We developed an inquiry-based learning model to better stimulate undergraduate students' cognitive development of exercise physiology laboratory concepts. The course core is the two independent research projects that students, working in small groups, complete during the last 9 wk of the semester. Student groups develop their own research question and hypothesis, design the experiment, collect and analyze the data, and report their findings to the rest of the class using presentation software. To help with success of the research projects, students are taken through a series of guided-inquiry laboratory activities during the initial 6 wk of the semester to develop laboratory skills and an understanding of the scientific process. Observations of student behaviors reflected a high level of enthusiasm and engagement in laboratory activities. Surveys, journal entries, and interviews indicated that students felt empowered by having ownership in their projects, which may be the key reason for the success of this model.

Key words: active learning; instruction; problem-based learning

Traditional approaches in a laboratory course tend to provide step-by-step instructions for completing experiments and/or laboratory procedures. Students generally focus on each step independently of the others, often resulting in failure to understand the overall concept of the experiment. Consequently, obtaining expected results and writing the prescribed laboratory report become the primary concern of students (5). This teaching approach promotes passive learning because it only requires students to provide answers to questions. In addition, students know that they are verifying already-known outcomes. Employing solely directed teaching strategies does not prepare them to develop or test a hypothesis, both of which are components of higher orders of thinking and learning (1).

In undergraduate exercise physiology laboratory courses, traditional-style approaches are commonly used, and furthermore, many of the laboratory activities are merely demonstrations that involve few students. Typically, the majority of students not involved in the experiment gather around the computer display of a metabolic measurement system to view data as they are collected from an exercising subject. This invariably leads to problems in maintaining student interest and diminishes learning. On the other hand, there are other laboratory activities, such as exercise responses to heart rate and blood pressure, which actively involve all students. However, laboratory skills necessary for these measurements are not usually mastered after only brief instructions and a few practice trials. Poor laboratory skills, the normal vari-
ability of human responses, and a lack of sufficient controls often result in flawed data and tend to increase the difficulty in understanding the experimental concept. As a result, students often discuss the expected “textbook” outcomes rather than attempting analysis and interpretation of their own data.

In contrast to a traditional-style laboratory class, inquiry-based laboratory approaches are more student-involved and evoke inductive reasoning. Fewer directions are provided, which places more emphasis on students taking responsibility for their own learning, both individually and as members of groups. This teaching strategy explicitly attempts to develop the scientific process skills, such as hypothesis formation, identification and manipulation of experimental variables, and discussion of and conclusions from data. Instructors focus inquiry predominantly on real phenomena where students are given investigations or guided toward designing investigations that are demanding but within their capabilities.

The use of inquiry-based learning in lecture and laboratory courses can no longer be considered novel or without empirical support. Numerous reports from national commissions consistently state: “what students learn is greatly influenced by how they learn, and many students learn best through active, collaborative, small-group work inside and outside the classroom.” (4) Science as well as mathematics, engineering, and technology (SMET) courses need to shift from teaching to learning (1, 2). The traditional-style approach results in graduates who lack skills for problem solving and fosters unfavorable attitudes and higher attrition rates in SMET fields of study (2).

Support for the use of inquiry-based learning continues to increase. Recently, Springer et al. (4) reported results of a meta-analysis on use of small-group teaching. Most notable of their findings was that academic achievement was higher (effect size = 0.51) with small-group instruction. Put in perspective, students in small-group instruction would have moved from the 50th to the 70th percentile on a standardized achievement test. Furthermore, their meta-analysis suggested that academic improvements were even greater in minority students, and attitudes toward SMET courses were more favorable, particularly in female students. In addition, their findings indicated that there was a 22% decrease in student attrition from SMET courses after having experienced small-group instruction.

INQUIRY-BASED LEARNING MODEL

We developed a model for inquiry-based learning for our undergraduate exercise physiology laboratory course to address the above-described problems and concerns that accompany use of traditional-style labs. With assistance from a National Science Foundation (NSF) Course, Curriculum, and Laboratory Improvement-Adaptation and Implementation (CCLI-A&I) grant (DUE-9950622), we adapted a model developed by A. M. Smith for an undergraduate physiology lab course at Butler (IN) University (NSF DUE-9650721). For our project, the primary objective was to improve students’ cognitive abilities of exercise physiology laboratory concepts, including critical thinking skills; secondary objectives were to improve verbal and written communication skills and technology skills.

In our model, after the first introductory laboratory course session, the next five laboratory activities covered topics considered central to the course and were presented in a traditional-style approach. Topics covered in these five activities included concepts on the exercise responses of respiratory exchange ratio (RER), blood lactate concentration, heart rate and blood pressure, motor unit activity [electromyogram (EMG) measurement], and on body composition estimation.

For the remaining 9 wk of the semester, students worked in small groups (3–4 students) completing two separate research projects (4 and 5 wk in length, respectively). Because projects were only for educational purposes and none of the data would be published, approval of the institution’s committee for the protection of human subjects was not required. Before beginning an experiment, though, the graduate instructors discussed each project with the faculty course director. The first class meeting for each research project was spent on groups developing a research question and hypothesis and, in consultation with the instructor, designing the experiment. The research question did not have to be original and could be on any topic related to exercise physiology but within limitations of the students and laboratory.
Also, research topics for the second project were required to be on a different physiological system than the first. During the following 2–3 laboratory classes, students collected data in an open-lab setting. On the last session of a project, each group delivered a 10- to 15-min talk on their results using presentation software, which was followed by a brief question and answer period.

In evaluating the first semester of using the inquiry-based learning model, students were noted not to fully understand the scientific process nor have sufficient expertise for operating laboratory equipment. This led to excessive time spent by students practicing lab skills rather than collecting data, which also affected the quality of the data. Consequently, the initial 6 wk of the course were revised to strengthen those skills necessary for conducting the research projects. Discussion of the scientific process was begun in the introductory laboratory session and emphasized throughout the semester. Furthermore, the next five laboratory activities were redesigned as guided inquiries to take students in a graduated approach to the semiguided inquiry research projects (Table 1). During weeks 2 and 3, students were provided with a focused research question, but the experimental design was developed through class discussion. For each activity, students collected data in small groups but returned to the large group to discuss significance of the data and how to best report the results. Week 4 was devoted solely to practicing using laboratory equipment (i.e., metabolic measurement cart and blood lactate analyzer) essential for exercise testing. Over the next 2 wk, the assigned laboratory activities required the use of these skills, which provided additional practice opportunities. The experimental questions for weeks 5 and 6 were more general, and students, working in small groups, had to first focus the question as well as design the experiment before collecting data. The transition of guided inquiries to semiguided inquiries was smoother, and students, for the most part, seemed to better understand what was

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**TABLE 1**  
Modified syllabus of an undergraduate exercise physiology laboratory course using the inquiry-based learning model

<table>
<thead>
<tr>
<th>Week</th>
<th>Topic</th>
<th>Content</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Course introduction</td>
<td>Review of working with data and graphs, discussion of scientific process</td>
<td>10-point quiz</td>
</tr>
<tr>
<td>2</td>
<td>Body composition assessment</td>
<td>Students provided with focused research question, develop experimental design in large groups, collect data in small groups, but return to large group to discuss results and reporting of outcomes.</td>
<td>10-point quiz; lab report from week 2</td>
</tr>
<tr>
<td>3</td>
<td>Motor unit recruitment</td>
<td>Students are trained to calibrate metabolic measurement system, perform finger sticks, and calibrate lactate analyzer. In small groups, students practice each skill during a simulated exercise test.</td>
<td>10-point quiz; lab report from week 3</td>
</tr>
<tr>
<td>4</td>
<td>Use of metabolic measurement system and blood lactate analyzer</td>
<td>Students provided with general research question. In small group, students focus question, develop hypothesis, design experiment, collect data, and discuss significance of results.</td>
<td>10-point quiz</td>
</tr>
<tr>
<td>5</td>
<td>Metabolic measurements during exercise</td>
<td>Students provided with general research question.</td>
<td>10-point quiz</td>
</tr>
<tr>
<td>6</td>
<td>Cardiovascular responses during exercise</td>
<td>In small group, students focus question, develop hypothesis, design experiment, collect data, and discuss significance of results.</td>
<td>10-point quiz; lab report from week 5</td>
</tr>
<tr>
<td>7</td>
<td>Research project 1</td>
<td>Students form small groups, develop research question and hypothesis, and design experiment.</td>
<td>5-point quiz; lab report from week 6</td>
</tr>
<tr>
<td>8–9</td>
<td>Research project 1</td>
<td>Students collect data in open-lab setting.</td>
<td>5-point quiz; (week 8 only)</td>
</tr>
<tr>
<td>10</td>
<td>Research project 1</td>
<td>PowerPoint presentations of project results.</td>
<td>5-point quiz; group paper for project 1</td>
</tr>
<tr>
<td>11</td>
<td>Research project 2</td>
<td>Students form small groups, develop research question and hypothesis, and design experiment.</td>
<td>5-point quiz; (weeks 12 and 14 only)</td>
</tr>
<tr>
<td>12–14</td>
<td>Research project 2</td>
<td>Students collect data in open-lab setting.</td>
<td>5-point quiz; (weeks 12 and 14 only)</td>
</tr>
<tr>
<td>15</td>
<td>Research project 2</td>
<td>PowerPoint presentations of project results.</td>
<td>group paper for project 2</td>
</tr>
</tbody>
</table>
expected of them and what leeway they had in the course. Even more importantly, students had a better sense of what science as a process entailed.

**Student assessment.** Students were assessed on three areas of evaluation: 4 laboratory reports (80 points), 10 quizzes (75 points), and 2 research projects (150 points; Table 1). One-page typed reports were required following each of the four guided laboratory activities early in the semester. The reports were to follow the scientific-style format (introduction, methods, results, discussion, and conclusion), although the grading emphasis was on the discussion section. Graphs and/or tables of results were to be attached to the back of the report.

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 broad topics. The purpose of these questions was to promote thought about laboratory activities on a broader scope than from a narrow element of the experiment. 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 having a second question included a question on the prelaboratory reading assignment.

The research projects were evaluated primarily on quality of the group paper, although individual contributions to the project were also considered. A grading rubric was developed for evaluating the paper with depth and quality of the discussion section weighted most heavily.

**MODEL EVALUATION**

During the first semester of implementation, students were required to submit weekly journal entries of 300–500 words. Students were asked to comment on and interpret experiences, discuss frustrations and accomplishments, or to evaluate the learning experience. There was also a specific question each week focused on students’ reactions to the previous week’s class. The weekly journals were replaced by the quizzes in the second semester of employing the model as a means to promote greater reflection on the course content.

Further information was obtained from student observations and semistructured interviews at the end of the semester. Although observations at this time are limited, they have been highly encouraging. The overwhelming majority of students were very excited about learning in this manner, because the increase of energy and enthusiasm compared with previous semesters was quite noticeable both to the instructors and to observers. Students valued the freedom they had in the laboratory to seek answers to their own questions. One student commented, “I’ve never had a lab like this. All of my other labs were doing things that I didn’t understand or already knew the expected results.” Another student reported, “This class will better prepare me for my career because I am thinking about why rather than just doing stuff.” Several students mentioned that they felt this was the best course thus far in their academic program. They also expressed excitement for the opportunity to decide their own research hypothesis and experimental design. However, they realized and appreciated the support for making certain the research plans were appropriate and sound. Most students did not want answers, just reassurance. Below is a portion of an interview with a student whose response typified the majority of students interviewed.

“We should be more involved in the development of experiments and data collection... Being more involved gives us a chance to look at things in our own ways from what we have learned previously and lets us use our own thoughts of what should and shouldn’t be done... We can share our expectations of what we think might happen and gather what we think is relevant information... and it gives us a chance to practice what we’ve learned from our other labs and studies.”

Remarkably, few students did not share these attitudes or preferred a traditional-style approach to laboratory instruction. Negative comments included concern about the workload and time constraints. These, however, are consistent with comments about the inquiry-based physiology laboratory course at Butler University on which our model was based. Despite that, other frequent comments by students were how
quickly the time passed during class and how much they were learning.

Perhaps the most significant realization is that students’ potential has been underestimated. If given ownership for a project and for their learning, students can and will respond to the challenge. Student ownership for the projects they developed was conspicuously greater than for an experimental question and procedures provided by the instructor. The issue of ownership may be the fundamental reason for the increased student effort. During data collection, students, with few exceptions, were actively engaged in their work. Group interactions were lively but productive, and groups frequently solved their own problems and recognized errors in their procedures. Moreover, performance by students on the research presentations far exceeded expectations. Although students sometimes misinterpreted data or failed to realize the significance of their findings, their ability to describe and discuss the project results was impressive. Students were able to respond to questions and discuss physiological principles in greater depth than from attending only a lecture or traditional-style laboratory course. This observation was also supported by the positive reactions of other faculty who viewed the presentations.

Laboratory instructors submitted regular journal entries as well during the first semester of implementation and were interviewed for their observations and reactions to the model. There was unanimous consensus of the instructors, all of whom had previously taught the course using a traditional-style approach, that students’ cognitive abilities of exercise physiology were far greater with the inquiry-based learning model. Additionally, the graduate teaching instructors, who teach 8 of the 10 sections offered each semester, reported a greater understanding and appreciation of the scientific process, which should benefit their own research endeavors.

**SUMMARY**

We developed an instructional model for small-group inquiry-based learning that places greater emphasis on students learning concepts and less on teaching facts. After students understood a physiological concept as a whole, they more easily remembered the facts behind the concept. The primary components of the model are the two independent research projects. During the last two-thirds of the course, students, working in small groups, develop a research question, hypothesis, and experimental design and collect and analyze data and report their findings to the class. This teaching model has promoted greater student collaboration inside and outside of regularly scheduled meeting times, analysis and interpretation of laboratory data, and has fostered more reflection on laboratory concepts. Students are given less guidance on laboratory experiments, which has forced them to develop and master their own procedures. Perhaps the key to the model’s apparent success was the unmistakable ownership by students for all parts of the experiment.

However, students need sufficient laboratory skills and an understanding of the scientific process to be successful in a semiguided inquiry research project. Our model develops these skills through a graduated approach of guided inquiry-based activities and by emphasizing the scientific process throughout the semester.

Early observations have been positive. Students reported that they enjoyed more fully this approach to laboratory instruction. Perhaps more importantly, instructor observations suggested that student understanding and integration of exercise physiology laboratory concepts has been stronger than with a traditional-style approach.

Future intentions for the project are to gather quantifiable data to better evaluate the model, including whether knowledge and understanding of exercise physiology laboratory concepts are affected by this model. Currently, we are assessing students’ attitudes toward learning styles before and after completing the inquiry-based laboratory course. In addition, we are planning to determine whether exposure to the inquiry-based learning model elicits changes in critical thinking. Furthermore, we will be performing systematic observations of instructors and students to chronicle their behaviors as the
amount of instructor guidance over the course of the semester is reduced.

The contribution of the laboratory instructors toward this project has been immeasurable and warrants their recognition: Krista Austin, Brian Bertram, Rita Klabacha, Danica Medina, Karen Pindroh, and Tony Sucec.

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