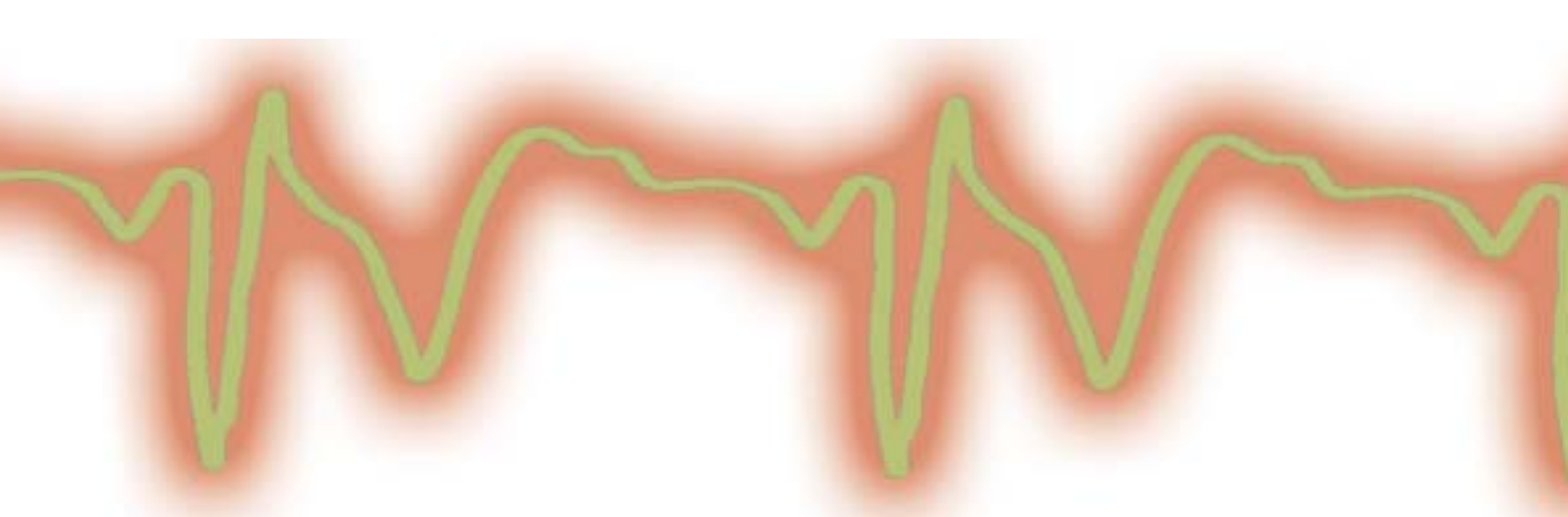


Exercise in Inquiry

Critical Thinking in an Inquiry-Based Exercise Physiology Laboratory Course

Students expressed strong positive feelings about inquiry-based teaching methods we developed and implemented in an undergraduate exercise physiology laboratory course. Inquiry-based learning resulted in a higher order of learning not typically observed with traditional-style classes. This teaching method provides students with the skills to be independent problem solvers and critical thinkers.

Dana M. DiPasquale, Cheryl L. Mason, and Fred W. Kolkhorst



When considering the great minds of science, we never think of the facts they knew. Instead, we are amazed by the insightful questions they posed and by the methods they used to answer them. Not only were these individuals students of science but they were also students of inquiry. As a result, they acquired analytical and critical thinking skills, which made it possible for them to become independent learners.

Although inquiry-based learning gained momentum in the 1970s, the approach was not embraced by mainstream college and university professors. Today, however, as inquiry becomes more central to the teaching of science at the precollege level, university faculty are realizing that they too should consider changing the traditional format of their teaching approach.

After seeing the frustration and lack of enthusiasm of students in our undergraduate exercise physiology laboratories, we restructured our teaching method and developed an inquiry-based atmosphere that nurtured critical thinking. Inquiry-based learning occurs when students seek information by questioning and, in doing so, construct new knowledge and resolve issues. Students are involved in the discovery as well as the

process leading up to the discovery. It is this involvement that results in understanding and the development of critical thinking and problem solving skills (NRC 2000).

In today's world, in which information is readily available and constantly changing, the memorization of facts is not the most necessary ability. Instead, students need skills to make sense of all the information (Sprenger 1999). Inquiry-based learning can teach students analytical and critical thinking skills. Analytical thinking allows students to determine trends in data and similarities or differences among variables. Critical thinking, however, occurs when a student is able to determine the reason for change in one variable and how this change affects other variables. By using critical thinking, students can integrate information from various sources to explain events as well as predict outcomes.

Working in small groups, students can collaboratively make decisions to develop these skills. Participation in small group learning usually includes the negotiation of ideas. Consequently, students have a forum in which to improve analytical and critical thinking skills. These skills can aid students in the classroom and, more importantly, throughout life.

Traditional classes are typically teacher oriented, with the teacher dis-

persing information to students. The focus is usually on what is known, and there is often only one correct answer to questions posed by the instructor (Lawson, Rissing, and Faeth 1990). This approach is further evident in widely used multiple-choice exams that do not allow students to express ideas or thoughts or ask questions.

In traditional-style undergraduate laboratory classes, students frequently follow step-by-step instructions to complete an experiment (Janners 1988). Students generally concentrate on the completion of individual steps and do not have a comprehensive understanding of the experiment or procedures. As a result, students characteristically write "textbook answers" by describing what might have happened in an ideal situation rather than analyzing patterns or inconsistencies in their own data. Furthermore, they see the scientific process as steps toward completing a lab report rather than as a method for solving a problem or answering a question. In cookbook-style labs, students tend to mechanically conduct experiments and/or rote memorize facts. The focus becomes accomplishing each step of the procedure and including all of the required information in the lab report instead of applying knowledge to real-life situations.

Conversely, inquiry-based classes are student-centered. The instructor shifts roles from dispensing information to facilitating learning (Arons 1980). Instead of just presenting facts, professors who teach in this manner show students how they come to know the facts. More importantly,

Dana M. DiPasquale (e-mail: DanaDiPasquale@aol.com) is a graduate assistant in the Department of Exercise and Nutritional Sciences, Cheryl L. Mason (e-mail: cmason@mail.sdsu.edu) is a professor in the Department of Biology and School of Teacher Education, and Fred W. Kolkhorst (e-mail: fred.kolkhorst@sdsu.edu) is an associate professor in the Department of Exercise and Nutritional Sciences, all at San Diego State University, San Diego, CA 92182-7251.



the student is the one to discover these lessons. In inquiry-based classes students construct their knowledge and understand through active involvement. Inquiry classrooms are open systems that have a general plan but are directed by student questions.

Because most students have grown up with traditional-style teaching methods, they often ask questions they could solve on their own. With inquiry-oriented teaching, students are gradually weaned from asking teachers to provide answers and instead are encouraged to answer their own questions.

In inquiry classes, student questions are often answered with “What do you think that means?” or “How could we investigate that?” Furthermore, in inquiry-based classes, students are not discouraged from making mistakes as long as they can offer an explanation of the error and its implications. Once students have learned basic concepts, they can draw on this pool, integrate ideas, and become independent thinkers—if we allow them.

Inquiry-Based Learning Model

To provide students an environment in which they can take more control of their own learning, we applied inquiry-based teaching methods to an undergraduate exercise physiology lab course consisting of approximately 120 third- and fourth-year exercise and nutritional sciences students. The course was previously taught in a traditional style and had been offered in the inquiry-based style for four semesters. Four graduate students and one faculty member taught 10 sections of the course each semester. The same instructors taught the traditional-style course and the inquiry-based course. A more com-

plete description of the evolution of the model is described in an earlier publication (Kolkhorst et al. 2001).

During the first third of the course students participated in five labs covering core exercise physiology topics, such as the effects of exercise on motor unit recruitment, volume of oxygen consumption, respiratory exchange ratio, blood lactate concentration, heart rate and blood pressure, and body composition measurements. Emphasis on defining the scientific process began in the first week of the course and continued as a recurrent theme throughout the remainder of the course. Teaching began as semi-

Several students said that this course sparked an interest in exercise physiology, scientific research, and even a graduate degree in the field.

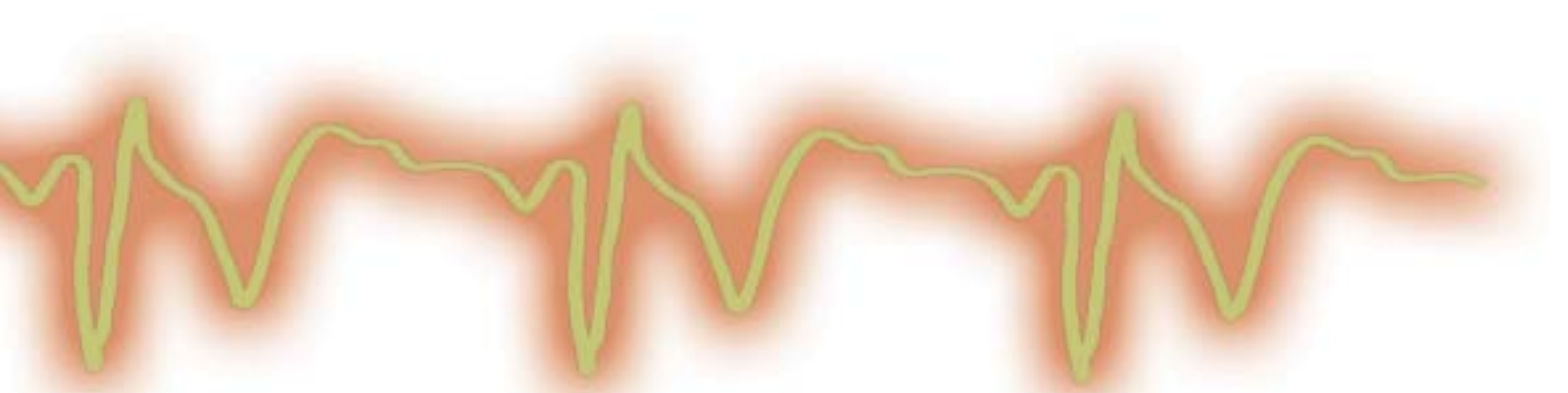


guided and gradually became completely inquiry-based.

Each week, instructors reduced the amount of information provided and increasingly rephrased student questions to encourage group discussion on how a problem should be solved (Kolkhorst et al. 2001). During the last nine weeks of the semester, students worked in small groups of three or four students and completed two independent research projects. During the first week of each project, students, in consultation with the instructor, developed a focused research question, hypothesis, and experimental design. During the next two to three weeks, students collected data while the instructor was available to help with problems. At the conclusion of each project, students analyzed their own data and submitted a five- or six-page group paper. They also gave a 10- to 15-minute oral presentation on their findings followed by a brief question-and-answer period.

Student performance was evaluated in three areas: four laboratory reports (80 points), 10 quizzes (75 points), and two research projects (150 points). One-page typed reports were required after each of the four core laboratory activities at the beginning of the semester. Quizzes had either one or two short-answer questions (5 points per question). Each quiz had one open-ended question designed to promote greater reflection on laboratory-related topics.

Two examples of these questions are: (1) Discuss the role of analytical and critical thinking skills in an exercise physiology experiment; and (2) How does control in an experimental design contribute to acquisition of knowledge? The five quizzes with a second question in-



cluded a question on the pre-laboratory reading assignment. This differed from the traditional-style course in which grading criteria included more lab reports and quizzes solely based on information learned from lab activities.

Student Evaluation

The effectiveness of a teaching strategy should encompass aspects that are not easily quantifiable yet provide invaluable information. Some of this information can be obtained through student observations, comments, and interviews. At the end of the semester, 10 students discussed the effect this laboratory course had on their understanding—not knowledge—of exercise physiology or science in general. This topic was asked on the next-to-last week of the semester as an open-ended quiz question. Students had approximately 10 minutes to complete the assignment and were graded on their ability to defend their opinion. Based on their comments, the inquiry-based learning model is an effective approach to developing students' cognitive skills in exercise physiology.

Students expressed strong positive feelings about the course. This was largely the result of the tremendous ownership that students felt toward their group projects as well as the occasion to collaborate with others. Students articulated an appreciation for the opportunity to study topics of particular interest to them. They also valued the independence afforded them to make their own scientific observations and conclusions. Furthermore, students felt capable and confident that they could design appropriate experiments to challenge existing theories. Many mentioned

they had fun and enjoyed the class, and others valued the research experience, noting that it inspired them to continue studying at a more advanced level.

After designing and performing their own experiments, students not only understood the job of an exercise physiologist (many for the first time) but also expressed a respect and appreciation for the hard work and dedication of researchers. Remarkably, several students said that this course sparked an interest in exercise physiology, scientific research, and even a graduate degree in the field. At the end of the course, students said they felt less intimidated about exploring new topics. As one student commented, "It has opened my mind to take risks, ask questions, and test the possibilities of the unknown."

Because this course forced students to use not only their hands but also their minds, it strengthened the understanding of exercise physiology concepts and generated new ideas. "The light bulb has been switched on," said one student. Students were able to see and actually put into practice information presented in textbooks and lectures. Following experiments, students recognized the complexity and integration of the biological systems; in traditional-style lab courses, however, students learn about systems as distinct units.

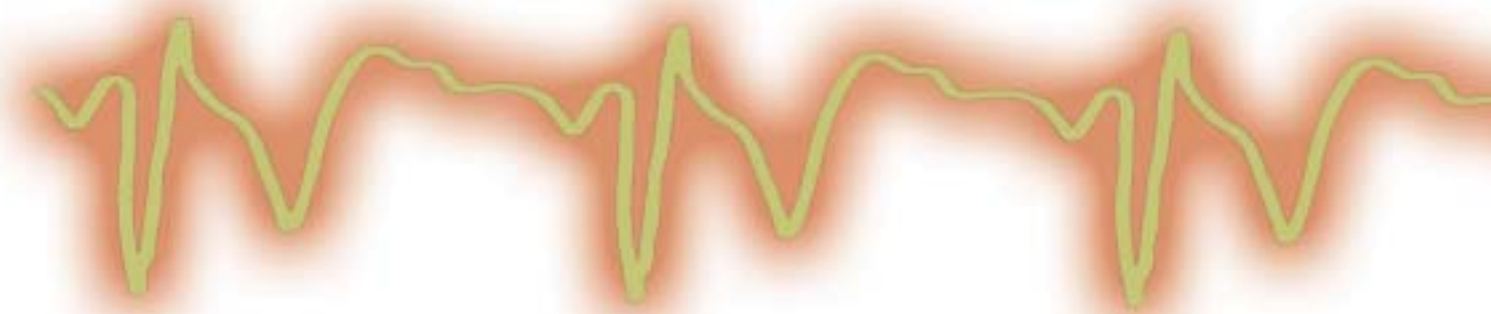
Two students noted, "This lab put everything together for me," and "The concepts that were discussed (in lecture) now make sense to me." The course also helped students understand concepts learned in other courses. While integrating information from other classes and sources, students felt this course gave them

the guidance to expand on what they already knew but with more detail. One student commented that he learned more than he ever could from a lecture class.

As a result of their experiences with research, students learned that the scientific process was a way of thinking and was more in-depth than they had presumed. They concluded that the scientific process was a series of logical steps taken to answer a research question rather than just a set of rules to be followed for a lab report. As one student expressed, "The scientific process is put to use in every question asked."

The most common theme in their comments was summarized well by one student who used the term "active learning." The consensus was that students were forced to think critically. They mentioned that they had to come up with answers to problems by thinking beyond already-known facts. They had to think about the experiment, controls, hypotheses, and conclusions from every angle. As one student said about inquiry-based learning, "The 'question-asking method' used by the teacher was helpful because we were constantly encouraged to think for ourselves and link knowledge together."

Because students were actively learning by thinking critically instead of learning passively by memorizing facts, they concluded that the course allowed them to figure out and understand "the why." Students realized that there are higher orders of knowledge they hadn't considered before. One student stated, "I understand the breakdown of processes more. It is no longer X equals Y , but more what it takes and what is involved in mak-



ing X equal Y . I am better able to understand how or why things occur, react, and impact a situation. I can state facts with confidence and see how everything ties together if asked a broader question or asked to elaborate.”

Another student agreed, “The labs and projects we did forced us to discuss why a given metabolic response is present and why it occurred. By understanding this I am able to apply theory to other topics. The presentations required us to discuss our experiment, and to do that I must understand what the knowledge means and how to interpret it. By designing experiments, the course guides you and helps/forces you to interpret data and understand it relative to other topics, whereas other courses make you memorize facts and demonstrate pure knowledge, not provide any background understanding of why something is the way it is.”

The comments from students were overwhelmingly positive. Of the 77 responses, only one student felt that the lecture course had a greater effect on her understanding of exercise physiology concepts than the laboratory course. However, she agreed with other students that the laboratory course helped to develop her ability to use technology and design experiments. The goal of inquiry-based learning is to provide an atmosphere in which students can make discoveries for themselves without being limited by an instructor’s expectations. In this environment, students better understood laboratory concepts, thought more independently, and were ex-

The goal of inquiry-based learning is to provide an atmosphere in which students can make discoveries for themselves without being limited by an instructor’s expectations.

cited about learning. As one stated, students came to believe that this course “allowed them to think more like a science major.”

Instructor Evaluation

Based on interviews and journals, instructors agreed with the student opinion. Course instructors believed that four elements of student learning were distinctly superior after three semesters of using the inquiry-based learning model than after the same laboratory course previously taught in the traditional style. These elements were: increased independent thinking, improved integration of information, looking at the larger picture, and students answering their own questions.

Students were thinking more independently than during traditional-style labs and accepted the increased responsibility of being self-sufficient. For example, a group of students decided to examine the effects of various abdominal exercises on motor unit recruitment via electromyography (EMG). When the first subject was tested, the EMG displayed what appeared to be one continuous muscle contraction instead of displaying several contractions as the students expected.

Whereas in the traditional-style class, students would have likely called on the instructor for help or failed to even notice the problem, these students instead located and solved the problem on their own.

Another group of students studied the perception of effort while running uphill

and downhill at the same relative workload. They recognized that because of the subjective design of the rating scale, the results might be contaminated if they participated as subjects. These examples demonstrate that students developed skills necessary to critically analyze situations and potential outcomes.

Additionally, based on lab reports and conversations with students, we observed that students more readily integrated information from other courses, as well as information learned in this course, than students who were taught in the traditional style. Early in the course, instructors prompted students to think of information they already knew about a topic when solving a problem. In this manner, students recognized the step-by-step process necessary to critically analyze situations. As the course progressed, instructors offered less information, and in doing so, placed greater responsibility on the student. Instructors agreed that students learned to take information from many sources, combine it, and form new ideas.

For example, a group of students examined the effects of environmental temperature on metabolism during exercise. They hypothesized that



a hot environment would result in increased skin blood flow for heat dissipation. The redistribution of blood flow to the periphery would result in less blood flow available for the working muscles. As a result, less oxygen would be consumed for aerobic metabolism, and there would be an increased reliance on anaerobic metabolism. Consequently, blood lactate concentrations would be higher than they would be if measured in a subject exercising in a thermoneutral environment. Students integrated information from several exercise physiology areas—cardiovascular, metabolism, and thermoregulation—to develop a complex hypothesis.

We also observed students recognizing control issues in an experimental design. Several groups of students regulated the speed of their contractions during EMG studies and subjects' hydration status prior to using bioelectric impedance analysis as an estimate for body composition. Other groups of students also noted dose-dependent responses as well as variation in responses of subjects from different populations. This illustrates that students developed more than just a superficial understanding of concepts.

In addition, students were beginning to look at the bigger picture. For example, a group of students studying the effects of caffeine and ephedrine on blood pressure and heart rate during exercise thought that a study should involve many subjects so that an outlier would not skew the results in a particular direction.

Furthermore, they realized that one study did not make a rule—several studies needed to be conducted on the same topic before the results could be applied to a popula-

tion. As a result of the independent projects, many students were able to identify issues central to science. These concepts, not specifically addressed by instructors, demonstrate student understanding on a much larger scale as compared to the same traditional-style course.

Throughout their work on the independent research projects, it was evident that students were searching for real answers to their research questions. We rarely observed textbook-type answers that did not explain the collected data; instead, we saw more conclusions based on data analysis. This was likely because the answers to many of the students' questions were not known. As a result, students did not know what the instructor "wanted to hear" and were forced to reflect on and analyze their own data to determine an answer.

As students resolved their questions, they began to see the scientific process as a whole, rather than as distinct parts. Scientific inquiry became a way of thought instead of steps for writing a lab report. By working in small groups, students used inquiry to learn from one another. They often negotiated, asking each other, "What are we measuring? What is our purpose? Why? How come?" Then, they collaborated to formulate theories and conclusions. In this respect, we observed students asking and answering their own questions.

Our inquiry-based model has been successful in improving student attitudes, involvement, independent thinking, understanding of exercise physiology concepts, and the integration of knowledge from other disciplines. As a result, inquiry-based learning resulted in

a higher order of learning not typically observed with traditional-style classes. If students have the opportunity to develop the necessary skills, inquiry learning allows students to be self-reliant and critical thinkers.

Note

This course and its evaluation were partially funded from an NSF Course, Curriculum, and Laboratory Improvement-Adaptation and Implementation (CCLI-A&I) grant (DUE-9950622).

References

- Arons, A.B. 1980. Using the substance of science to the purpose of liberal learning. *Journal of College Science Teaching* 10(2):81–87.
- Janners, M.Y. 1988. Inquiry, investigation, and communication in the student-directed laboratory. *Journal of College Science Teaching* 18(1):32–35.
- Kolkhorst, F.W., C.L. Mason, D.M. DiPasquale, P. Patterson, and M.J. Buono. 2001. An inquiry-based learning model for an exercise physiology laboratory course. *Advances in Physiology Education* 25(2):45–50.
- Lawson, A.E., S.W. Rissing, and S.H. Faeth. 1990. An inquiry approach to nonmajors biology. *Journal of College Science Teaching* 19(6): 340–346.
- National Research Council (NRC). 2000. *How People Learn: Brain, Mind, Experience, and School*. Washington, D.C.: National Academy Press.
- Sprenger, M. 1999. *Learning and Memory: Brain in Action*. Alexandria, Va.: Association for Supervision and Curriculum Development.