Effectiveness of inquiry-based learning in an undergraduate exercise physiology course

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Nybo L, May M. Effectiveness of inquiry-based learning in an undergraduate exercise physiology course. Adv Physiol Educ 39: 76–80, 2015; doi:10.1152/advan.00161.2014.—The present study was conducted to investigate the effects of changing a laboratory physiology course for undergraduate students from a traditional step-by-step guided structure to an inquiry-based approach. With this aim in mind, quantitative and qualitative evaluations of learning outcomes (individual subject-specific tests and group interviews) were performed for a laboratory course in cardiorespiratory exercise physiology that was conducted in one year with a traditional step-by-step guided manual (traditional course) and the next year completed with an inquiry-based structure (I-based course). The I-based course was a guided inquiry course where students had to design the experimental protocol and conduct their own study on the basis of certain predefined criteria (i.e., they should evaluate respiratory responses to submaximal and maximal exercise and provide indirect and direct measures of aerobic exercise capacity). The results indicated that the overall time spent on the experimental course as well as self-evaluated learning outcomes were similar across groups. However, students in the I-based course used more time in preparation (102 ± 5 min) than students in the traditional course (42 ± 3 min, P < 0.05), and 65 ± 5% students in the I-based course searched for additional literature before experimentation compared with only 2 ± 1% students in the traditional course. Furthermore, students in the I-based course achieved a higher (P < 0.05) average score on the quantitative test (45 ± 3%) compared with students in the traditional course (31 ± 4%). Although students were unfamiliar with cardiorespiratory exercise physiology and the experimental methods before the course, it appears that an inquiry-based approach rather than one that provides students with step-by-step instructions may benefit learning outcomes in a laboratory physiology course.

bachelor students; designing exercise tests; learning outcome

Scientific inquiry usually begins with a research question or definition of an issue of interest, and, before the study is designed and the experimental protocol developed, it usually involves a process based on previous knowledge within the field, review of relevant literature, evaluation of available methods, and discussions with colleagues. However, in our educational system, the pupils/students traditionally begin with the protocol, and the experimental design is developed by the teacher, who provides the students with step-by-step instructions that the pupils are expected to follow when they enter the laboratory. In physiology education, we also tend to follow this approach, and, at our department, we have a long tradition, at both the bachelor and master levels, of conducting experimental courses in respiration and cardiovascular exercise physiology with a step-by-step instructed manual. However, with this approach, students miss a large and essential part of the research process, and they have a tendency to focus on each step independently of the others, often resulting in failure to understand the overall concept of the experiment (11). Consequently, obtaining the expected results and writing the prescribed laboratory report may become the students’ primary concerns (1, 8). Recently, we have developed experimental courses at the master’s level with an approach that may be characterized as guided or semiopen inquiry. It is clear that student motivation improves when they experience ownership of their experiments (12), and students’ abilities to design experimental protocols are improved with this approach (5). Conversely, at the bachelor level, the traditional approach with step-by-step instructed manuals has been maintained as it has been argued that implementing problem-based learning would compromise the academic depth, since students would not possess the knowledge and competences required. Thus, students’ methodological insights and abilities to design experiments would be limited at this stage of their education.

However, the lack of involvement in designing experimental protocols and selecting relevant methods is in conflict with the competences later required in the educational career of students as they may become involved with experimental bachelor projects or experimental master courses. Furthermore, the ability to independently investigate physiological issues and address specific questions is also of importance after graduation, when students continue with their professional careers. If it is not implemented in mandatory courses, some bachelor students may completely miss this element in their education as we know that some conduct theoretical bachelor projects, whereas others become involved with larger research projects where they have little influence on the overall research design. In accordance, Biggs (2) suggested that the teacher’s job is to organize the teaching/learning context so that all students are more likely to use higher order learning processes in inquiry-based approaches.

Therefore, we developed an existing experimental course and implemented elements where students, at an early stage of their education in exercise physiology, would get experience with designing an experimental protocol and selecting relevant approaches to investigating a specific issue within exercise physiology. With this aim in mind, we changed the experimental part of a mandatory physiology course for bachelor students from a predesigned step-by-step guided protocol (traditional course) to a guided inquiry-based approach (I-based course), where students were instructed to design and plan experiments with certain predefined goals and methods. Specifically, students were instructed to design a protocol to evaluate cardiorespiratory responses in the transition from rest to exercise and...
include an assessment of aerobic power with submaximal indirect and maximal direct testing. Available methods and materials/equipment were briefly described and suggested references to relevant literature were provided in the manual, but students had to design the protocol, select the exercise mode, and choose when and how to obtain the relevant measures. Furthermore, students were instructed to report changes in ventilation, heart rate, and $O_2$ uptake from rest to submaximal and maximal exercise and evaluate/compare the aerobic capacity of the subject or subjects with reference values for untrained and trained individuals. In contrast to the manual for the traditional course, they were not provided with instructions for inclusion of specific figures and tables in the result section or given specific questions/bullets for the discussion section.

We chose a guided (semiopen) inquiry-based approach because it could be implemented while insuring that students would achieve experience with certain central methods. We hypothesized that the inquiry-based approach would be feasible to conduct and that it would obviously strengthen the elements of the course related to designing and planning an experiment. However, it was a major concern to implement the inquiry-based approach without disadvantageous effects on essential physiological learning outcomes. Therefore, we specifically addressed this issue, and the present article is focused on reporting the effects of the changes described above. It includes a quantitative aspect with testing of selected/central learning outcomes from the experimental course and a qualitative part with a focus on student learning processes related to participation in the two different structures.

**MATERIALS AND METHODS**

**Study settings.** This cross-sectional study was conducted at the Department of Nutrition and Exercise Sciences at the University of Copenhagen (Copenhagen, Denmark) with second-year bachelor students from the education program in exercise and sport sciences. All students were invited to participate, and ~80% of the students participated in the assessment process (the remaining students were either absent at the given class/lecture or did not, for unknown reasons, hand in the questionnaire).

**Subjects/students.** In total, 160 second-year undergraduate students (third semester at the bachelor level) participated in the quantitative part of the investigation [79 students in 2012 in the traditional course (age: $21 \pm 1$ yr, mean $\pm$ SE) and 81 students in 2013 in the experimental I-based course (age: $22 \pm 1$ yr, mean $\pm$ SE)]. The course of interest was focused on cardiorespiratory physiology, and it is the second physiological course in the bachelor students’ curriculum. Their mean grading for their first physiological course (muscle and nerve physiology) was $8.2 \pm 0.2$ for the traditional group and not different for the I-based course, as students had a score of $8.3 \pm 0.4$ on the 12-grade scale used in the Danish education system. The laboratory part of the course was the only structural change implemented from 2012 to 2013, and the lectures, textbook, and course structure remained unchanged. Sixteen of the one hundred sixty students (8 students/yr) also participated in qualitative focus group interviews.

**Questionnaires and quantitative testing.** Without prior notice or time for preparation, questionnaires and tests were distributed at the onset of a normal lecture ~4 wk after students had completed the laboratory course. Students then had 5 min to fill out background information and answer the following questions (translated from Danish):

1. What was your grade in Exercise Physiology 1 (students’ first physiology course)?
2. Did you read the entire course manual before conducting the laboratory course?
3. Did you read additional literature (other than the instructor/course manual or your textbook) before conducting the experiments?
4. How much time did you use in total for preparation (before entering the laboratory)?
5. How much time did you spend on your report?
6. Did you search for and read additional literature during the writing process (i.e., other than your textbook)?
7. How do you evaluate your own learning outcome of the experimental course in cardiorespiratory testing (on a scale from 1 to 5, with 1 as low/poor and 5 as high/good).

After completing the questionnaire, students had a total of 30 min to answer two tests (tests A and B) to evaluate their knowledge related to the laboratory exercise. Test A was a test of the ability of students to account for and analyze typical exercise responses (similar to those observed in their experiments). Test A included short questions, and, specifically, students were asked to draw two figures illustrating the change in pulmonary ventilation and $O_2$ consumption from rest to moderate-intensity exercise with specification of the time course and magnitude of the changes (realistic values) and provide the corresponding values for breathing frequency and tidal volume. In the report for the traditional course, students were explicitly asked to plot $O_2$ uptake as a function of time, but illustrating pulmonary ventilation over time was not a specific requirement in those reports. Thus, students were asked to draw graphs similar to the report requirements but also draw and evaluate figures not directly asked for in the report in the traditional course. Therefore, test A was intended to test the students’ ability to account for physiological responses and the time course and to provide realistic values to identify if this knowledge would be lost when students were not specifically asked to draw the graph in their report.

Test B addressed the students’ ability to comprehend and explain the rationale for submaximal and maximal test protocols. Test B included short-answer questions asking the student to identify the prerequisites for submaximal indirect testing (linearity between heart rate and $O_2$ uptake, choice of intensities, estimation of maximal heart rate and exercise efficiency, steady state, etc.). Furthermore, on the basis of a specific case, students were asked to evaluate test results and judge the criteria for attaining a “true” maximal $O_2$ uptake (on the basis of maximal heart rate achieved in the test, respiratory exchange ratio, peak $O_2$ uptake, and blood lactate, with background information about the subjects’ sex, age, weight, and habitual activity level and a description of a specific incremental test protocol).

The protocol in the traditional course included a detailed description of a submaximal two-point test and an incremental protocol, with step-by-step instruction of how the experiments should be conducted. The protocol and examples presented in test B were similar to experiments that students conducted in the traditional course. In contrast, in the I-based course, students were allowed to conduct any (valid and physiological reasonable) submaximal test and design their own protocol for this test. For the maximal test protocol, students could choose between running or cycling as an exercise mode, and they could decide themselves how the maximal test should be conducted. A tutor supported the students with handling of equipment and provided relevant feedback on the experimental setup, but the tutor was explicitly instructed that the students should design their own protocol. Links to literature describing different tests (including similar tests as those conducted in the traditional course) were provided in the manual, but as students could define their own test protocol, they did not necessarily conduct tests similar to those they were presented with in test B.

Both tests were evaluated on a scale from 0% (no correct answers/information provided) to 100% (comprehensive responses to all parts of the test) by a researcher/physiologist involved in the present study but not directly responsible for the course. Furthermore, the scoring was verified for 20 of the test responses (10 responses/course) by a
The overall time expenditure on preparation, data analysis, and writing of the report was not significantly different across the two groups with 21 ± 1 h used in the traditional course and 18 ± 1 h used in the I-based course. There also was no difference in the percentage of students that read the course manual before the experimental part (67 ± 3% for the traditional course vs. 71 ± 3% for the I-based course; see Fig. 1).

However, students in the I-based course used more time in preparation (102 ± 5 min) compared with students in the traditional course (42 ± 3 min, \( P < 0.05 \)), and 65 ± 5% of the students in the I-based course reported that they had read additional literature before the course compared with only 2 ± 1% of the students in the traditional course. In addition, the use of a literature search for additional references (other than the manual and textbook for the course) was significantly higher for students in the I-based course compared with the traditional course (Fig. 1).

The student’s self-evaluated learning outcome [scored from 1 (poor) to 5 (very high)] was 3.3 ± 0.1 for the traditional course and 3.1 ± 0.1 for the I-based course and was not significantly different across groups. However, as shown in Fig. 2, both test scores were higher in the I-based course compared with the traditional course. The overall grade for the course was 6.4 ± 0.4 in 2013 (when the experimental I-based course was included) and significantly higher than 4.9 ± 0.5 in 2012 (when the traditional course was part of the curriculum, \( P < 0.05 \)). The linear regression analysis failed to identify any significant correlations between scores in the two tests and any of the quantitative data, and there was no correlation between scores in test A and test B.

Qualitative interviews. In the focus group interviews, difficulties or an inability to account for respiratory responses to exercise (e.g., illustrate kinetics for ventilation or \( \text{O}_2 \) consumption) or provide realistic values (as required in test A) were typically expressed as follows: “I did not notice how large the ventilation was during the submaximal part of the protocol as we were not specifically asked to illustrate this in the report” (student A from the traditional course) or “I did not look at the screen [on the system used for measuring oxygen uptake] during the experiments, so I did not see if the oxygen uptake reached a plateau or pay attention to the oxygen uptake value during the first exercise period, but I know that some of the others looked at it, because we wanted to make sure that [the subject] reached steady state” (student B from the I-based course). When asked if they analyzed the response afterward (which was required in the
In the present study, we demonstrate that an inquiry-based approach may be implemented and improve learning outcomes of laboratory courses for bachelor students previously unfamiliar with applied methods or the design of exercise studies. The change from step-by-step guidelines to the guided inquiry-based (semiopen) instruction manual implied that students used more time on preparation and searched for literature and information before commencing the experimental part of the course. Based on the overall improvement in tests scores (the quantitative tests) and the impressions from the qualitative interviews, we suggest that when students become involved in designing their own investigations rather than following a predetermined protocol, they pay more attention to the physiological responses and the methods they use.

Interactive lectures have been validated and proven beneficial for students learning in a variety of courses and disciplines in higher science education (7), including medical teaching (6) and respiratory physiology (4). Guiding and stimulating thinking rather than providing ready-made solutions appears important to enhance the student learning outcomes (2). The present findings support this concept and demonstrate that for experimental classes it is equally important that students become actively engaged in the learning activities preceding the experimentation phase (1, 10). Important goals for higher education in human physiology are the ability to develop problem-solving skills, independent thinking, critical thinking, and the willingness and ability to experimentally explore new ideas (8). Accordingly, several of our master courses in human physiology have included inquiry-based elements in the experimental parts of the curriculum. Nevertheless, for undergraduate courses, our institution has, until the present intervention and redesign of the described course, maintained the traditional step-by-step instructed structure due to the limited background knowledge of students and their lack of experience in the laboratory. This lack of knowledge and experience has so far kept us from implementing an inquiry-based model of teaching because it was the impression among the teaching staff that it would compromise the academic level and quality of the course if the students designed their own experiments.

However, problem-based learning has been implemented successfully in experimental courses for undergraduate students (3, 8), and the present data clearly demonstrate that a guided inquiry-based approach can benefit rather than compromise scientific learning outcomes. We hypothesized that the ability to account for and explain the methodological considerations and study design (as evaluated in test B) would benefit from the new structure, whereas we were somewhat surprised by the improved scores in test A (testing the ability to account for and analyze exercise responses that students were specifically asked to measure in the traditional course). Yet, from our later analysis of the focus group interviews with students from the two courses, it became clear that although the step-by-step instruction manual assured that the students recorded, illustrated, and discussed certain respiratory responses, the actual learning outcome was rather low. Both for the I-based and traditional courses, some students scored high in the tests, and these students probably achieve high grades and conceptual understanding of respiratory physiology no matter how the experimental class was constructed. However, we speculate that, in general, the very detailed step-by-step instructed experiments may reduce learning outcomes for the participants, whereas the inquiry-based approach will stimulate higher-order thinking and benefit engagement for the majority of undergraduate students.

Based on a multilevel analysis, Scott (14) concluded that problem-based learning may, in general, favor knowledge gain compared with traditional teaching methods, but this is not always the case (see Ref. 14 for a discussion). Analogously, changing a traditional experimental physiology course to an inquiry-based approach may not automatically improve all learning aspects (5), and it seems important to define the intended learning outcomes of the experimental course with respect to the central conceptual physiological aspects that
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need to be trained and the methodological aspects and academic skills that students should adopt through participation in the course. For the present experimental course, we interviewed the responsible teacher to identify intended learning outcomes, and we discussed how learning outcomes could be maintained or improved with a guided instruction manual that allowed for an inquiry-based approach while assuring that students gained insights into central methods and aspects of physiology. For example, the new instruction manual stipulated that the experiments/study design should include a sub-maximal exercise test as well as a maximal evaluation of aerobic power (maximal O₂ uptake) for at least one subject and that changes in breathing frequency and pulmonary ventilation from rest to exercise had to be investigated and reported. Designing and implementing inquiry-based learning requires attention to the characteristics of the participants and their past experiences as well as an awareness of the difficulties commonly experienced by students introduced to exercise physiology. These variables were considered for the present course, but the knowledge gained from the first year with the new structure allows for further refinement and improvement of the course.

As indicated by the modest scores in the two tests, there is indeed space for further improvement, but it should be considered that the tests were undertaken extemporaneously and constructed with a degree of difficulty that would challenge the entire spectrum of undergraduate students. In other words, the second part of both tests A and B required an integrated overview of cardiorespiratory physiology that we and others normally only observe for the best students at this early stage of their education (9). The tests were constructed in this manner as we wanted to be able to track learning effects for both skilled and less skilled students. The inquiry-based approach could be considered as a form of differentiated teaching that would allow for further knowledge gain also for the more skilled students, whereas the step-by-step instructed course could limit the development of experimental competences and conceptual knowledge for this group (2, 13). On the other side, the traditional course could be better suited for less skilled students. However, both the final grades for the course and the scores from the two tests indicate that it is the “broad middle group of students” rather than the upper 10th of students that mainly benefit from the inquiry-based approach. Thus, there was no change in the percentage of students scoring >80% in the presents tests or achieving top grades in the final exam (equal to the upper 10th), whereas average test scores in the present tests increased by ~50% and the overall average grade for final exam was significantly improved, whereas the proportion of students failing to pass the exam in the first attempt decreased from 13% to 5%.

The present findings let us conclude that undergraduate students may benefit from a guided inquiry-based approach to an experimental course, even when they are not familiar with cardiorespiratory physiology and are inexperienced with the experimental methods before a course. Rather than providing students with step-by-step instructions, the instruction manual may present students with guidelines for the experiments as well as the relevant background information and brief descriptions of available methods. We suggest that the process should be supervised by a teacher or instructor with whom the students may interact during the design phase and get support from during the experiments. We emphasize, however, that students should be in charge of their own experiments and be explicitly informed that they may seek advice/sparring with the instructor during the design phase and that the instructor will support them with technical guidance in the laboratory, but that they are entirely responsible for developing and completing the experiments.

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DISCLOSURES

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AUTHOR CONTRIBUTIONS

Author contributions: L.N. and M.M. conception and design of research; L.N. and M.M. performed experiments; L.N. analyzed data; L.N. and M.M. interpreted results of experiments; L.N. prepared figures; L.N. drafted manuscript; L.N. and M.M. edited and revised manuscript; L.N. and M.M. approved final version of manuscript.

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