Session 2531

Cross-Disciplinary Approach to Developing Challenge-Based Instruction

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Abstract

This paper describes our cross-disciplinary collaboration to design and implement educational materials in the domain of biotechnology. We designed our course activities to follow a challenged-based model of learning and constructed our learning environment to align with current theories of how people learn. The nature of our work was cross-disciplinary since it involved applying educational principles to a complex engineering domain. In this sense engineering faculty worked closely with education faculty to create enhanced learning materials for biomedical engineering education. We describe the process we followed to develop these materials and highlight several components that led to the success of our collaborative effort. In addition we describe our course materials, the reformed learning environment, and present student feedback from the initial implementation.

Introduction

The current work was undertaken as part of the VaNTH (Vanderbilt, Northwestern, University of Texas, and Harvard/MIT) Engineering Research Center [1]. One goal of VaNTH is to reform undergraduate engineering courses such that they 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. 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[2, 3.] In addition, the Accreditation Board of Engineering and Technology (ABET) has compelled engineering schools to re-examine their curricula and to make appropriate changes to align learning outcomes with the new criteria [4].

The overall mission of the VaNTH ERC 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'[1]. 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.

One critical issue we face as we restructure courses to align with new learning goals is how to effectively work as a cross-disciplinary team to create effective learning opportunities that enhance the learning experience for engineering students. Specifically, while engineering faculty understand the subject matter extremely well, they do not necessarily have the time or expertise to independently develop appropriate curricula materials. The VaNTH ERC is 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 a cross-disciplinary team to create learning opportunities that adhere to a challenge-based model of learning and align with educational principles. 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 focuses on the process followed at Northwestern University and specifically describes materials developed for a course on the topic of Microbial Biofilms.

Pedagogical Foundation for VaNTH Curricula Reform

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 [5]. 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 How People Learn (HPL) framework suggests that the classroom environment be 1) learner-centered (LC), 2) knowledge-centered (KC), 3) assessment-centered (AC), and 4) community-centered (CC)[5]. We have used these four principles to guide how we restructure courses within the VaNTH ERC.

Components of Cross-Disciplinary Collaboration

For the project described here, four faculty worked together to create course materials for the biofilms class. Two faculty were in the engineering school (one in biomedical engineering and one in civil engineering), one was from the school of education, and one was from the computer science department. The VaNTH ERC is also exploring effective ways to use technology in education so our collaboration included a learning technologist from computer science. We began our collaboration approximately two months prior to the course offering and met on a weekly basis. During our weekly meetings we discussed several issues such as the learning objectives of the course and aspects of the HPL framework.

As a first step it was important to understand and outline key concepts we wanted students to learn. The engineering faculty explained these key concepts so that the non-engineering faculty gained a working understanding. This enabled the team to engage in meaningful dialogue about the subject matter. In parallel to these discussions the education faculty suggested teaching strategies to engage students in activities that align with the HPL framework. Each team member served as an interpreter of their area of expertise: the domain faculty interpreted the subject matter and the learning scientists interpreted the learning theory and suggested strategies for classroom practice. In this way the team shared expertise to inform the design of the learning materials.

One concrete output we sought during these discussions was an outline of specific learning goals. Once we outlined the learning goals we began constructing the challenge problem and considering how we could restructure the classroom environment to align with HPL principles. Outlining the learning goals was a critical first step in order to set the direction for the challenge problem. The challenge problem was taken from an actual industry problem that the instructor of the course had consulted on in the past. We refined the problem to make it accessible to students, to highlight specific learning goals, and approachable in scale for a one term project. The resulting challenge problem we created is given in Figure 1 and is an open-ended problem that requires students to integrate several concepts from the course.

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 problem.

In addition to creating the challenge problem the team brainstormed ideas on how to implement the challenge in the classroom setting, given the constraints of the course and the instructor. Our goal was not just to create an interesting problem for students to solve, but to have them solve the problems in an HPL fashion. This entailed several discussions regarding how to structure the classroom setting to be more learner-, knowledge-, community- and assessment-centered. Details of our course changes are described in the next section.

As we reflect on the process of creating learning materials for the biofilms course we can identify several factors that were necessary for successful collaboration. Holding regular team meetings allowed for ongoing communication and sustained momentum in the curricula reform process. Several tasks needed to be addressed and continuous meetings and discussion were necessary in order to meet the deadline of the start of the term. In this way we kept the 'lines of communication' open, continuously monitored the status of our progress, and adjusted our work plan as necessary.

The process required flexibility in several ways. The team members made a commitment to the process and as such made the team meetings a priority. All four faculty attended every weekly meeting. Both sides kept an open mind about the types of learning activities that we developed. We recognized that, even though we were following the HPL framework, our course innovation could take a variety of forms. For example, there is more than one way to make an environment community-centered.

Recognition of the multitude of options sometimes required compromise. For example, the instructor of the course may prefer to spend a certain amount of time lecturing. On the other hand the education perspective may strive for an ideal intervention which may be at odds with the lecture approach. In this case compromise may be required to develop learning materials that meet instructor's needs and goals as well as adhere to sound educational principles.

Table 1 summarizes the primary activities that each of the team members engaged in during our collaboration. The activities given in Table 1 outline important steps to keep the process moving forward. We note that while some of these activities follow sequentially many occur in parallel and require iteration between each other.

➢ Describe learning goals
➢ Identify challenge problems that embeds appropriate concepts
➢ Discuss course structure and decide how to make more HPL-like
➢ Outline how students will engage in solving challenge problem (individual vs. team, etc.)
➢ Decide when and how class time will be devoted to challenge assignment
➢ Map challenge activities to HPL framework. i.e., ensure the materials and activities are community/learner/knowledge/assessment-centered.
➢ Implement challenge and activities in course
➢ Observe what happens in classroom and with students
➢ Debrief periodically throughout term to gauge success of new materials
➢ Revise where necessary

Table 1. List of activities of cross-disciplinary collaboration.

Details of Biofilms Course

The materials we developed as a result of our cross-disciplinary collaboration were offered in a course titled *Microbial Ecology of Bacterial Biofilms*. This is an upper division course and since it is a special topics course enrollment is usually small. There were six students in the class, five females and one male. Students were enrolled from a variety of disciplines including Biology, Civil and Environmental Engineering, and Biomedical Engineering.

Prior to becoming involved with the VaNTH project the instructor of the course taught in a fairly traditional manner. Class time was spent almost exclusively in lecture format. Students were given homework and exams at discrete intervals for assessment purposes. As part of our collaboration we discussed how we could revise the class and still fall within the course constraints and comfort level of the instructor. While the primary instructional strategy remained lecture, we incorporated several novel aspects to the course to create a more HPL-like environment. Each of the changes is described below.

One unique aspect of the course was that students were given a challenge problem to solve. Students worked in teams of three throughout the entire term to solve the problem. 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. Every two weeks student teams gave a progress report presentation to the class.

The biweekly presentation served a few purposes. First, they provided an opportunity for students to share their knowledge with others in the class. We found that sharing of knowledge helped others to think through issues and generate new ideas and approaches to solving the problem. Second, the presentations served as a way to monitor student progress. If students had difficulty or misunderstood particular concepts, the presentations revealed these to the instructor. In this way the instructor could correct for mistakes or misunderstanding in a systematic way. Finally, the presentations served to scaffold students during the problem solving process. They provided support in helping students to generate ideas, correct for misunderstandings, monitor progress, and keep to a work plan.

Table 2 summarizes the aspects of the course we implemented to align with the HPL framework. Each of these aspects was new to the course and represent the activities developed as a result of our cross-disciplinary collaboration.

HPL Guideline	Course activity associated with HPL guideline
Assessment-Centered	• Students were asked to reflect on problem solving process continuously throughout the term • Students evaluated peer presentations • Students generated evaluation criteria
Community-Centered	• Students presentations allow for interaction and sharing of ideas • Teamwork • Increased dialogue between instructor and students
Knowledge-Centered	• Focus on integration and application of concepts • Added knowledge goal of developing teamwork and communication competencies
Learner-Centered	• Bring student ideas to the forefront • Presentations reveal and address misunderstandings • Create an engaging and motivating engineering problem
Challenge Problem	• Open-ended • Requires integration of concepts • Based on actual engineering problem

Table 2. Features of the 'Reformed' Biofilms Course.

Student and Instructor Feedback

Various data were collected to gauge the success of our reforms. We interviewed the instructor before and after the class as well as the students after the course. The interviews were structured to obtain feedback on the class experience, gauge how well we created an HPL environment, and identify areas for improvement. In addition we implemented an end-of-course questionnaire, videotaped student presentations, and administered several reflection questions to gauge student understanding and knowledge development. In this paper we present results from the questionnaire and student and faculty interviews.

First we present one student group's solution to the challenge problem. The solution is provided in Figure 2 and is given to show the nature of the challenge problem. Figure 2 is illustrative of the complexity of the problem and demonstrates integration of several key concepts in the solution. This solution demonstrates students understanding of gradients, differences between biofilm and liquid culture communities of bacteria, and where biofilms are found and how to control them.

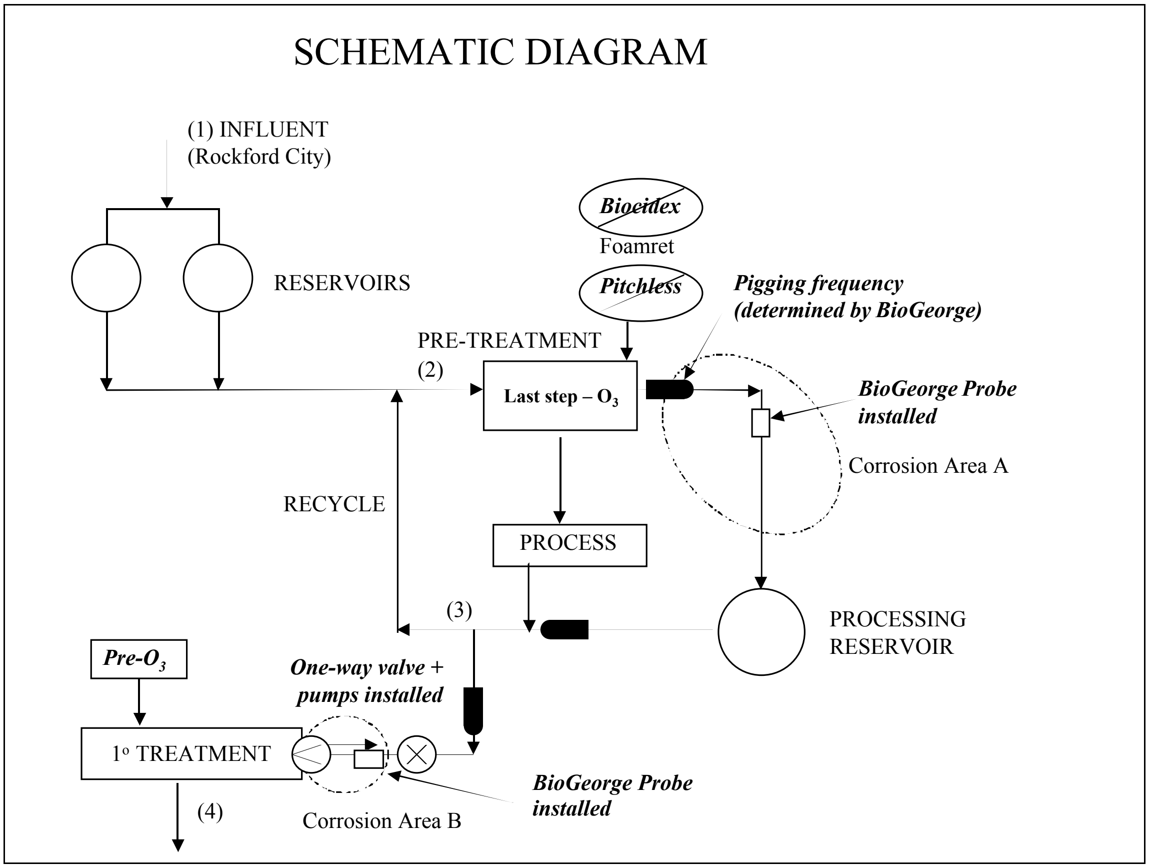

Figure 2. Student team solution to biofilm challenge problem.

The challenge questionnaire consisted of 13 Likert-type questions (see Table 3) and six open-ended questions. We included these questions to obtain student feedback on the presentations and the perceived value of the challenge assignment. We focus on student responses to questions 4, 9, 11 and 1, 5, 7 and combine results from these questions with interview data.

	Strongly Disagree		Somewhat Agree		Strongly Agree
1. The challenge was interesting.	1	2	3	4	5
2. Investigating the challenge helped me to learn about sulfate reducing bacteria.	1	2	3	4	5
3. The challenge related to the course content.	1	2	3	4	5
4. Listening to the group presentations helped me to generate new hypotheses.	1	2	3	4	5
5. The challenge was difficult.	1	2	3	4	5
6. Investigating the challenge helped me to learn about gradients of biofilms.	1	2	3	4	5
7. The challenge assignment was a valuable learning activity.	1	2	3	4	5
8. I found it difficult to make connections between the lecture material and the challenge assignments.	1	2	3	4	5
9. Listening to the group presentations helped me to interpret the data.	1	2	3	4	5
10. Adequate time was given to complete assignments.	1	2	3	4	5
11. Listening to the group presentations helped me to think about appropriate tests that could be run to determine the problem.					
12. The challenge handouts given at the very beginning of the course were sufficient to begin investigating the challenge.	1	2	3	4	5
13. Investigating the challenge helped me to learn about phylogenetic analysis.	1	2	3	4	5

Table 3. Biofilms course questionnaire.

Results from questions 4, 9 and 11 are given in Figure 3. We found that students responded highly to the value of the presentations in helping students to generate hypotheses. Combining this result with information from the interviews provides interesting insight to the impact of the presentations and group activities. Two excerpts are provided below to illustrate this point.

<u>Excerpt One</u>

"…From the other group we didn't even think to ask the question is the water ever drained. The other group did…then it clicked in my head from the other group about the pipes being drained. That means that it's corroding in that region. I never would have asked that question in the beginning...Then I had to kind of think in a different way and come up with different kinds of questions." (CC, KC, LC)

Excerpt Two

"I think something that challenges, like this, like working in a group where you're challenged in a social, professional capacity instead of just an intellectual or problem solving way. I think that that adds a whole new dimension to the challenge. Definitely they feed into each other and having to interact with group members and integrate their input with yours helps stretch you intellectually too." (CC, LC, KC)

Based on these excerpts we see that group interaction enabled students to hear different points of view which, in turn led students to consider new options and served as a catalyst to integration of ideas. We also used the interview data to help us determine how effective we were in creating an HPL-like learning environment. After each interview excerpt we listed the HPL guidelines we believe the excerpt to illustrate. Excerpt one and two are descriptive of a learning experience that was community-, knowledge-, and learner-centered (CC, KC, LC).

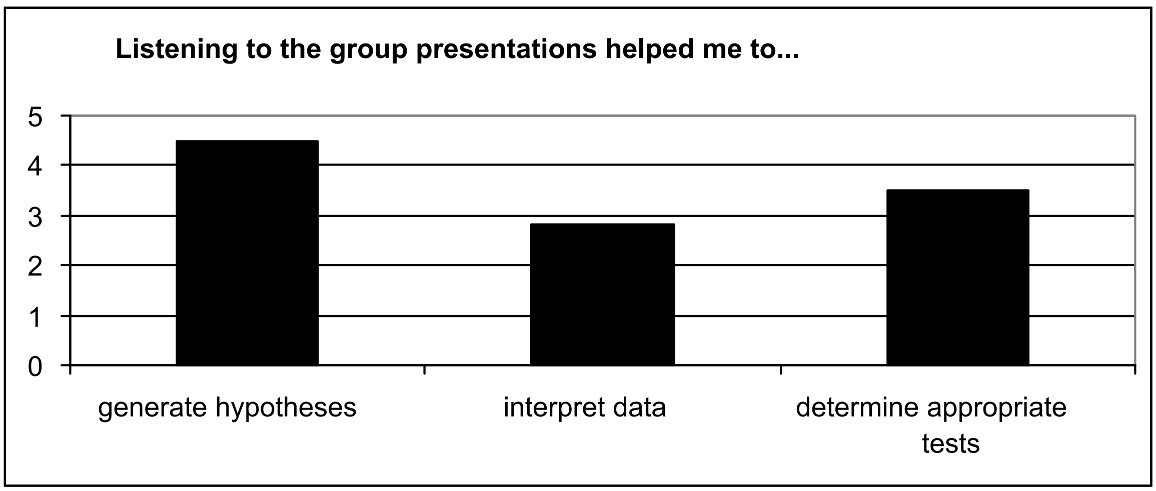

Figure 3. Student responses to questions 4, 9, and 11; max score = 5, N = 6.

Figure 4 shows student responses to questions 1, 5, and 7. Based on this data we see that students thought the challenge assignment was interesting and a valuable learning activity. The data also indicate that students believed the challenge to be difficult which we interpret as a positive response. We were initially concerned that the challenge problem may appear too obvious and students would solve the problem quickly. Instead, students devoted considerable cognitive effort in developing a solution to the problem.

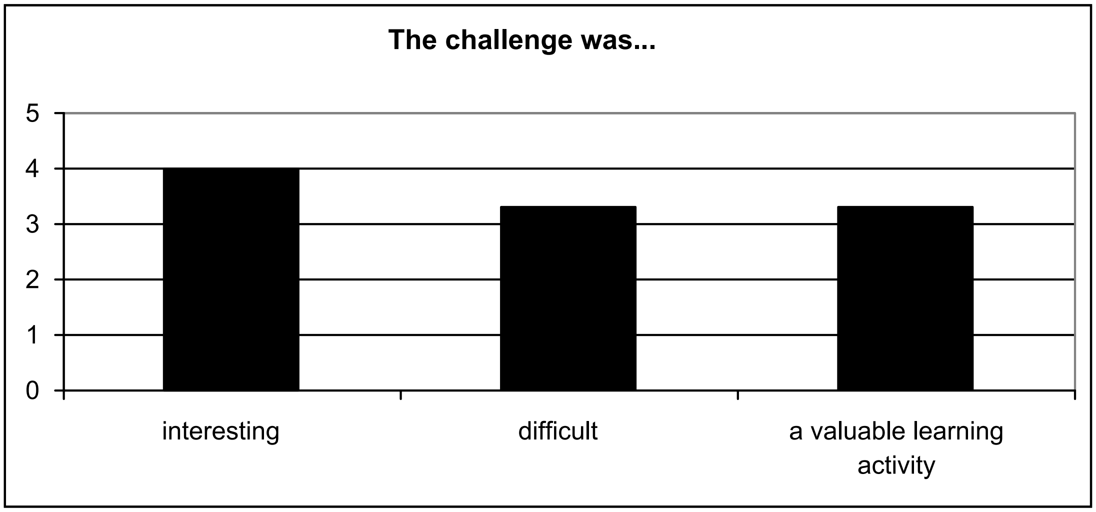

Figure 4. Student responses to questions 1, 5, and 7; max score = 5, N = 6.

Below is another excerpt from the interview data. Excerpt three provides additional information regarding the value of the challenge problem. This student nicely articulates how different factors are involved in finding a solution. This demonstrates that the challenge problem caused students to consider these factors and integrate different concepts from class. In addition this excerpt also introduces issues of identifying a starting point in the problem solving process. Many times determining where to start can be the biggest hurdle. In this way we feel the challenge-based approach provides opportunities for students to engage in authentic engineering problem solving tasks.

<u>Excerpt Three</u>

"You have this problem and you know that a lot of different factors like biological, chemical, physical could all come together and be keys to finding the solution. So it taught me..I'll have to combine all of these different principles to come up with a solution that'll work. I think the biofilm challenge helped me to try to identify a starting point, different questions to ask, so that I can make some sense of it and come up with some kind of solutions and explanation." (LC, KC)

Finally, we provide two excerpts from the interviews conducted with the instructor of the course. Excerpts four and five provide detail about the collaborative process and the value of this novel instructional approach from the instructor's perspective. Excerpt four is a wonderful explanation about how the instructor gained an enhanced understanding about pedagogy. In this sense the students were not the only ones engaged in learning. As part of our collaborative process and implementation of HPL materials in the classroom this instructor has changed his approach to teaching. In several off-line conversations the instructor mentioned he would never again teach using just a lecture format. After this experience he has seen the value of engaging students and creating more interaction in the classroom.

<u>Excerpt Four</u>

"*I also learned, I don't know how to word this, I learned a little bit about learning. I think seeing how they went about this made me realize that this really is a valuable tool, a non-traditional approach like this. Even right before we implemented the challenge I thought, well, this is interesting, but ultimately my time would probably be better spent lecturing about more material…then I saw it first hand, usually you have to see to believe, right?...There's different ways to learn. As simple as that is, as obvious as that could seem, I needed to see it to understand it*." (LC, KC, CC)

<u>Excerpt Five</u>

"*Generating that initial momentum, I remember when I went in the first meeting with you, Gulnur, and Chris, I was like, well I'm part of this VaNTH thing, but I'm not really involved. I don't know what's going on. I think generating that initial momentum, getting something down on paper the first time and then building on that, if I hadn't had you guys, it probably never would have happened, quite honestly. So to me that was the most difficult part was overcoming that initial inertia*." (CC, LC)

Excerpt five provides direct insight into the value of our cross-disciplinary collaboration. This excerpt adequately captures the important issue of overcoming inertia to get the process started. The team interaction overcame this inertia and provided the necessary momentum to keep things moving forward.

As we reflect on our faculty collaboration we also considered how well we followed the HPL framework during *our* team activities. That is, the HPL guidelines should not only apply to students and the classroom but also to how we interacted as a collaborative team. As such we examined the instructor comments through an HPL lens. In this way excerpts four and five indicate that our process was in many ways community-, knowledge-, and learner-centered (CC, KC, LC).

Summary

This paper described our cross-disciplinary collaboration to design and implement educational materials in a course devoted to topics on biofilms. In developing new educational materials we followed the pedagogical guidelines outlined in the HPL framework and engaged students in challenge-based problem solving. Engineering faculty worked collaboratively with education faculty to structure academically rigorous learning experiences based on sound educational principles.

We described details of our collaboration and highlighted several components that led to the success of our collaborative effort. Specifically we note the importance of on-going communication and regular meetings to share expertise and sustain momentum. We also remained flexible and open-minded about the types of learning activities that were developed. Flexibility and compromise were strategies that were necessary to meet the constraints of the course and instructor while creating effective and educationally valuable learning materials.

Finally, we outlined specific details of the course, described the challenge problem and revised learning environment, and presented data from an end-of-course questionnaire and from student and faculty interviews. Results from these data suggest that we were successful in creating a learning environment that was learner-, community-, knowledge-, and assessment-centered. Student responses also indicate that the challenge activities pressed students to integrate concepts and supported generation of ideas and development of appropriate solution paths.

Acknowledgements

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