Tracking student problem-solving strategies in online PBL case discussions: a method to target interventions to individuals and groups most in need of help.

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Summary

For the past 4 yr, faculty at the University of New Mexico (UNM), Department of Biochemistry and Molecular Biology have been using interactive online Problem-Based Learning (PBL) case discussions in our large-enrollment classes. We believe the use of online PBL-cases is a way to get small-group discussions into our large classes, to encourage students to use their basic biochemical knowledge in practical contextual situations, to develop the ability to integrate different pieces of their knowledge, and, most importantly, to practice and improve their problem-solving skills. We have developed an illustrative tracking method to monitor student use of problem-solving strategies that enables us to provide targeted intervention, as appropriate, to groups and individual students in this area of student development. (1)

Context

We use PBL cases with biochemical problems as the basis for online discussions in classes of 60 to 150 students in three different biochemistry courses (two courses for our biochemistry majors; and a one-semester service course, primarily for premedical and pre-pharmacy students). All students are juniors and seniors, and fully represent the diversity of student backgrounds, both academic and cultural, that define the University of New Mexico demographics. Students need access to and comfort with use of computers in order to participate successfully in the online discussions.

The online PBL discussions are one of several constructivist teaching modalities that we have incorporated into our Biochemistry curriculum over the past 5 years, which has resulted in the establishment of what we consider to be a multicontextual learning environment (2, 3). The courses also integrate interactive lectures, and some face-to-face small-group discussions. Assessments within the courses include standard multiple choice/short essay exams, individual and group quizzes, and electronically-administered individual PBL-based assessments.

Goals

Our overall learning goals for our students were for them to:

- Apply biochemical principles by working with the content in contextual situations
- Improve written communication skills to optimize collaborative exchange of ideas
- Develop awareness and appreciation of the real-life applications of biochemistry
- Practice the higher order learning skills necessary for problem-solving
- Explore their individual strengths/weaknesses in addressing problems

Though the learning goals incorporate aspects from the various levels or dimensions of learning (4, 5), we focus on promoting the higher order skills used in solving problems (applying, analyzing, synthesizing, evaluating) because they are relevant to the physical and life sciences, and are of clear future value to professionals. We judge that these skills are recognizable, measurable, and amenable to instructor-modeling. However, there is debate on whether or not the skills are actually teachable. We define problem-solving skills as those used to address problems through a set of clearly-delineated strategies that are a subset of critical thinking, or higher-level learning.

PBL refers to an assortment of educational methods that have been adapted to a variety of curricular settings including undergraduate STEM courses (3, 6-11). In all of its guises, PBL initially presents learners with a vague problem, and data is then progressively disclosed in order to stimulate students to work towards a solution, usually in collaborative small groups. A variety of assessment methods have been described, (12-13) but overall, assessment of students in PBL groups continues to be a challenge for the instructor. In medical schools, which is where PBL has been most heavily used, one or two faculty members (basic scientists and clinicians) work with 5-7 students, for several hours a week, for perhaps months at a time.

Student resources at large undergraduate institutions are not usually as robust as at medical schools. In fact, though some of our earlier work indicated that using PBL cases in face-to-face small groups provided our students exposure to and practice in problem solving that translated into higher scores on authentic assessments of these skills (3), we actually were forced by this very experience to conclude that it was not practical, and it imposed unreasonable time and energy expectations on the faculty participating. We therefore have taken advantage of the technological option of online asynchronous PBL discussion groups in our Biochemistry classes.

PBL has been variously modified for use in distance learning situations for more than 10 yr (14-16). The literature implies that in some ways these interactions are less satisfactory than face-to-face discussion; evaluations of the use of online discussions (based on PBL cases or on other prompts) have pointed out some disadvantages of students not being in face-to-face contact during conversations: lack of facial cues from other discussants, delayed rather than immediate responses (in asynchronous discussions), and decreases in overall group learning. However, use of "virtual" groups also alters the learning environment in some ways that may be unexpectedly positive for certain learners. For instance, online discussions can be beneficial to some students who are normally shy, or who have English as a second language. Asynchronous online communication allows these students more time to develop their responses and to participate more confidently (17-22). In addition, there are very practical advantages of electronic communication even in traditional on-campus classes, and the major benefits to us of holding PBL-case-based discussions online have been, in fact, both logistical (all students in a large class were able to "talk" within their small groups despite incongruent schedules, the lack of small rooms in which to meet, and limited number of tutors), and procedural (the conversations of the students within their groups were able to be kept as permanent transcripts, and therefore available for multiple assessment).

In general, studies of online PBL discussions do not include assessment of problem-solving capabilities. Many recent studies are of non-STEM courses (such as education courses), and assess other measures such as development of group trust and perceived success of collaboration, development of academic literary skills and self-reported perceptions of learning outcomes (18, 23-24). Examples of studies on online PBL courses in the sciences (physiology, biotechnology) compared exam scores and student feedback on the course (25-26). Studies of online cooperative learning (but not using PBL cases) have looked at retention of content (27), and also provided important clues about the value of social interaction on student achievement (28). Other studies on assessments of problem-solving strategies in undergraduate STEM courses emphasize that these skills do not necessarily come easily to many -- if not most -- students, and that measurement of the skills is difficult (29-30). We completely agree, and this may be one reason why there are only a few research articles to date that address routine assessment of problem-solving skills using online PBL prompts (1, 31).

Our departmental goals in using this approach are essentially those put forth in the books and essays of the NRC and by other educators (32-39). All of these address the key needs for improving STEM undergrad education through activities that:

- Encourage immersion in content that is useful and relevant for the future professional goals of the students, thus promoting an interest in the field and engendering a desire to learn more (i.e., encourage life-long-learning)
- Include active, student-centered learning strategies that usually require collaborative group interactions
- Appreciate the different learning styles of diverse student populations
- Allow the iterative evaluation necessary for the practice of scientific teaching (40)

Our approach to developing this practice was to let pedagogy drive the course design, and then utilize the least-intrusive existing technology in order to realize our goals.

<u>Specific Outcomes</u>

As a result of this educational strategy, our specific learning outcomes for our students are that they be able to:

- Generate reasonable and relevant <u>HYPOTHESES</u>
- Propose a strategy that will appropriately <u>INVESTIGATE</u> the hypothesized questions complete with appropriate controls
- Correctly <u>EVALUATE</u> supplied data, based upon its usefulness and reliability
- <u>INTEGRATE</u> conclusions from the data with known biochemical mechanisms or facts, in the context of the whole problem
- <u>REFLECT</u> on the next steps (e.g., another experiment); and also evaluate self-efficacy and understanding, and design an appropriate learning plan.

<u>Example</u>

In the biochemistry classes described earlier, students were presented with 4-6 PBL cases per semester through the course web site (Table1). An example of a vague initial case presentation is given here:

<u>"CSI-Albuquerque: </u>An elderly biochemistry professor at an unnamed Southwestern medical school failed to show up for class. Every student in the class was sitting in excited anticipation of hearing a lecture about energy metabolism, but, the professor was missing. Before the time required to wait for a professor (3 min) had expired, a dashing detective from CSI-Albuquerque arrived to inform the class that their professor had died under suspicious circumstances. There was a suggestion that the professor was the victim of foul play. However, he could have died from an undiagnosed metabolic disease. CSI-ABQ needs the help of the class, now local experts in biochemistry, to assist them in their investigation. You have a limited budget, and all biochemical tests and medical procedures will cost you."

Assigned groups composed of 5-10 students (depending on the particular course) were required to work on the case problem in asynchronous electronic discussions, communicating with their group members only. Student time on this task was ~1-2 hours/week, but this varied greatly between students. Though the online groups sometimes met face-to-face, they were directed to report all discussions through the online forum. The complete transcript of a group's discussion normally ran about 10-15 printed pages, so reproduction of a typical case conversation is not practical, but student contributions to the group discussion (postings) variously took the form of

- initial and secondary hypotheses: "I think he was poisoned by his graduate student, what was she working on in the lab?"; "That widow is a bit too happy…what does she do for a living herself?"
- requests for data from the instructor: "Can we get information from his last doctor's visit, specifically a list of the illnesses he has had in the last year?"; "Can we test his leftover blood for glucose and lactate concentrations?"
- biochemical information pulled from texts or other resources
- analyses of data provided: "The lactate levels in his blood from his last checkup were extremely high; something is wrong with his energy metabolism, somewhere, and we need to test the levels of other metabolites."
- summaries or integration of the information available at each stage of the case.

The instructors acted as guides to keep the online conversation on track, and as sources for data (in many cases, we provided actual experimental or clinical data from the primary literature), but only inserted comments when necessary, and only provided data if relevant to the problem and requested by group consensus. Examples of instructor responses to the above student postings in the "CSI-ABQ" case would include

- the information that the grad student was studying the effects of arsenic in the ground water on skin cancer, and the wife was a specialist in arachnid poisons;
- that the professor had suffered from a variety of annoying but not serious maladies in the last year, including several colds, a sinus infection, stomach complaints, and tingly, painful feet, and that the glucose levels were low, and lactate levels very high.

More general strategic instructor suggestions were made to individual groups through the online discussions, and also to the whole lecture class as needed, usually in the form of a conversation that modeled the way an "expert" approaches a similar problem: ("Many of the groups seem to be lost…if I were in a situation like this, my first question would be…").

Concurrent with the online case-based discussions, which lasted about 2-3 weeks each, the students were exposed to text readings and traditional in-class presentations that included content pertinent to the case, but the solution was not provided in lectures. At the end of each case a summary provided the full answer to the problem, and commented on the various successful and unsuccessful strategies used by different groups.

A portion of the course grade depended on involvement in the case discussions. The scientific content of each individual student posting was given a numerical score of from 1-10, indicating its closeness to the final solution based on the grading rubric (Figure 1). Grading of all the 5 to 10 groups in one course required roughly 1 h/day of instructor time when the cases were underway (about 8 weeks spread out through a 16 week semester). At the beginning of a case, it was not expected that a content contribution score would be high; a PBL-case by definition starts as an ill-defined puzzle, without enough information present to allow an immediate solution. As the students defined the problem, asked appropriate questions related to their learning issues, and received specific data from the instructors, they were able to hone their postings more narrowly. A successful group would therefore show a pattern of sequential individual student postings that had a general trend of increasing content scores over the course of the case (Figure 2, both gray and maroon bars). All of one individual student's sequential contributions (Figure 2, maroon bars only) could also readily be evaluated in the context of the whole group; for example, this student was a regular contributor to the group discussion, and the student progressed, in concert with the group, to the correct solution.

Not all groups were successful in every case. As occurs in classic face-to-face PBL discussions, a combination of collaborative accrual of content knowledge and application of problem-solving skills was necessary for a group to reach the final correct answer to the case problem. Not all students were equally helpful contributors to a group's advancement to the solution; some only rarely participated, or simply agreed with another student, while others made frequent and intellectually substantive contributions. In addition, not all groups progressed through the case at the same rate. Each case lasted for about two weeks, but some groups did not begin posting until close to the end of the assigned discussion time.

Some students who had seemed to be successful at solving problems as part of the group, as indicated by their frequent postings and increasing content scores within a case discussion, subsequently failed course exam questions that we considered to represent problem-solving challenges (for example, essay questions that required data analysis, evaluation, and integration of new information). When approached for help by such students, we returned to the transcripts of the group discussions for a further assessment of their strategies, in an attempt to guide and improve their performance. For these analyses, we reprised the use of the content grading rubric as above, but also re-evaluated each posting in terms of its problem-solving utility. Knowing content and using content to solve a problem requires different skills.

We used, essentially, the scientific method as an additional way to categorize student contributions, classifying each posting by an individual student as belonging to one of the following "domains" of problem-solving:

- Hypothesis: “What do you think might be the underlying cause of the problem/ situation?”
- Investigate (research): “What would you like to do to test your current thinking?”
- Evaluate: “How has this new information changed your thinking?”
- Integrate: “On a mechanistic basis, how does the underlying problem result in the current findings / situation?
- Reflect: “Now that you have a lot of information, what do you want to do to address the problem and advance your own learning on this topic? Do your findings suggest new problems/areas of investigation?”

The categorization by domain of a student’s contributions was separately done by two content-experts (the instructors of the courses, MO and WA), and then compared. We found that our categorizations were very similar except when a posting was so incongruent with the above problem-solving process that categorization was implausible. Examples of this ranged from postings discussing many domains simultaneously (an outstanding problem-solving strategy, but hard to categorize), to postings of “…a house to rent.” However, because this part of the analysis was done not to assign a summative grade, but rather to provide the instructors with a tool to help a student broaden his problem-solving skills, we have not quantified the inter-rater reliability of these categorization judgments.

Individual student problem-solving “roles” in their groups tended to vary over time, with most students taking responsibility for different pieces of the problem-solving tasks in different cases according to interest, background, and time available to them during a particular part of a semester. For example, a student involved in undergraduate research in a biochemistry laboratory would be more active in offering suggestions for techniques during one case that involved protein-purification (“Investigate” domain), but would participate less in a case discussion concerning the evolution of membrane transport proteins in snakes. Sometimes, the members of a group would specifically partition tasks (through the online conversation), similar to a face-to-face PBL group dividing up the research to be done on different learning issues.

As described above, we initially carried out our domains analysis of problem-solving strategies only if there was a request for help from a student; we expanded this evaluation as we began to see patterns when we graphed the individual student postings according to problem-solving domain, content score, and sequence in the discussion. Each pattern discussed below represents the set of an individual student’s sequential postings from one case, and is presented without the rest of the group postings; a full understanding of a pattern usually requires knowledge of the group performance graph as well.

A pattern of responses such as that shown in Figure 3A suggested to us that a student was not comfortable with hypothesis generation, or able to evaluate experimental results. Instead, this student preferred to randomly (not logically) Investigate; i.e., to ask for multiple experiments to be done, whether they were relevant to the problem or not. We call this a "shotgun" approach to problem solving: by asking for every possible test or procedure to be run, a student might, with luck, receive information that will lead to the solution to the problem. Such a student appeared to be unable or unwilling to design a thoughtful experiment-based approach and did not know what to do with acquired data; these tasks had to be done by other members if the group was to be successful. This became a problem when the "shotgun" student was asked to solve a full problem by herself, but had not practiced the other domains when part of the group.

Patterns such as that shown in Figure 3B led us to diagnose a student as a "summarizer." The ability to summarize, which is one aspect of the Reflect domain, is an integral part of a successful problem-solving strategy that is particularly helpful in a group, but not as useful a skill when it is the single tack taken in the solution of a problem. Often, when such a student's postings were read in their proper sequence in the rest of the group's conversation, this evaluation became more definite; we have found that such a student's reflective postings almost always came after several other students' contributions of hypotheses, evaluation of data, and integration of several pieces of information.

Figure 3C shows the domains analysis pattern of an individual student in a very inactive group. The student was forced to solve the puzzle essentially as an individual, because the rest of the students were not contributing (the group performance graph, not shown here, verified this). This student was very methodical, and successful, in applying a problem-solving strategy to the solution of the case: repetitively cycling through identifying a hypothesis; designing experiments to test the hypothesis; evaluating data from the experiment; and then checking the validity of the results by comparing them to the known relevant basic science. This pattern mimics the classic scientific method. It has been a fairly rare individual student pattern in the 4 yr of the study, only occurring when there were few contributions from other members of a group to detract from the single student's problem-solving strategy.

Finally, we have identified a few students who were actually working at an expert level, whose postings spanned several domains at once, making leaps of understanding without using defined steps (Figure 3D). Consistent with the educational literature, we find that "experts" make connections faster than the observer can identify (36).

We have used this type of domains analysis to evaluate students over several semesters of courses that used the online discussions. We have found that most students take cues from feedback of their instructors and peers and become more comfortable in applying all domains of the scientific method. However, there are some who do not learn from their lack of success and who repetitively apply the same single-minded strategies. Figure 4 depicts one such student's attempts, in six different cases, over two semesters.

We cannot do these *post-hoc* evaluations for every student, but we can use the PBL-case transcripts to understand why a particular student is having difficulty with the course exams, and we can then provide targeted help. We as instructors can also use the group transcripts to gauge our own efficacy at getting across the material, and therefore alter our teaching strategies as necessary to address misunderstandings before they become rooted. We have found that we now have an incredibly clear view into how our students think about biochemistry, and problem solving, and the scientific method. We believe that we can therefore act as better guides to them in their learning.

Assessment

Our "promising practice" *is* essentially an assessment, of group and individual problem-solving strategies. It is also a tool that allows incorporation of a problem-solving community into the learning environment, in which students can be introduced to a set of skills with which they have had little experience, so that they can struggle with and practice these skills in low-stakes situations. It allows the instructors to model successful strategies, coach the students as they attempt to apply the problem-solving domains, and then "fade" out of the coaching role as the students become more expert. It is, therefore, an application of a cognitive apprenticeship of problem-solving (41).

The application of the content grading rubric for assessment of individual postings demonstrates a high inter-rater reliability (Figure 1). A statistically significant correlation between student performance in the online problem-solving sessions, and on course examinations, has not been robustly established. In addition, over the 4 yr of the study, our department did not offer concomitant, comparable biochemistry classes without the online PBL cases; therefore, the question of whether the online group discussions improved overall biochemistry learning, as measured by conventional exams, cannot be answered. However, we have seen no significant differences in overall student grades on our standardized final exams in any of the courses that used the PBL online cases, compared to earlier courses that did not use the online cases. It is clear our students have not been harmed in their learning of biochemistry content.

We judge that a comparison between performance on standardized exams, which measure mostly content knowledge, and performance on authentic problem-solving tasks, which measure application of content, is not valid. The assessment tool must reflect the learning experience. We are continuing longitudinal studies with our biochemistry majors to determine whether the consistent use of PBL case discussions throughout a six-course curriculum leads to measurable increases in productive use of problem-solving strategies. For these long-term studies, assessment tools that specifically evaluate the skills practiced in the online discussions have been developed and are being included in each course. (A manuscript is in preparation on the use of this set of tools).

Course evaluations have confirmed that most students appreciate the chance to work in groups and practice their scientific writing skills, and that the PBL-approach has made them aware of a way to solve problems that will be useful to them in real-world scientific situations. We have seen differences in the affective responses to the approach related to the gender, age, and cultural backgrounds of our students in terms of perceived benefit from the use of the PBL cases, and we are attempting to quantify this. Our department has a very high percentage of under-represented minority (URM) students. Incorporation over the past 6 yr of a variety of constructivist teaching modalities (including the PBL cases) into our biochemistry curriculum has resulted in the establishment of what we consider to be a multicontextual learning environment (2). Concurrently we have seen an increase in the graduation rate for our URM students, with no decrease in the average exit examination scores on the American Chemical Society's Biochemistry Exam for the graduating biochemistry majors.

Dissemination

We have made some efforts at dissemination of our strategies (see the List of Presentations after the Figure Legends). Some of the PBL cases have been shared in an informal way with colleagues. Two graduate students at UNM are working on development of new cases as part of their Certificate of Teaching within the UNM-Biomedical Sciences Graduate Program. And, the upper-level undergraduate student participants in a special topics course, Biochemistry Education (who all have had at least one year of experience in using the PBL discussions in their previous courses), are acting as teaching assistants and PBL discussion-graders.

This practice has provided us with an analytical tool to help individual students address their problem-solving strategies, even in large undergraduate classes.

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There has been a lot of work done on the use of technology to deliver educational content, to provide a framework that allows evaluation of higher-level thinking skills, including scientific problem-solving, and to allow large classes or distant populations of students to interact as if they were small groups. Sources for technological advice on "how to do it" include:

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Table 1: Examples of PBL cases and the topics covered in each case. The data provided in the cases could be altered from semester to semester, leading to different final solutions, while utilizing the same general opening presentation. Not all cases were used in all classes.

PBL-Cases	**Biochemistry Topics covered**
Not Frozen Fish	**Characteristics of biomolecules, separation protocols**
John's High Altitude Adventure	**Hemoglobin, allosterism, ligand-binding curves**
Terrorist Attack	**Enzyme mechanisms, kinetics**
Poisons in Paradise	**Membrane transport, signal transduction**
CSI-Albuquerque	**Carbohydrate metabolism**
Million Dollar Baby Yeast	**Electron transport, bioenergetics, carbohydrate metabolism**
Too Late for Julie	**Nitrogen metabolism**
Hike to Snakebite Mountain	**Nucleotide metabolism**
Designer Weed	**Information pathways, Molecular techniques**

Figure legends

Figure 1: Grading rubric for a PBL case. The grading rubric allows the grader to assign a point value describing how close the student's contribution is to the solution of the problem. Grading rubrics are developed by several faculty members and modified over time based on student contributions. This rubric is for the case "CSI-Albuquerque".

Figure 2: Group performance. Sequential individual student contributions within one online discussion group during a PBL case. The order of the contribution is listed on the abscissa, and the ordinate reports the average score for each contribution. Each bar represents an individual student response, graded for scientific content as measured by the grading rubric. The error bars indicate plus or minus one standard deviation in the scores assigned by five different graders. The maroon bars indicate all the contributions made by one particular student in the group; this allows determination of both that individual's performance, and the group performance.

Figure 3: Common individual student patterns in problem-solving. Each panel (A,B,C,D) represents one individual student's sequential contributions to a case discussion. The student contributions were first assigned a numerical score using the content grading rubric; the numerical scores were translated into colors, with lighter shades representing low scores and darker shades representing scores closer to the correct answer. The contributions were also evaluated according to problem-solving domain (Hypothesize, Investigate, Evaluate, Integrate, Reflect, Other). These four individual student patterns have been seen several to many times in the three years of the study.

Figure 4. An individual student's approach to problem-solving over two semesters. The domains analysis patterns for a single student, in six different cases, over two semesters. The patterns are relatively consistent over time, with the student's responses concentrated in the Reflect domain; most contributions by this student were summaries of the contributions of other students.

Dissemination: List of presentations

2005, "Bringing High Context Interactions Into Large Low Context Lecture Classes: Using On-line PBL Tutorials to Promote Student Understanding". Improving Biology Education: Theory and Practice. November 2005, Santa Fe, NM.

2006, "Shifting the Paradigm: Constructing Extended Questions to Evaluate Critical Thinking Skills", Annual WGEA Spring Conference May 2006, Asilomar, CA.

2006, "Using On-line PBL Tutorials to Promote Student Learning With Understanding" Invited talk, June 2006, Simon Fraser University, Vancouver, BC.

2007, "Scholarship of Teaching and Learning" Biology Leadership Conference IV. March 2007, Albuquerque, NM.

2007, "Evaluating Critical Thinking Skills Using On-Line PBL-Cases", Internal Workshop, June 2007, UNM-SOM.

2007, "Cooperative Discussion to Unravel a Puzzle: Using On-Line PBL Cases to Provide Practice in Group Problem Solving"; and "Encouraging the Leap to Doing it Alone: Using Domains-Based Assessment to Develop Individualized Student Profiles," Invited talks, August 2007, James Madison University, Harrisonburg, VA.

2008, "Teaching and Evaluating Problem-Solving Skills: Assessment of Individual Performance" and "Teaching and Evaluating Problem-Solving Skills: Assessment of Performance in a Cooperative Learning Environment". UNM-CAPS Workshop on Teaching and Learning, February 2008, UNM.

2008, "Using Domains-Based Assessment to Develop Individualized Student Profiles" Stemmler Grant Advisory Board Meeting, August 2008, UNM-SOM.