Constructing knowledge in the lecture hall

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If I were not aware of it from my own experiences, even a cursory reading of pedagogical literature would reveal that there are inherent flaws in the lecture/note-taking teaching format. As many have noted, this approach leads to passive learning that results in poor retention of information and does not encourage the flexibility, inquiry skills or higher order thinking that are necessary for handling the increasing scientific knowledge base (Ahern-Rindell, 1999; Crowther, 1999; Lord, 1994). Yet, as concisely stated by Lord (1994), "the present way we teach our discipline to undergraduates simply does not stimulate active learning." Accordingly, numerous articles suggest methods for shifting the focus from teaching to learning. Predominant among the proposed methodologies are those that foster environments that promote constructivism (Ahern-Rindell, 1999; Crowther, 1999; Lord, 1994; Yager, 1991). However, many of the articles that describe constructivist techniques are not applicable to the type of class that I teach; they are either based on laboratory courses, on courses for non-majors, or courses with smaller enrollments (Caprio et al., 1998; Fortner, 1999; Herman, 1999; Hufford, 1991; Martin, 1995). Furthermore, essentially all of these articles focus on changes that are achieved during class time, whereas I wanted to consider another major avenue of change that concerns students outside of class time.

The concept of active learning suggests that it is incumbent upon the student to take an active role in the learning process. Not all active learning has to take place in the classroom, it can also occur through preparation and studying. However, most students do not prepare by studying prior to class and furthermore do not review their notes or the text after class, until an exam is imminent (Lord, 1994). I describe an approach that encourages active participation by students before, during and after class. This approach was adapted to meet the constraints of a large university course that
does not have a laboratory component, that serves as a prerequisite to upper division courses and that is taught to 250 to 350 students in a fixed-seating lecture hall.

Striking a balance among conflicting goals

My first goal was to devise a method that would alter the study habits of my students. I wanted to find a way to encourage them to read before coming to class and to later review the material that we covered during class. A second goal was to create a learning environment that fostered constructivism. I had experimented with constructivist and group learning approaches with my course (Klionsky, 1998) and became convinced of their value. I was not satisfied with using a group learning approach only in discussion sections as described by Malacinski and Zell (1995) or Posner and Markstein (1994) because I found that the quality of the approach depended too much on the skill and commitment of the teaching assistants. In addition, one day a week of group learning was not sufficient for the students to develop the appreciation for, and realize the benefits of, this methodology. Accordingly, I decided to implement a group learning approach in the "lecture" sessions. On the other hand, because my introductory course is a prerequisite for four upper division courses, my goal was to strike a balance between inherently slower group learning and coverage of topics that were pertinent to these other courses.

Altering study habits

To encourage the students to complete the assigned reading for my class, I wanted to minimize the amount of material they had to read. In general, introductory textbooks are lengthy. In addition, students often complain that the texts are too broad and cover too much information so that they are difficult to study from. These texts are better as references than study guides (Caprio et al., 1997;
Musheno and Lawson, 1999). As an alternative to the textbook, I made my lecture notes available to my students prior to class. I included the first two days of notes along with the syllabus handed out on the first day of class. Due to departmental monetary constraints, the students needed to purchase the remaining notes through an on-campus copy service. The notes are condensed relative to the textbook and cover the minimal amount of information I consider necessary. The textbook served as a supplementary source of information. As a result, the students only had to read six to eight pages per session. My notes for approximately 40 "lecture hours" were contained on 62 8.5x11 inch pages running horizontally with each page containing two pages of notes at 75% reduction.

I took two additional steps to assist the students with the reading. First, each topic was preceded by an outline that would help in organizing the material. Second, the syllabus included guideline questions for the entire course. These were generally five to ten simple questions covering the key points from the reading. For example, on the topic of energetics some of the questions I suggested the students should be able to answer were, "What is the starting fuel molecule in glycolysis?", "What is the end product of glycolysis?" and "What is the purpose of fermentation?" All of these points were clearly covered in the reading.

To ensure that students would read even this minimal amount of material, on the first day of class I announced that grades for the course would be based entirely on quizzes, there would be no midterms or final exam. Half of the course grade would be based on reading quizzes that focused on material exclusively derived from my notes. These quizzes would be administered prior to any class discussion so that the reading had to be completed by the time the students arrived for class. The remaining half of the grade would be based on concept quizzes. Material for the concept quizzes was based on problems that the students solved in groups.
Promoting active learning through problem-solving

Class met twice a week for two hours per session. On the first day, I explained the course policies and the rationale behind the problem-solving approach. The students were overjoyed to hear that there were no large exams. This resulted in an immediate and unanticipated reduction in anxiety that was almost palpable. Large one-day exams that typically account for 25% to 50% of the course grade put enormous pressure on students and are not especially conducive to effective learning. I also pointed out that grading would be done on an absolute scale because I wanted to create an atmosphere that fostered interactions and reduced any sense of competition (Kohn, 1992; Malacinski and Zell, 1995). Finally, I made the point that the students would work in groups and that answers would reflect the group's consensus. In this way, I hoped to make the students more willing to share their responses. In addition, by soliciting responses from the entire class I avoided putting pressure on individual students or groups to answer questions. As an additional benefit, by seeing how many groups responded correctly to questions, I had an easy way of measuring the class' comprehension on each topic, a more effective approach than simply asking for questions from individuals. As noted by Silvia and Hom (1996), peer pressure inhibits students from asking questions that interrupt the flow of the class.

The second day of class started with the first reading quiz. I had to ensure that these quizzes were relatively simple and straightforward. The reading quizzes were only meant to demonstrate that the students had done the reading and answered the guideline questions. In addition, I wanted to provide a positive reinforcement for studying. The reading quizzes were designed to be three or four questions taking approximately five minutes to answer. On the topic of energetics, typical quiz questions that were based on the guideline questions from the syllabus were, "What is the main
useful product of the TCA cycle?" and "Name an end-product of fermentation." After the quizzes were collected, I lectured for ten minutes on that day's topics and answered questions. The majority of class time was devoted to problem-solving. I thought it was essential that I set the right tone for group learning, so that the students could see its value right away and gain confidence in the approach. The first subject we were going to cover was carbohydrate structure and function. I make a point of trying to show to my students the relevance of the material we cover in this course. It is clear that students become more engaged when material is presented in the context of their everyday lives (Norton et al., 1997). Rather than starting off immediately with a conceptual problem for our in-class discussion, I took a different approach. I asked each student to list five carbohydrates they routinely encountered. Then I had them exchange the list with a neighbor. This had the advantage of making them interact with another student in a very simple way. I next asked them to raise their hands if their neighbor's list had at least one item that was different from their own. Almost every hand went up. This allowed me to point out one advantage of the group learning approach in that they would be taking advantage of each other's knowledge and understanding. I followed this exercise with specific examples of carbohydrates in our lives, such as lactose intolerance and the reason some milk has Lactobacillus acidophilus for breaking down the lactose into digestible monosaccharides.

Now that the students were warmed up, I put up the first question on the overhead: "If you add glucose to a jar with oil and water and mix the contents, what will happen to the glucose?" I told them to form groups of two to four people and to discuss the question for a few minutes. Because the seats are fixed in my lecture hall, the groups tended to be two or three people sitting next to each other, although I noted students occasionally turning around to confer with those sitting behind them. Somewhat to my surprise, the students had no hesitation engaging in discussions with their
classmates. I attribute this to the fact that they had done the reading and were prepared to discuss the material. I tried to judge when the students had enough time to answer the question based on the level of conversation and their body language. I must point out that I found it difficult to stand at the front of the room patiently while the students discussed the questions. I was tempted to jump in and explain the answer. When I decided that enough time had been permitted for discussion, I asked for group responses. I stressed every time that these were group responses. What I mean is that I would generally say something like, "Raise your hand if your group thinks the answer is that glucose ends up in the water phase. Raise your hand if your group thinks it ends up in the oil phase," etc. After getting the responses from the class, I would go over the answers.

Each subsequent day started with a concept quiz based on the material from the previous problem-solving session. Initially, I administered the concept quiz at the end of the class session immediately following the in-class problem-solving. However, there were several problems with this approach. With the second quiz at the end of the class, it was almost impossible to get the students to continue working after the quiz was over. That is, in the minds of the students, taking a quiz signalled the end of class no matter what time it was. This usually resulted in a loss of several minutes at the end of every session because I had to be sure to allow sufficient time to complete the quiz. In addition students would tend to leave as soon as they finished the quiz, which was disruptive for those completing their quizzes and made collecting quizzes difficult. In contrast, with both quizzes at the start of class, I could continue with problem-solving until the very end of the session. Accordingly, the conceptual quiz was moved to the following day and at the start of each class I administered the concept quiz from the last session's topic.

The problems on the concept quizzes were substantially more difficult than those on the reading quizzes. For example, on the topic of energetics a typical question was, "Describe what happens to
your muscle cells if you exercise strenuously and run out of oxygen.” Administering this quiz in the
following class session allowed students time to study the material and/or seek help from
classmates, the instructor and/or the teaching assistants. I think this modification also helped with
longer term retention because the students were encouraged to review their notes prior to taking the
quiz. Following the concept quiz, I gave the students a couple of minutes to look at their notes and
then administered the reading quiz for that day's topics. The remaining class time was spent with
problem-solving preceded by a few minutes of lecture to highlight important points from the
reading. This format was followed throughout the course.

Assessment of the problem-solving, quiz-based format

Two methods were used to assess the value of the modified learning format. First, I monitored
scores on quizzes in cases where I purposely used the exact same question as in previous years
when I had taught through a lecture format. As seen in figure 1, the students generally performed
better when they had learned the material through the quiz-based approach. There were exceptions
to this trend in particular with material on the topics of DNA replication and transcription as
discussed below. It is also important to note that this method of evaluation may be biased. I placed
a much greater emphasis on problem-solving when using the quiz-based, group learning format.
Accordingly, it is not surprising to see that the students generally performed better on exam
questions when they learned the material through this approach.

Second, student evaluation for the instructor and course using the quiz-based method were
compared to those from the same instructor and course using a lecture format. Students were asked
to separately rate both the instructor and course on a five point scale ranging from "excellent" to
"poor". Figure 2 shows evaluations for the course that I taught through a standard lecture format at
the same time of the year (Fall 1996) to control for seasonal differences in student performance, taught in the same year (Spring 1999) to control for improvements in my own teaching skills and a cumulative response from the course taught seven times from 1992 to spring 1999 based on 1,491 student responses. A comparison is shown when 225 students learned the material through the quiz-based approach in Fall 1999. Two differences are worth noting from these evaluations. First, the students rated both the instructor and course higher when they learned the material through problem-solving. In fact, I received the highest evaluations I have ever gotten in nine years of teaching this course. Second, under the lecture format the students consistently gave the instructor the highest percentage of scores in the "excellent" category while the course material ranked predominantly in the "very good" range. In contrast, when using the quiz-based approach the course now also received a majority of scores in the "excellent" range. That is, student appreciation for the course itself improved substantially relative to when the course was offered in the lecture format. Written student evaluations indicated that the students found the numerous quizzes challenging but beneficial and included comments such as the following:

"The quizzes were so much more helpful in learning the material because we were forced to keep up in class and really understand the material."

"The quizzes…allowed us to see our improvement in the class or where we needed to review."

"Learning material ahead of lecture really helped…"

"The quiz system works! I learned a lot…but most of all I still remember it!"

"Quizzes made me learn the material beforehand and review it after so I learned the material three times, instead of only once."
Concerns with a quiz-based, group learning approach

Motivation: It is clear that my approach advocates the use of a large number of quizzes. I am aware that there is some controversy concerning the use of grading as an extrinsic motivator (Kohn, 1991). However, based on my own experience I have to agree with Slavin (1991) that when students are not self-motivated an extrinsic reward may be helpful. The students in my class have many demands on their time, real or perceived. Few are sufficiently motivated to prepare adequately for this required course. This attitude is frustrating because I think biology is inherently interesting. However, students have told me that without the reading quizzes they simply would not read prior to class. They make a cost-benefit analysis and prepare for other classes that demand their immediate attention. Part of my justification for using frequent quizzes is that I think the positive reinforcement is likely to make students more active learners. If students are prepared, they will have a greater sense of success in the course and are more likely to participate. This encourages a cycle of preparation and active involvement. Conversely, if I do not force them to prepare, I condone a cycle marked by a lack of understanding and a feeling of futility that only serves to drive these students further from having an interest in the subject. Finally, most of my students have not experienced active learning approaches. In general, students who are accustomed to a standard lecture/note-taking format are uncomfortable with the idea of eliminating lectures (Caprio et al., 1998; Orzechowski, 1995). The quiz format provides a level of familiarity that eases this transition.

Time: Handing out and collecting two quizzes per day took approximately 25-30 minutes per two hour session even though each quiz was designed to take five to seven minutes to complete. While this may seem like a large amount of time, it was well worth it. First, there are the benefits of frequent quizzes discussed below. Second, because I could rely on the students being prepared
and could hold them accountable for the material, I did not need to lecture at length. This more than compensated for the time lost in administering quizzes. In addition, the time I did have available was spent in more productive ways such as problem-solving. Having class for two hours per session twice a week instead of one hour four times a week was better because of the added flexibility; problem-solving generally took longer than anticipated and one-hour sessions would have disrupted the flow of the group interactions. The students did not find two hours to be excessive because they were not taking notes for most of the session. However, several students did request a short break half-way through the period and I made this part of our routine.

Balance: I ended up lecturing to my students approximately 20% of total class time. However, some topics lend themselves extremely well to problem-solving and group discussion and others do not. For example, cellular energetics and the lac operon (Klionsky, 1998) seem particularly well-suited for problem-solving. I have also found a way to cover organelle structure and function through group learning (Klionsky and Tomashek, 1999). I thought this approach was less successful with DNA replication, transcription and translation. I think these subjects were sufficiently difficult that the students did not gain a good understanding simply from reading the notes. In addition, I found it difficult to come up with good in-class problems for these topics. In hindsight, the students would have done better with these topics if I had devoted more time to lecture and had them do fewer problems. Striking a balance between lecture and group work is key to a successful approach (Airasian and Walsh, 1997).

Reading: Most of the students appreciated the brevity of my notes. However, some students indicated that they could not understand a topic because it was not explained thoroughly enough in the notes. There is clearly trade-off between detailed and concise reading assignments. At the start of the course, I probably overemphasized the need to read the notes that I provided instead of the
textbook. It would have helped if I pointed out the availability of the assigned text whenever
questions came up in the reading or when we were covering more difficult topics. Alternatively,
modifications to my notes including expansion of some areas could eliminate this problem.

Grading: I was able to have the quiz grading done by graduate teaching assistants and
undergraduate readers. Clearly grading this number of quizzes in a large class is very time
consuming. Without the benefit of student assistance I would have been forced to reduce the total
number of quizzes, reduce quiz length, rely more on multiple-choice questions and/or use midterms
instead of the concept quizzes.

Benefits from quizzes and group learning

Keeping up: Many students came to me during office hours to tell me that the quizzes on the
reading forced them to keep up. Furthermore, they admitted that they normally do not keep up but
felt much better about this class because they actually knew what we were talking about. They
speculated as to how they might benefit from this same approach in their other classes!

Larger participation: Because I required everyone to read prior to coming to class, a greater
proportion of students was able and willing to answer questions. This has the advantage of showing
students that they do know the material and that it can be enjoyable to participate, thus encouraging
further participation.

Learning style: Some students learn better in groups, while others prefer to think about the
material on their own prior to group discussion. By emphasizing both studying outside of class and
in-class problem-solving, this approach provides learning opportunities for both types of student.

Feedback: The frequent quizzes gave daily feedback to the students on how well they were
learning. This stands in sharp contrast to midterms and especially to a final exam. In general,
midterms and final exams do not serve the purpose of being learning aids, but rather they are used solely for assessing what a student has already learned. I was able to see the trend in student responses from the quizzes by visually scanning them before they were even graded. This allowed me to alter my plans for the next day's material prior to the next session. The ability to tailor the coverage of the material to the level of the class that rapidly was a fantastic aid for me and allowed me to move at a pace that fit with the students' needs. Finally, as mentioned earlier, the reading quizzes gave positive daily reinforcement so that if students studied, they did well on the quiz and realized that they were learning. The in-class problems also provided me with immediate feedback. When the students were confused, I was able to make up additional problems or lecture briefly right on the spot rather than waiting to see midterm or even quiz results.

Student and instructor enjoyment: The group learning approach was fun for me as an instructor. I usually get reasonable participation from my students. However, that meant getting five to ten questions from students in a lecture hour. When I asked the class to answer a question that I posed, there were seldom more than one or two responses. There was quite a difference in my sense of how well the students were learning the material when I got 50, 100 or even 200 responses each time I asked a question in the new format. Knowing that the class was clearly following the material proved exhilarating. The use of reading quizzes and increased student preparation also meant that a larger proportion of the class asked challenging questions about the material. My role as the instructor was no longer to convey an existing body of knowledge. As a result, class discussions were more likely to head in unplanned directions. It was incumbent upon me to encourage this type of creative thinking, but to also be prepared to respond to unexpected lines of thought. As noted by Vance et al., (1995) the need to respond to hundreds of students who are thinking about the subject matter can make the class much more exciting. The students also
enjoyed the combined quiz and group learning approach as clearly reflected in their course evaluations.

Conclusion

The approach I have described can be used in large lecture classes so size is not a limitation. It can also be done without relying on computer-based teaching aids, therefore it is extremely low cost. The use of reading quizzes broke the cycle of lack of student preparation coupled with lack of participation. The large number of quizzes provided frequent feedback to the students and instructor so that we could each gauge learning progress. By demanding that students take responsibility for the reading, I could eliminate the need for excessive lecturing. This in turn afforded me the time to demonstrate how to solve problems on a range of material and permitted the class to work on the problems in a group setting. The use of group learning can afford opportunities for improved communication skills, and self-evaluation of comprehension (Malacinski and Zell, 1995). Allowing the students to construct the knowledge to answer the questions I posed should substantially improve their ability to learn the material covered in introductory biology.

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References


Figure 1. Scores on identical problems from midterms administered during lecture-based teaching and from quizzes administered during quiz-based learning formats. The results are presented in pairs where each pair of bars represents the percent of correct answers on a single question from a class where teaching/learning took place through the indicated format. The represented topics are: PS, photosynthesis; MI, mitosis and meiosis; DNAR, DNA replication; TR, transcription; M, mutation; TL, translation; LO, lac operon; RD, recombinant DNA technology.
Figure 2. Comparison of student evaluations of the instructor (A) and the course (B) for introductory biology taught through a lecture format (Fall 1996, Spring 1999 or Cumulative 1992-spring 1999) or when students learned through a problem-solving and quiz-based approach (Fall 1999).