A Student-Centered Approach to Teaching General Biology That Really Works: Lord’s Constructivist Model Put to a TEST

Patricia A. Burrowes

In the comments section of a course evaluation a student once wrote, “I sleep throughout most of my Biology lectures. My professor tries hard but I just get tired of listening to so much information.” This was the end of the spring semester of 1998, and I suddenly realized that I had to change the way I taught! This realization took me a long time, for in the past decade educators have been concerned with the way science is being taught, and several national efforts have been directed to redesign the instruction of pre-college science courses (AAAS, 1993, 1994; NRC, 1996). The main concern was that traditional science teaching has relied primarily on lecturing facts, and frequently requires memorization of long lists of specific vocabulary (Leonard et al., 2001). In general, the results of such teaching have been in lack of student motivation for the sciences, and limited learning reflected on poor content retention, few scientific skills, and inability to apply concepts.

When professors started to examine college instruction, they found that the same traditional teaching model was followed throughout the universities, and identified serious repercussions on the quality of science education acquired by higher level students (Adams & Slater, 1998; Anderson, 1997; Rice, 1996; Yager, 1991). Thomas Lord (1998) questioned why college students demonstrated difficulty when making connections between concepts that they had learned before, or when applying their knowledge to problem-solving situations. He thought that these problems might be a consequence of the traditional way science courses were taught, because the traditional method does not provide time for discussion, or engagement of students on inquiry-based exercises. Subsequently, Lord dramatically modified his method of instruction. Lord’s innovative teaching method is student-centered and uses constructivism, active teaching, and cooperative groups. His method has proven effective in lectures and laboratories for General Biology and Environmental Science at Indiana University of Pennsylvania (Lord, 1997, 1998, 1999). Because I was impressed with the positive results of Lord’s teaching techniques, and the potential application of his methods to large and small

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classes, I decided to test his model in my large lecture sections (100 students) of General Biology. This paper describes the results of a controlled experiment that tested the effectiveness of Lord's teaching model in:

1. Helping students achieve better grades on standard midterm exams.
2. Develop higher level thinking skills.
3. Modify their attitude towards biology at a large, urban university.

The objectives are to provide further evidence in favor of constructivist teaching over the traditional model, and to motivate fellow university professors to accept this challenge and move towards a more student-centered method of instruction.

Experimental Design

During the fall semester of 1999, I taught two large sections of General Biology I (cellular and molecular biology). One section was arbitrarily designated my control group (100 students) and was taught in the traditional manner, where instruction was based on lecturing, with little opportunity for student interaction. The other section was designated the experimental group (104 students) and taught following Lord's (1998) constructivist method (see Figure 1). Both sections met in the same large amphitheater with concentric rows of seats staggered progressively higher than the chalkboard and projection screen, which were located at the bottom and center of the room. The meeting times were equally bad for both sections of the course; the control group met Tuesdays and Thursdays from 11:30am–1:00pm (when students were starving for lunch), whereas the experimental group met Mondays and Wednesdays from 1:00pm–2:30pm (when students were sleepy from lunch). The amount of content-covered, as well as the order it was discussed, was the same in both traditional and experimental sections

Furthermore, to ensure that the amount of content was not a confounded variable in this experiment, I followed the same syllabus that had been used for the instruction of this course at our institution in previous years.

Teaching Strategies

"Traditional teaching" was limited to my control group where a teacher-centered environment prevailed, and course instruction emphasized content recitation, without allowing time for students to reflect upon the material presented, relate it to previous knowledge, or apply it to real life situations (Figure 1). However, natural personality attributes, such as my inborn enthusiasm for biology and tendency to modify the volume and pitch of my voice depending on the topic I am discussing, were not excluded.

"Experimental teaching" was based on the Constructivist Learning Model as described by Yager (1991), the "5E" (Engage, Explore, Explain, Elaborate, Evaluate) model developed by Bybee (1993), and cooperative learning, as modified and applied by Lord (1998, 1999, 2001). Instruction consisted of a series of short (10 to 15 minutes) lectures in which I introduced new material (Engage), followed by the formulation of a problem or exercise (Explore). Depending on the task involved or the degree of difficulty, students were given 2 to 10 minutes to solve these problems with the members of their cooperative group (Figure 2). This provided an opportunity for interaction with other classmates as they tried to make sense of the new information relevant to past experiences or previous knowledge. Their consensus answers were written on a sheet that was turned in at the end of the class period (Explain). When the designated time to work on a problem ended, I called on 2 or 3 groups to present their answers to the rest of the class. Then, I proceeded to the Elaborate phase in which I either addressed misconceptions evidenced by student responses, or proceeded to tie the discussion to the introduction of new material. Listening to student responses to biological problems right after new content had been introduced provided immediate feedback on how effective my teaching was. In that sense, I had the opportunity to Evaluate several times within a class period. This cycle was repeated 3–5 times during each lecture period, and represented a slight variation from Lord's (1998) bookshelf approach to the "5E" model. A final Evaluation occurred at the end of the class period when I received group answers to all...
the questions posed in class, and I offered a quiz related to the material that was discussed and worked on that day.

**Organization**

Pre-class planning and organization were key factors to the success of this experiment. Keeping cooperative groups throughout the semester, and being able to identify each student within a group with a color code were essential factors. On the first day of class, I used Lord's

4. One Quiz sheet (see Figures 3–5).

The Cooperative Group Composition sheet (Figure 3) was used to make an immediate class roster organized by groups, which made grade recording much easier than using the alphabetically ordered lists provided by the Registrar office. Color assignments are related to the assessment procedure. Following Lord (1998), ten minutes prior to the termination of each class period, students were informed that it was time for a quiz. A wave of suspense took over the class. From a cloth bag I drew one of four colored balls (yellow, blue, green or red); the color drawn indicated the quiz-takers for that day. With the exception of the quiz-takers, all students (~75%) were excused from the room, leaving me with only 25 quizzes to grade after every class. The scores attained by the quiz-takers were given to all members of the cooperative group that attended class that day.

The Student Profile sheet (Figure 4) was completed by all students on a voluntary basis. It was designed as a data gathering instrument to test homogeneity among groups. Analysis of these data revealed that control and experimental groups were not significantly different with respect to age, sex, urban or rural origin, faculty, private or public high school education,

(1994) syllabus numbering to corresponding seat technique to establish formal cooperative groups in the experimental section. Groups were formed by four students seated next to each other in a row (Figure 2). After all cooperative groups were established, members were encouraged to meet one another and exchange e-mail addresses or phone numbers. Later, each group received a legal-size manila envelope that contained important information:

1. One Cooperative Group Composition sheet
2. Four Student Profiles sheets
3. One Group Answers to Class Work sheet

![Image](image-url)
or high school grade point average (G.P.A.) and thus, were comparable. If one group had been heavily biased in any of the attributes measured (for example, 80% male in one section, versus 20% in the other), one could argue that observed differences in student academic performance among groups were due to sex composition, and not to the teaching strategy.

The forms entitled Group Answers to Class Work and Quiz sheet were distributed in the envelopes not only the first day of class, but every day thereafter (Figure 5). These forms provided a means for students to show their answers to a variety of questions and problems formulated in class, and to resolve the quiz given at the end of the period. A thoroughly worked-out Group Answers to Class Work sheet was worth one point for all group members who attended class that day. This was Lord's (1998) way of rewarding students for coming to class, and it worked very well. To avoid falling behind in my record keeping, I made sure that all papers were graded and corresponding scores put into a computerized roster immediately after class. This process took approximately one hour.

Two college seniors majoring in biology education contributed to the success of this project. They served as teaching assistants and attended all my classes. During the experimental section, they joined me in walking around the large amphitheater, lending help and support to cooperative groups. In addition, they participated in the design of questions and exercises for class discussion. In the control section they helped prepare, distribute, and grade quizzes, and served as unbiased critics to help me conform to "traditional" instruction methods. As the teaching assistants helped me pursue this project, they learned about the teaching strategies and action research methods.

**Evaluation**

In both the control and experimental sections, students could earn up to 400 points (perfect 100% grade) throughout the semester. However, the distribution of points for in-class work, quizzes, exams, and laboratory work varied slightly among control and experimental groups (Figure 6). In-class assessment for the control (i.e., traditional) group was based on eight 10-point pop-quizzes which all students were required to take. Students who were always present when a quiz was given were more likely to attain the 60 maximum quiz points considered for grade computation, and could earn up to 5 more points as a bonus. In this manner, control students were encouraged to attend class every day. When students in the experimental group attended class for more than 20 periods, they were rewarded by the opportunity to accumulate up to 5 extra points via daily Group Answers to Class Work sheets. I wrote my own midterm exams (not those of a departmental committee), in multiple choice fashion. Exams consisted of approximately 50% content recall and 50% conceptual understanding/application questions. For comparative purposes, the same tests were administered to both experimental and control groups on the same nights during the semester. Additionally, all students took the same comprehensive, departmental final exam during the last week of the semester. This was a concession to

continued on page 496
the department, to assure other faculty members that I was going to cover all the content material usually taught in this course.

**Academic Achievement Results**

Exams were taken on computer sheets and graded electronically. Grades achieved by students in experimental (constructivist teaching) and control (traditional teaching) groups were contrasted graphically (Figure 7) and the mean test scores were compared statistically by students’ T-tests using Minitab 12 software. The first partial exam was offered after six weeks of instruction and included content on the cell as the functional unit of life (atoms, molecules, the cell membrane, organelles, energy transformations, cellular respiration, and photosynthesis). Although average scores of students in the experimental group were significantly better than in the control group ($X = 65\%$ versus $58\%$, $T = 2.65$, $P = 0.004$, $n = 204$), and they attained more As and Bs, and fewer Fs, the differences are not as impressive as later in the semester (Figure 7). The second exam was given 12 weeks into the semester, and evaluated knowledge on the continuity of life (mitosis, meiosis, DNA structure and replication, protein synthesis, and inheritance). Results of this exam showed grade improvement in both groups (Figure 7); however, the mean score of students in the experimental group was significantly higher than that of students in the control section ($X = 72\%$ versus $67\%$, $T = 2.41$, $P = 0.009$, $n = 192$). The outcome of the third exam (evolution and origin of life) was striking because performance of students in the experimental group approximated an ideal normal distribution of grades (Figure 7). Although students’ achievement in the control group improved, students in the experimental section still did significantly better ($X = 74\%$ versus $68\%$, $T = 3.05$, $P = 0.001$, $n = 190$). For the final exam, it is common policy at our institution to excuse students who by the end of the semester have attained an ‘A’ average in the course. As a consequence, when comparing final exam grades between experimental and control groups (Figure 8), the best students were not considered. Mean final exam grades were not significantly different between sections ($X = 67\%$ versus $64\%$, $T = 1.29$, $P = 0.20$, $n = 172$); however, more students earned As and Bs in the experimental group than in the control. Thus, it is clear that students instructed in a constructivist, active-learning
environment were able to perform better on the same tests than students taught in a traditional fashion. The drop in grades in the comprehensive final exam is a typical phenomenon that I have observed for several years. It may be related to pressure from other finals, lack of ability to deal with large content material, attention drifting to vacation activities, or simply exhaustion.

Conceptual Understanding Results

To train students to become scientists, we must provide opportunities to participate in all aspects of the scientific method. By participating in the scientific process, students learn to think scientifically (Marbach-Ad & Claassen, 2001). One of the benefits of Lord’s (1998) constructivist model is that it offers students many chances to develop higher-order thinking skills through a variety of in-class exercises—the idea is that practice makes excellence. I refer to higher-order thinking skills here as the ability to think critically, make reasoned judgements about complex issues or data, and apply concepts to resolve problems or investigate questions. Examples of exercises that help develop these skills are multi-answer questions, concept maps, discussion scenarios, graph interpretation, graphing of data, drawing conclusions, solving problems, etc. Concrete examples of some of these activities for biology are listed in Appendix 1, but more can be found in Lord (1998) and Burrowes and Nuzario (2001). Other curriculum models have been developed to improve thinking skills among college students (Crow, 1989; Lawson, 1992, 1999; Pheneey, 1997), and recent literature provides examples of how to reform laboratories to an inquiry-based format allowing students to learn science by inquiry (Marbach-Ad & Claassen, 2001; Sundberg et al., 2000). Having provided such an environment in the experimental section
only (Figure 1), I hypothesized that these students should do better than control-group students on exam questions that addressed higher-order thinking skills. To test this hypothesis I selected 21 questions (seven from each of the three midterm exams) that required interpretation of graphs or data, application of concepts to solve problems, establishing connections among related topics, or the ability to make inferences from given facts. When the answers to these questions were compared among experimental and control group students, a significantly greater number of experimental group students provided the correct answer \( (T = 3.79, \ p = 0.001, \ n = 21) \), suggesting that, indeed, in-class practice of problem-solving techniques does help to develop skills for scientific thinking.

**Attitude Assessment**

An identical course evaluation that included questions related to students' interest towards biology, impression of the classroom setting, and the professor's work was given to control and experimental sections after the first midterm exam, and again during the last day of class. The objective was threefold:

1. To obtain preliminary information on how students felt about the class and my teaching.
2. To determine if I was being fair to both groups.
3. To record if and how students' opinions changed by the end of the course.

Results from the pre-evaluation helped identify problems before it was too late to solve them. Some students in the experimental group commented that not all group members participated actively or did equally well on the quizzes, so I took the time to give them a brief "pep-talk" on real cooperative work. Others mentioned that I spoke too fast, and still others complained about not having enough time to solve some of the problems given in class. All these issues were attended to immediately. Another asset of the pre-evaluation was that it revealed that students from both groups rated highly my performance as a teacher. This implied that students in the experimental section liked the change, and that control-section students felt comfortable with my "traditional" instruction. Once I had the results of the post-evaluation, I compared students' response to the question, "How would you rate your interest in biology—high, medium or low?" At the beginning of the semester, the majority of the students answered "medium" to this question, and responses were independent from experimental vs. control sections. At the end of the semester, there were differences in attitude toward biology that could be significantly associated with groups \( (X^2 = 6.52, \ p = 0.04, \ df = 2) \); more students in the experimental group (70% vs. 50%) expressed that their interest in biology was high. This kind of change in perception suggests that a student-centered, active learning environment was more effective at motivating students to become interested in biology than a teacher-centered, passive approach.

There were other interactions that took place during the semester that revealed a more assertive, intellectual, and competent attitude when discussing science among students from the experimental group. For example, the day after every midterm exam, I brought copies of the test to class and distributed one copy to every cooperative group in the experimental section, and one copy to every four students that happened to sit together that day in the control section. Working in groups, students had the opportunity to solve the test for a second time, but with only half the time provided during the original exam. If they were able to obtain a perfect score, each student from that group would receive 3 bonus points (to be added to the score obtained on the test); those who scored 95-99% could add 2 points to their original test, and those who scored 90-94% could add 1 extra point. More groups obtained bonus points in the experimental section than in the control section of each of the three exams (Exam I: 5 vs. 1; Exam II: 8 vs. 3; and Exam III: 10 vs.
In addition, the discussion that took place within groups was more lively and led students to challenge the way questions were written or the possibility of alternate answers much more frequently in the experimental section than in the control. This attitude difference can be explained by the fact that in the constructivist-active learning environment, the groups were established at the beginning of the semester and students had been given many opportunities to discuss and interact in a cooperative fashion. On the other hand, students taught in a teacher-centered traditional manner did not necessarily know their neighboring classmates and were not accustomed to discussing biology in a group (Figure 1).

Frequently Asked Questions

I have had the chance to listen to Tom Lord present talks on his constructivist teaching strategy to biology scholars on three occasions, and I have twice presented a seminar on my own work to colleagues. As I have heard people ask the same questions every time, I decided to include a "Frequently Asked Questions" (FAQ) section. Hopefully, I will be able to address some of the general concerns about problems that may arise when using this technique, and how to go about solving them.

1. How do you manage the time allocated to problem solving in class so that it does not get out of hand?

I use a stop watch with a loud bell (such as those used to keep baking times in the kitchen). Once I have told the students how much time they have for a particular exercise, I set the stop watch and when the bell rings, I immediately move on to the discussion.

2. Did you fall behind on content coverage in your experimental section with respect to the control group?

No, not even for the first exam when I was still inexperienced. This teaching approach does not require more class time, it just cuts from the time the teacher is speaking, and gives it to the students to question, discover, and learn on their own.

3. What happens if the student who is supposed to take the quiz (according to the colored-ball that was drawn) is absent that day?

I draw another ball, and another if necessary, until all groups have a quiz-taker present.

4. What do you do with a group that is upset because it has a particular quiz-taker who always flunks the quiz?

- CATLAB
- KANGASAUROUS-TRANSMISSION GENETICS
- POPULATION STUDIES
- NATURAL SELECTION
- KARYOTYPES AND GENETIC DISORDERS
- ENZYMES
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STUDENT-CENTERED APPROACH 499
First, I remind the unhappy students that they have a legitimate problem and that they should try to solve it by talking to the culprit themselves. If that does not work, I will intervene. This problem has never gone beyond a private chat between me and a student about responsibility and obligation to his/her group.

5. How did the number of students dropping out of the course compare between experimental and control groups?

Four experimental-group students dropped the course after the first exam, whereas 12 students dropped out of the control section at different times during the semester.

6. How did the number of students excluded from the final exam for having an A average in the course compare between experimental and control groups?

As expected from the partial exam results, more students from the experimental group (12) were excused from the final exam than from the control group (4).

Conclusions & Implications

This study provides substantiated evidence that teaching in a constructivist, active learning environment is more effective than traditional instruction in promoting academic achievement, increasing conceptual understanding, developing higher level thinking skills, and enhancing students interest in biology. In their final course evaluations, students in the experimental section commented that they enjoyed this class much more than their traditional classes, felt they had learned more, made valuable friendships in their collaborative groups and—particularly important to me—they never fell asleep! Thus, I am convinced that constructivism works better for our generation of students, and I will never return to a traditional style of teaching. Although the constructivist method of instruction requires a greater investment of time and effort from the professor for preparation, organization, and grading, the majority of this investment is made in the first semester of teaching. During subsequent semesters, effort/payback increases dramatically, as less time is required. For example, with experience, I have become more efficient at formulating questions and coming up with ideas for problems, scenarios, and case studies, which help students develop their own knowledge of the material. Additionally, help from trained teaching assistants in grading, book-keeping, and organizational tasks associated with instruction can reduce some of the workload required of the instructor. Suggestions to help professors and students make the transition from a teacher-centered to a student-centered learning environment, where pupils assume responsibility for their education, are available in the literature (Lord, 1998; Modell, 1996). In most cases, I recommend this change to be an on-going process in which professors experiment and evaluate techniques to find one that makes them most comfortable. As a result, educators will engage in active research—a tool to learn about the effectiveness of our teaching and how our particular population of students learn best. I have been applying this constructivist, student-centered teaching method in my Biology and Zoology classes for the past four semesters, and I am happier as a professor, not only because I enjoy my teaching experience much more, but also because the overall results of empowerment among my students is overwhelming.

Acknowledgments

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References


Appendix I. Examples of exercises that can be given to student groups to work in class. Approximate time to be allocated is in parenthesis.

**Concept maps.** After discussing evolution, ask students to draw a concept map to connect the following terms: evolution, gene bank, variability, natural selection, mutations, recombination, gene flow, selection pressures, genetic drift, and reproductive potential. Every term should be connected with arrows labeled with a word that describes the link between the processes — example: change, causes, provides, directs, etc. (15 minutes)

**Scenarios.** When you are discussing homeostasis, tell the students that you just received a VIP letter asking for help from your students in solving a problem of unknown purpose that concerns "National Security." The students are now part of a multi-disciplinary team put together to design "the perfect animal" that can survive and reproduce successfully under the following conditions: an environment that is very hot and dry during the day, but turns cold and windy at night, and that has many fast and aggressive predators. In their design of this animal, they should consider integument, body support, reproductive strategy, excretion and mode of locomotion. (15 minutes)

**Graphs.** After studying animal circulation, ask students to draw a graph showing the relationship between blood pressure (mmHg) or velocity of flow, and the diameter of blood vessels. Depending on your group of students, you may want to provide some additional instructions like how to set the axis, and then give them the freedom to do a projection, curve or bar diagram. (5 minutes)

**Brainstorming.** When reviewing thermoregulation, ask students to come up with five ways in which snakes can prevent overheating on a hot summer day. (3 minutes)

**Observations/Predictions.** When you are about to explain the cell membrane models, show an illustration of the fluid mosaic model and ask students to make a list of six observations. If they do not recognize a particular structure, they can describe it using terms like "blob," "cylinder," or "ball." (3 minutes)

When you discuss the fluid mosaic model with the students, they have already spent time studying its structure and will be more receptive to learn the proper names of the molecules and their function. Then, ask students to predict what would happen to the permeability of the cell membrane if the proteins were removed. (5 minutes)

**Problems.** This problem was designed to help students understand the difference between passive and active transport. A famous musician (make it relevant — I used Ricky Martin) is giving a concert in town. People are camping out to purchase tickets the night before the ticket counter is to open. There is a single, very long line to purchase tickets until, suddenly, a second window opens for sales. Predict:

1. What will happen?
2. What will happen if one of the two lines gets a little longer than the other?
3. What will you need to do to get people to move from a shorter to a longer line? (5 minutes)

**Data to graph.** On enzyme action. Mothers complained that their children would not eat the fresh apple wedges they sent to school in lunch boxes because they turned "brown and disgusting." Discuss with your students what causes the change of color in apples when they are exposed to air. The following data were collected during an experiment. Graph the data, interpret the results of the experiment, and make concluding remarks regarding the best way to pack fresh apple wedges in students' lunch boxes. The results of graphing these data will set the basis for a follow-up discussion on enzyme optimal and saturation levels. (15 minutes)

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<tr>
<th>Time (minutes)</th>
<th>Color of apple: normal = 1, to very brown and disgusting = 5</th>
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<tr>
<td>0</td>
<td>Wedges alone = 1</td>
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<td>5</td>
<td>Wedges in lime juice = 1</td>
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5    2    1    1
10   3    1    1
15   4    1    2
20   5    1    2
25   5    1    2
30   5    1    3