apply appropriate scientific principles to solve open-ended problems.

Research Question	Data Collection Instruments	Utility of Data
• What changes took place in the course?	Interview instructor Interview students Review course documents Observations	Data from multiple sources will 'triangulate' results—does one source confirm or contradict the other?
• How can the class activities be improved to better follow the HPL framework? -learner-centered -knowledge-centered -assessment-centered -community centered	Videotape Observations Interviews Surveys	Video and observations capture what happened in the class. Interviews and surveys reveal student/faculty perceptions and experiences in class.
• In what ways did the challenge activities benefit student learning? -interesting/motivating -relevant to course objectives	Interview students Thought/reflection questions Surveys Pre/Post-tests	Data from interviews and responses to questions will gauge how well the challenge addressed conceptual understanding and specific core competencies. Pre/Post-tests measure gains in student understanding.
• Did the class activities support answering the challenge? In what ways can they be improved?	Observations Interview students Open-ended reflection questions	Interviews provide direct feedback from students. Reflective questions gauge student understanding of the purpose and utility of the activities.
• What concepts are particularly difficult for students to understand about this topic?	Student work (presentations, reports, etc.) Interview instructor Interview students	Self-explanatory

Table 2. Summary of research questions and assessment methods.

Second, the revised course materials were structured to enable students to practice and develop engineering skills, or core competencies. In order to gauge students' proficiency in these skills, and how well the course addressed these skills, we videotaped all student presentations, observed students performing experiments, and collected classroom artifacts such as lab reports and power point slides.

Finally, we wanted to learn more about how specific changes made to the course affected the development of engineering skills or subject matter understanding. Course materials and activities were revised to include real-life challenges and to align with the HPL framework. Were these changes effective in accomplishing our learning goals? Perhaps the challenges were too easy or uninteresting. Maybe the classroom environment did not become as community-centered as we hoped. Data from our multiple assessments help us to address potential deficiencies and refine the course for future implementations.

The classroom was our research site and students, faculty, course materials, and classroom activities were variables in the study. As such many questions arise when conducting research studies in real classroom settings. Our work follows in the tradition of 'design experiments' where the aim is to examine cognitive phenomena in a complex setting because this is precisely how learning takes place in actuality[9].

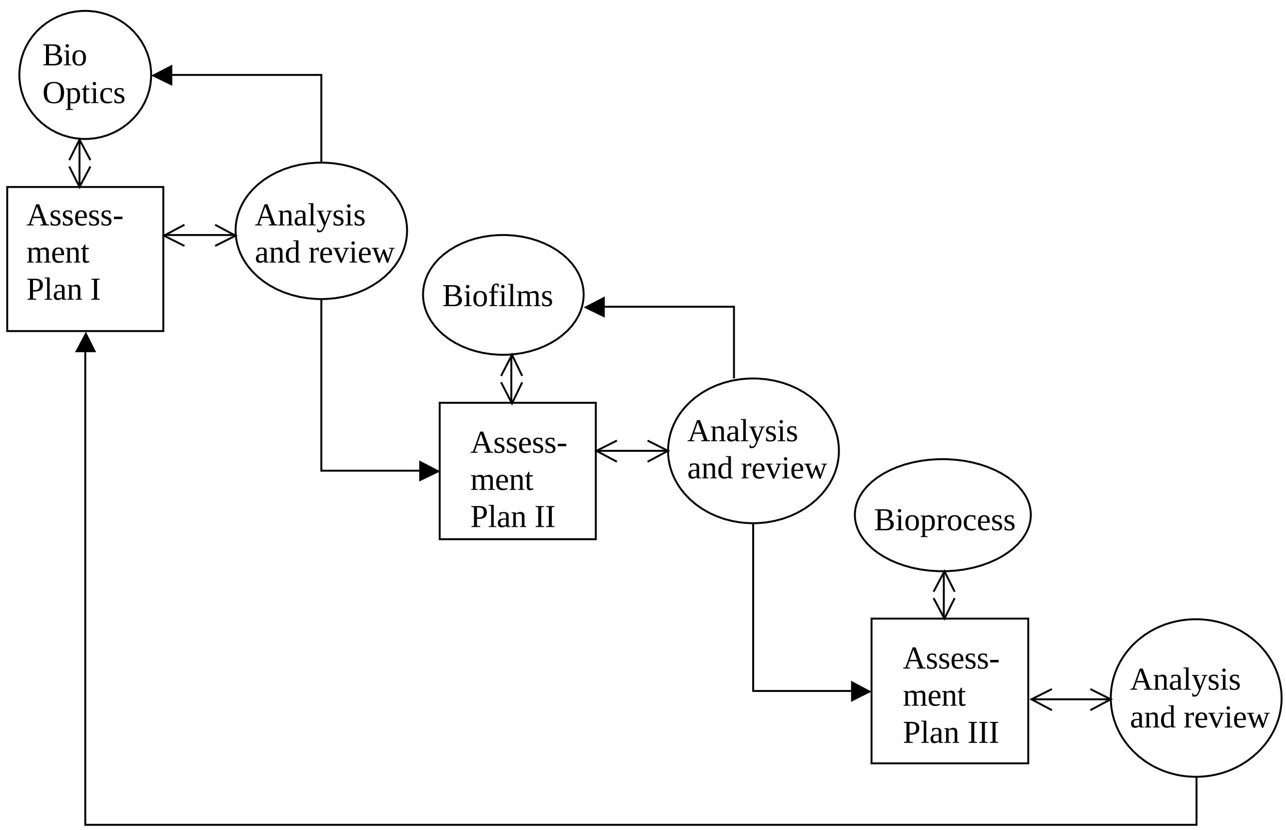

Figure 3. Diagram of our iterative approach to course and assessment plan refinement.

Our assessment was multi-tiered in that we hoped to answer multiple research questions using multiple methods. In addition, each iteration provided data that informed the redesign of the course as well as the assessment approach used to evaluate the next course. Figure 3 represents this iterative approach. Each assessment plan was designed to evaluate the specific course objectives. That is, each course covered particular scientific concepts and unique subject matter. Specific assessment questions were therefore designed to measure learning and understanding of appropriate concepts. However, several learning objectives were consistent across all of the courses. Each course aimed to develop problem solving skills and proficiency in core competencies. As such, after each iteration, we better defined these skills and refined our assessments to capture these skills.

One example of an assessment measure that was continuously refined after each iteration was the pre and post-test. At the time the bio-optics course was offered we were in the initial stages of developing the assessment plan. As such we did not have the pre-test developed so this first iteration did not implement a pre or post-test. In the next iteration, biofilms, we implemented a pre and post-test that focused primarily on subject matter understanding. Results from this test provided information about students' concept development but did not provide much data on students' ability to apply the subject matter. Since we also wanted to capture general problem solving skills such as the ability to solve open-ended problems we revised the pre/post-test for the bioprocess course.

Recent sports reports have focused on the use of proteins as supplements to enhance an athlete's performance. As such, there is great interest in the pharmaceutical industry to produce protein-based products that can be used in over-the-counter performance enhancing supplements. You have just been promoted to project manager at ProteinPlus Corporation. ProteinPlus Corporation's primary role is to design protein production facilities and to oversee the implementation and production process. Your first task in your new role as project manager is to design a protein production facility that will supply the necessary protein products for use in these supplements.

As part of this assignment please address the following tasks.

- Discuss the factors that are involved in the design of a protein production facility. This should include biological issues, modeling issues, and any other technical or practical issues you feel are important.
- Describe a plan for how you would carry out the necessary steps in your design.
- Identify who you would recruit to help you with this project and why.

Figure 4. Example of a question used on the pre/post-test in the Bioprocess Technology course.

Assessment plan III, from fig. 3, included a pre/post-test that captured conceptual understanding as well general problem solving abilities. After successive refinement, based on lessons learned from the previous two course iterations, we have an assessment measure that captures a broad range of understanding. Figure 4 provides an example of one question on the bioprocess pre/post-test. This is an example of an open-ended question that asks students to discuss relevant scientific and practical issues, develop a solution plan, and identify necessary resources. The focus is not so much on understanding scientific concepts but on integration, synthesize, and application of problem solving skills. Presently, the refined pre/post-test is being used to define the assessment plan for the bio-optics domain.

Summary and Future Work

This paper provided an overview of three courses that were offered at Northwestern University in 2001. As part of the VaNTH ERC these courses were revised to include real-life challenge assignments and aspects of the HPL educational framework. The challenges for each of the courses were presented and HPL features were described. Each of these courses implemented a range of assessment methods to capture student learning and provide feedback on the utility of course revisions.

Several VaNTH research questions were outlined along with the appropriate assessment methods to answer these questions. Each course iteration provided data to refine specific course materials. For example, challenge statements and classroom activities were revised based on review of the data. In addition, each iteration also informed the refinement of the assessment plan for the next course. The pre and post-test assessment measures were refined to better capture a broader range of student abilities and understanding.

This paper provided a general description of the assessments used and traced the refinement of one specific assessment, the pre/post-test. Since there is much data for each course, the analyses and presentation of all the results are beyond the scope of this paper. Future work will describe each course in detail and provide the results of each course assessment plan.

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