Session #2002

Learning Assessment in Problem-based Learning for BME Students

Wendy C. Newstetter, Paul J. Benkeser
Wallace H. Coulter Department of Biomedical Engineering
Georgia Institute of Technology

Abstract
In the fall of 2001, the Department of Biomedical Engineering at Georgia Tech inaugurated its undergraduate degree program. The two anchor courses in the curriculum, BMED1300/2300 have adopted an innovative educational approach called Problem-based Learning or PBL that has been used in medical schools for more than a decade. In this approach, teams of eight students tackle real world Biomedical Engineering problems guided by a faculty tutor. In this paper, we discuss the challenges of designing appropriate assessment instruments for a PBL course. Since the primary emphasis in PBL is on students developing identified cognitive behaviors and collaboration strategies as well as science and engineering concepts, the assessment instruments must mirror these priorities. These behaviors, however, are more qualitative than quantitative in nature, which is where the challenge comes in. Here, we describe the assessment tools we have developed, present a justification for their development and report on the overall success of this educational experiment.

Problem-based Learning in Biomedical Engineering: A Rationale
The field of Biomedical Engineering (BME) represents a merger between traditional engineering disciplines such as mechanical, chemical, and electrical engineering and the biology-based disciplines of life sciences and medicine. This merger was prompted by the need to improve procedures such as diagnostic testing, noninvasive surgical techniques, and patient rehabilitation. In the last twenty years, BME has evolved into one of the fastest growing fields while having a significant impact on medicine, biotechnology, and basic science.

The multidisciplinary nature of Biomedical Engineering creates particular challenges on the educational front. Medical technology changes at such a rapid pace that classroom practitioners are hard pressed to keep abreast of advancements in all the related fields. On the student front, the multidisciplinary nature of the field demands that students develop multidisciplinary skills and knowledge. They need the modeling and quantitative skills of traditional engineers, but they also need the systems understanding representative of a more biological approach. In short, they need to be fully conversant in two intellectual traditions that are in some ways at odds with one another. While engineering seeks to analyze the world in order to set constraints and design, the life sciences work from hypotheses towards explanatory accounts of phenomena. Reconciling these two disparate practices requires cognitive flexibility and true interdisciplinary thinking.

In an attempt to reconcile these worlds and foster interdisciplinary thinking among our undergraduate and graduate students, the BME Department at Georgia Tech has adopted a model of learning and a set of educational practices that have been used in medical education for more

Copyright © 2002, American Society for Engineering Education

than a decade. Referred to as Problem-based Learning or PBL, this approach draws on constructivist pedagogy, which assumes that learning is the product of both cognitive and social interaction arrived at through authentic problem solving. The PBL tutorial, as the learning environment is called, consists of a group of no more than eight students, a problem to be solved and a tutor/facilitator. The classic PBL version used in medical education utilizes rich authentic medical problems, which support free inquiry. This freedom encourages student-directed learning and increased learning motivation[1-3]. In our undergraduate program, we have adopted the same version. For two semesters, freshman and sophomore BME students tackle complex real-world problems in teams of eight with the guidance of a faculty tutor. What gets learned, the routes the team takes to solve the problem and the problem solutions arrived at are determined by the group, not the facilitator. His/her role is to question, prod and help students develop skills at the process or problem attacking level. To support students in handling complex, ill-structured problems, the group utilizes the in-class white boards divided in such a way as to scaffold the reasoning strategies used by engineering in solving problems. The PBL tutorial, a cornerstone of the BME educational program, aims to provide students with valuable real-world experiences (clinical and research) which help them develop true interdisciplinarity.

Learning Goals in Two Environments: Traditional Classrooms and the PBL Tutorial

While traditional classrooms and PBL tutorials both aim for students to learn engineering/ science concepts and skills, the PBL setting has additional learning goals. Altogether there are five: the development of effective self-directed learning strategies, the construction of useful disciplinary knowledge, the development of disciplinary-specific reasoning strategies, increased motivation for learning and improved collaboration skills. Students become better at self-directed learning by identifying areas of interest and going after the information that will help them understand those areas. In PBL, this is referred to as *inquiry*. Inquiry or information gathering and application activities assist students in defining and solving problems. Since student teams receive no resources except for the problem statement, they must first identify what they are missing to solve the problem, and then go out and find what they need to move forward in the problem space. A sample problem statement is provided below.

How to Sterilize Mad Cow Disease Contaminated Waste? You work for Biodyne Inc, based out of Medina, OH (NASDAQ Symbol PBL). Biodyne stock has plummeted along with the rest of the high tech stock market. This makes investors unhappy. Thus management is looking for new markets to help Biodyne reclaim its position as a biotech innovator. Your select team of bioengineers has been selected to work out the design parameters for the disposal of waste infected with Mad Cow Disease. Our illustrious management team, after reading much of the popular literature and performing many spreadsheet calculations, has determined that there is a one billion-dollar a year market for the sterilization of such waste. While the waste sterilization market is a mature one, this new potential market opportunity presents itself primarily due to the fact that incineration alone is not enough to render Mad Cow infected waste safe. We need to formulate and evaluate methodologies for the effective sterilization of such waste. Management at Biodyne has the fullest confidence that you will use your advanced knowledge of macromolecules and proteins to accomplish your task within the next two weeks. However, we do realize that your task will not be an easy one but know that you will be inspired by our company motto – “FAILURE IS NOT AN OPTION!” to attain complete success in the most topical (and potentially lucrative) of topics.

The student team tackles the problem by first mining the problem statement for what they already know. In the problem above, students may know something about Mad Cow disease

Copyright © 2002, American Society for Engineering Education

from the popular press. They soon realize, however, that they know nothing about the disease at the biological level. What causes it? Why is incineration ineffective? How is it transferred to humans? This realization prompts them to develop a set of learning issues or questions to be answered, which constitutes the inquiry for the next session. From this list, each student chooses an area that s/he will research and report back to the group. This self-directed learning phase involves tracking down the resources necessary to answer the identified questions, digesting the material and bringing information back into the group. This cycle of finding and developing knowledge, bringing it into the problem space, identifying new learning issues and research is repeated until a solution is reached. Undergraduate students, however, rarely have sufficient experience in locating appropriate materials to answer the evolving questions. Their search skills are generally poor; they have no experience reading journal articles and they often lack the disciplinary knowledge that would help them understand the papers they locate. These are all things that improve as the semester proceeds, but not without several cycles of moderate failure in achieving what they had gone out to achieve. The assumption that follows from this cycle is that students will develop more effective research strategies over time and also feel more motivated to learn because they have identified their own learning issues rather than responding to those identified by the instructor. They are further motivated since they are responsible to the group for learning the material well to teach it to others, so that they can move forward toward a problem solution.

Students in a PBL tutorial just like those in traditional engineering classrooms are expected to learn course content, but *the facts and concepts should be anchored and integrated into a complex problem*--one they have just solved. This means that there is no sequencing of content from easy to hard. Rather easy and hard content are both discovered within the same problem and students have to make sense of it for themselves with the help of the group members. Their understanding, as a result, looks more like a rich case history of interrelated nodes and links rather than a collection of facts and concepts loosely linked. Ideally recall of course material will be situated or contextualized in the rich problem context, more closely resembling the understanding of experts' rather than novices'. Further storage and recall of material will be more successful because it is integrated and applied to a problem, not sequenced and delivered step by step through lectures.

As should be clear, good team skills are essential to this process. Learning how to collaborate is critical to solving the problems since they are too complex for an individual to even begin to solve. It is therefore critical that each member develops collaboration skills that will allow her to drive the problem solution forward in concert with others. Asking pertinent questions, challenging others' ideas, asking for clarification, proposing novel routes through the problem, noting when others are not pulling their weight are some of the more specific collaborative skills that they are building towards. At the end of each problem, in a wrap-up session each student and the faculty facilitator evaluate their performance. Members are then asked to respond to an individual's self-evaluation. This session is used to make explicit what worked and did not work, what behaviors in the group were helpful and want behaviors need to be changed. Each student receives face-to-face feedback on his/her contribution to the problem solving so s/he can alter activities if necessary in the next problem.

Copyright © 2002, American Society for Engineering Education

Overall, the goal of a PBL tutorial is for students to be able to take on a complex, open-ended problem, develop a strategy for handling uncertainty and lack of resources internal to the problem and move collaboratively towards a problem solution. These cognitive/social skills are not restricted to a particular course, or problem type but can be recycled to reason through any type of ill-structured, open-ended problem. Thus, PBL is designed to help develop high-level reasoning strategies that approximate those used by practicing engineers in BME settings.

Mapping the Learning Goals to Assessment Instruments

In BMED1300/2300, we are wrestling with ways to fairly, accurately and consistently assess the five learning goals of a PBL setting. We are concerned with developing instruments that are both *valid* and *reliable*. We want to ensure content and construct validity such that the test content is representative of the sample behaviors we want to measure and that the test items really do measure the traits we have targeted. We want the instruments to be reliable in consistently rating a student's performance such that differences in student scores are attributable to real differences rather than scoring discrepancies or testing errors. When the behaviors being measured are primarily qualitative, achieving validity and reliability are extremely challenging. Here we report on our preliminary efforts in that direction.

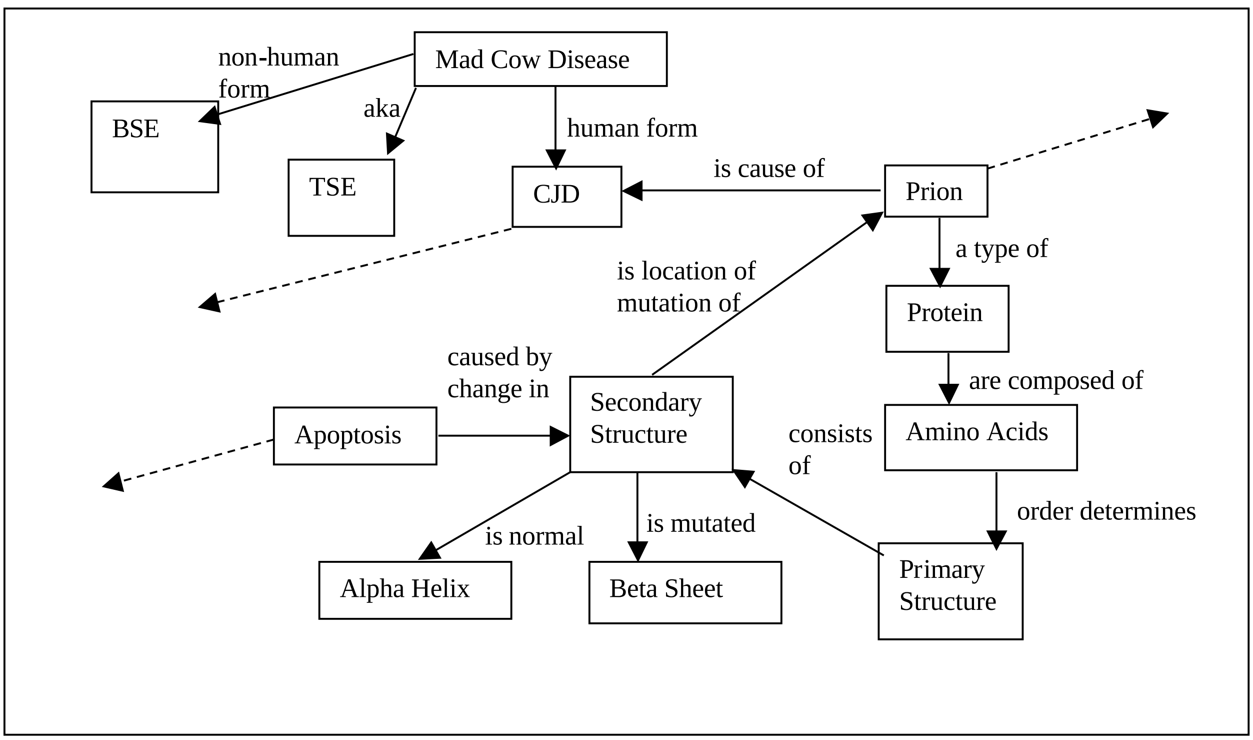
In the first semester, we piloted several alternative testing instruments to determine whether the students were making progress in the targeted areas. In the table below, we present each learning goal, the assessment instrument used to collect data, and a brief description of the instrument.

Learning Goal	Instrument(s)	Description
Disciplinary knowledge	**Concept maps**	At the end of a problem, each student develops a concept map of the concepts used to solve the problem
Reasoning/Inquiry skills	**Problem response**	Each student is given a complex problem and asked to identify three areas of inquiry that would drive initial research. They also provide a rationale for the choices.
Motivation for learning	**Group interviews**	Each team is interviewed using open-ended interviewing techniques to determine their engagement with the problem areas
Collaboration skills	**Tutor evaluation**	Using a grid with numerous identified behaviors the tutors rate each students development over the term.

We could develop standard engineering tests to be used at the end of each problem which would tell us whether they had learned what we had hoped in designing the problem. In some cases, we did that. However, while we are interested in *what* they learned we are just as interested in *how* students have integrated and interpreted all the concepts in relation to the problem and to the other new concepts. To use a metaphor of sorts, we are interested in the topography of their learning rather than a fixed snapshot of parts. We want to see a landscape of all the information they have gleaned from their own and the research of others in the group. We want to see the complexity of the relationships across concept types. We want to understand how their new knowledge is anchored in the problem and integrated so as to reflect relationships and linkages. For this reason we have used concept maps as the data collection instrument because they force students to link concepts and articulate the ways that those concepts relate.

Copyright © 2002, American Society for Engineering Education

In the first semester, using note cards or Post-it notes, the student teams at the end of a problem would generate a list of all the concepts they had learned and then work together to create a coherent web of terms by moving the cards around. The outcome was a group concept map. This process presented many problems. First, getting the group to finally agree on one concept map when there were competing versions was frustrating and in some cases, non-productive. Also it was not clear what the quieter students in the group had learned since they were less vocal in the process. But most importantly, we were not getting individual accounts of what students had taken away from the problem. In other words, we could not tell what any one student had actually learned. Most recently, we have dispensed with group maps. Now each student develops his/her own map, which s/he presents and explains to the other students and tutor. This sharing reveals the varieties of knowledge constructions as well as the holes that may exist. Sharing it with others makes also the learning public and a focal point for discussion and further learning. To date, we do not having scoring rubrics for the concept maps because we are all piloting the problems. After we have stabilized the problems, we plan to focus on reliable and fair ways to score the maps. Whether this is the best instrument for assessing the topography of learning is yet to be determined. An example of a section of a student concept map is provided below.



Developing instruments to assess student reasoning and inquiry strategies has been by far the most challenging task. Somehow we needed to simulate in the test setting an authentic problem-solving scenario in order to tease out some of the behaviors we wanted to examine. We wanted to know how well they were able to deconstruct a problem at the beginning and use the statement itself as a scaffold to the problem solving. We wanted to assess their inquiry strategies: how they identified the critical learning issues and avoided the insignificant ones. We wanted to determine

Copyright © 2002, American Society for Engineering Education

whether they were engaging in the kinds of reasoning strategies used by engineers when starting in on a new problem. Ideally we would have given students a hard problem and then follow them for three weeks as they worked on it, but this is hardly realistic. With these goals in mind, we decided to give them a complex problem statement and have them do the first steps towards problem structuring. This would allow us to begin to assess how they were developing initial reasoning and inquiry skills. A sample problem is provided below.

EXAM QUESTION

Foot and Mouth Disease (FMD) is a highly contagious and economically devastating disease of cattle and swine. It also affects sheep, goats, deer, and other cloven-hooved ruminants. Many affected animals recover, but the disease leaves them debilitated. FMD causes severe losses in the production of meat and milk. Because it spreads widely and rapidly and because it has grave economic as well as physical consequences, FMD is one of the animal diseases that livestock ownes dread most. The disease does not affect humans.

As we have seen recently throughout Europe, the foot and mouth virus could spread very easily and rapidly to other areas. So far our country has been fortunate to be spared from this dreadful disease. If not prevented and irradiated properly, however, it could have a devastating impact on our food as well as the American meat industry and economy. There is a potential that it could be used as a biological weapon by terrorists. The most likely vector for the virus to enter into North America is through the shoes and clothing of airline passengers inbound from already infected areas.

Your job is to devise a method to disinfect/inactivate/irradiate the Foot and Mouth virus hitchhiking on the clothing and shoes of inbound airline passengers. Do not consider the case of stopping the incoming passengers. 1) Propose initial models or hypotheses regarding your method of disinfection/irradiation. 2) Identify five (5) (and no more) specific learning issues that you believe to be critical for the development of a method. 3) Justify your five choices.

Having given this test question, the next challenge was coming up with a scoring rubric that could be used to achieve consistent marks. One of our faculty members, Bill Ditto, devised this scheme. Each learning issue was worth a total of 5 points-2 for the choice and 3 for the justification. A student could score as much as a five for a learning issue or a zero based on the criteria stated.

Choice (2 pts)	0 - Not relevant or trivially relevant to problem solution	1- Important but most likely a secondary issue that while important is not on the critical list.	2- Clearly a critical issue that MUST be investigated if any solution is to be found.	
Justification (3 pts)	0 - Poor or little justification or incorrect justification	1 - Minimal justification, simplistic, incomplete or misleading.	2 - Reasonable justification or enumeration of key points relating to learning issues and problem solution.	3 - Persuasive or insightful reasons that choice is critical and identification of several key points of entry into solution through choice.

Having developed a rubric for scoring. Bill then developed example test answers for each category in order to have a description of the target. He then used this to actually grade the papers. Because of the qualitative nature of this test, we kept the scorer constant to insure consistency. The example test answers are provided below.

Copyright © 2002, American Society for Engineering Education

5 pts - Determine the mechanisms through which the structure of the FMD virus can attach and survive on clothing or surfaces. This is clearly a key entry point into the solution as any information or delineation of how viruses attach to and survive on materials. This learning issue then becomes key towards the development of techniques for deactivation. This issue relates to environmental breakdown of viruses, active measures to disassociate such viruses from materials and surfaces with the ultimate goal of rendering such viruses inactive. If one can effectively disassociate the virus from the clothing then the job of virus decontamination becomes a simpler one. If one cannot find such a method, then one must find a method to deactivate the virus on the surface itself (which significantly constrains possible solutions and might significantly increase cost or reduce practicality!). 4 pts - Determine how the FMD virus attaches itself to clothing. This is clearly a key entry point into the solution as any information or delineation of how viruses attach to and survive on materials. This learning issue then becomes key towards the development of techniques for deactivation of the virus. 2 pts - Determine how people pick up FMD on their feet and clothing. If we knew this then we could prevent them from getting it on their clothing. This is important, as they would then not carry the virus into the airport. 1 pts - Determine how people pick up FMD on their feet and clothing as this would help.

The fourth area of concern to us is student motivation. Standard surveys would have been possible but we were interested in determining not only whether motivation for learning had increased but also why. We therefore conducted open-ended interviews with each student team. These lasted for thirty minutes and started with the question, “Well how is PBL going for you?” The open-ended format was used to uncover the lived experiences of the students rather than the scripted responses, which are indicative of an interview using a question protocol. We discovered that almost without exception the forty students liked PBL better than any of their other classes although it was a lot of work. We had numerous spontaneous accounts of how they spent more time on this class than others, that they had learned more in this class than in others and that they were motivated to learn because of the team environment. Results from this study are still being analyzed.

Finally, we want to assess student collaboration skills. As mentioned earlier in the paper, an important component of PBL is the end of problem group session, where each student orally assesses herself and the others respond to that assessment. In addition to this, in the first semester, each tutor met with each student to talk about the student’s activities and work in the tutorial. In the next semester, we developed a rubric of specific behaviors that the tutor now uses to assess the students. This serves two purposes: to insure consistency of focus across the many tutors and as tangible feedback to each student. The sheet does not focus just on collaboration per se but on the interactive behaviors that impact the group as a whole. You might say that the sheet represents a broadening of the notion of collaboration beyond the ability to work well with a group to cognitive skills that enhance the working of the group in solving problems. The tutor evaluation sheet we are currently using is shown below.
Please use the following table to assess the members if your group. Use the following scale: 5 = strongly agree → 1 = strongly disagree.

Copyright © 2002, American Society for Engineering Education

Knowledge Building • Asks key questions and identifies relevant inquiry topics in a way that promotes deeper understanding of the problem. • Communicates ideas and information clearly and in a manner that promotes deeper understanding. • Demonstrates the ability to identify the next layer of information to be tackled	
Self-Directed Inquiry • Consistently brings new and relevant information to the problem solution to group discussions. • Demonstrates that they have spent the time to understand the information they have uncovered in their inquiry • Accurately assesses the reliability of sources	
Problem-Solving/Modeling • Identifies the goals of the problem • Plans a strategy to attack the problem • Develops provisional hypotheses/models for the problem	
Group Skills • Present and engaged with group process • Provides thoroughly researched and digested information in a timely fashion • Expresses support/disappointment/disagreement directly and openly • Listens to and shows respect for the ideas and opinions of others	

Conclusion

In implementing a PBL approach in the BME undergraduate program at Georgia Tech, we have attempted to develop assessment instruments that mirror the learning goals of the approach. Given the qualitative nature of these goals, we have had to experiment with new ways of testing. This experiment in engineering education has only just begun. We have another group this semester and expect to refine and improve what we have done so far. Whatever the outcomes, it is clear that if we are to instill expert-like reasoning strategies in our students, we must work to create new forms of assessment in tandem.

Bibliography

1. Barrow, H., *The tutorial process*. 1988, Springfield, ILL: Southern Illinois University Press.
2. Barrows, H.S., *How to design a problem-based curriculum for the preclinical years*. 1985, New York: Springer.
3. Hmelo, C.E., *Problem-based learning: Effects on the early acquisition of cognitive skill in medicine.* Journal of Learning Sciences, 1998. **7**: p. 173-208.

WENDY C. NEWSTETTER is Director of Learning Sciences Research in the Department of Biomedical Engineering at Georgia Tech. She is a faculty member in the Cognitive Science Program.

PAUL J. BENKESER is an Associate Professor and the Associate Chair for Undergraduate Education in the Department of Biomedical Engineering at Georgia Tech

Copyright © 2002, American Society for Engineering Education