Evaluating the impact of physical renovation, computerization, and use of an inquiry approach in an undergraduate, allied health human anatomy and physiology lab

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This paper describes and evaluates a major renovation of a human anatomy and physiology lab for allied health students. A Howard Hughes Medical Institute award funded an extensive collaboration between faculty involved in teaching the course and faculty with expertise in industrial and furniture design. The resulting physical lab has unique features designed to improve work in groups, student movement, and integration of computers with wet laboratories. The anatomy curriculum was switched from fetal pig dissections to the use of human cadavers, computer animations, and plastic models. An inquiry approach was integrated into the physiology curriculum. Student attitude surveys suggest that the physical and curricular changes resulted in a significant increase in student learning. An experiment designed to specifically test the effect of new vs. old equipment did not support a benefit to new equipment independent of changes in the lab physical environment and curriculum. Because the improvements in student attitude surveys occurred in the physiology but not the anatomy labs, we suggest that at least a portion of the increase is due to the institution of the inquiry approach.

Key words: assessment; critical inquiry

Because of advances in knowledge, technology, and educational theory, anatomy and physiology education often undergoes changes as teachers attempt to find better methods to train students. Also, as buildings and furniture age and student enrollments increase, it becomes necessary to renovate or replace physical lab environments. Such renovations are expensive but offer exciting opportunities to improve physiological education (5). The goal of this paper is to describe a major physical and curricular renovation in an undergraduate allied health anatomy and physiology lab. We highlight unique design approaches used in this renovation and also describe how we utilized an inquiry approach in development of the physiology laboratory exercises. Finally, we present results of our assessments of how these laboratory changes affected student attitudes.

GOALS OF THE RENOVATION

The renovated laboratory was Biology 202, the second semester of a 1-yr course titled Human Anatomy and Physiology. The first semester (Biology 201) covers biochemical, musculo-skeletal, and nervous system mate-
rial, whereas Biology 202 covers cardiovascular, respiratory, digestive, renal, and endocrine physiology. The course serves ~400 students per year, with 24 students per lab. Most of the students are exercise science or nursing majors, with some students from other allied health fields. There are no prerequisites for this course, although general chemistry is a corequisite; most of the students are freshmen and sophomores.

In the original laboratory, the room, furniture, and physiology equipment were all ~30 yr old. We had several goals in designing the physical and furniture renovation. First, because we wished to utilize human cadavers for the anatomy labs, we needed to improve room ventilation to meet current environmental safety standards. Second, because we wished to promote student-student and student-teacher interactions, we wanted to change the table designs away from straight rows and organize the room to improve circulation and lines of sight among the students and teaching assistant. Third, we wanted a physical design that would promote the simultaneous use of computers and wet laboratories and facilitate the use of computers in teaching. Fourth, we needed to make the new laboratories accessible for physically handicapped students. Fifth, we wished to make the new lab room a comfortable, pleasant environment that would encourage collaborative learning.

Our major goals in revising the laboratory curriculum were twofold. For the anatomy labs, we wished to make the material more human focused by switching from fetal pig dissections to using human cadavers and computerized anatomical animations. For the physiology labs, we wished to switch from “cookbook” laboratory exercises in which the students follow a set procedure to arrive at a preknown conclusion to inquiry-based labs in which the students develop some of their own hypotheses and tests of physiological function. Introduction of an inquiry-based approach to science education has been advocated as a key change necessary to improve science education (1–3). In addition, we wished to convert the physiology labs from our ancient analog chart recorders to computerized data acquisition systems.

FUNDING AND PLANNING THE RENOVATION

The laboratory renovation was funded partially by an award from the Howard Hughes Medical Institution (HHMI). From this award, $113,000 was spent on physical renovation, $60,000 in design and architectural costs, and $70,000 on equipment and supplies. Arizona State University provided $130,000 in additional funds toward the physical renovation. Assuming 25 yr of use for the $303,000 in physical renovations, 7 yr of use for the $70,000 of equipment, and consistency in class sizes over the duration of use, the complete cost of the lab renewal represents approximately $55 per student.

To efficiently use these funds, we included a large planning period in this process in which we attempted to fuse the expertise of the course instructors with experts in fields of classroom design. Faculty from the Arizona State University School of Architecture and Design College with specialties in industrial and furniture design were employed to plan and oversee the renovation. We had a series of planning meetings over 1.5 yr involving the design faculty, the Biology 202 instructors and lab coordinator, and university physical plant experts. HHMI funded a separate faculty training workshop in critical inquiry techniques. Planning criteria for the lab from a design perspective are discussed in more detail by Cutler (4). The Biology department also allotted additional funding for summer salaries for faculty to write the new labs and teaching assistants to test the new labs and equipment.

KEY FEATURES OF THE RENOVATED LABORATORY

Physical space. The newly renovated laboratory room has several key, relatively unique physical features that we would like to emphasize. First, modular tables were designed to accommodate computers and wet laboratories with computer lobules supplied with power and Ethernet distal and separate from the areas used for wet biochemistry (Figs. 1 and 2). There is a central region for observation of the two cadavers, which are kept on rolling tables that can be removed to a refrigerator during physiology labs (Fig. 2). The tables were designed as lobular, rather than the traditional straight tables, to facilitate student circulation, collaborative learning, and handicapped access. The tables end at the room corners, allowing power to be supplied to the tables from the walls (Fig. 2). A rolling stand is available with a computer, Proxima projector,
and Ethernet access, which allows the teaching assistant to demonstrate computer programs from the center of the room (Fig. 1). Soundproofing was added to the upper quarter and white boards to the middle third of all available walls (Fig. 1). This design provides space for students to discuss data and plan experiments while significantly reducing classroom noise. Soft, adjustable lighting was used to reduce glare problems on computer screens and the projection screen. The metal backless stools of the original lab were replaced with sturdy, padded adjustable chairs with backs (Fig. 1).

Curriculum. For anatomical teaching, the new curriculum uses human cadavers that are dissected by the instructors and teaching assistants. Students also work in pairs on the computer using ADAM anatomy computer animations and MEDPICS for histological training. Finally, a variety of plastic anatomical models (primarily torsos) are available.

The goal of each of the physiology labs is to combine teaching of physiological concepts with training in the scientific method. Each lab begins with a short section on the theoretical context for the lab, followed by teaching students how to make measurements using MacLab data acquisition systems. After making a few observations, students are required to generate one or more hypotheses about how a physiological system works and suggest experiments that test predictions of their hypotheses. Then, within their group of four, they collect data to compare to their predictions.

To illustrate the change in teaching approach, we will compare the old cardiovascular physiology lab with the new version. In the old lab, students recorded an electrocardiogram on themselves, measured the effect of exercise on heart rate, and observed a demonstration of the effect of drugs on a turtle heart. The goal of these labs was for students to learn how certain equipment could be used and to demonstrate the response of physiological systems. In all cases, there was an expected “correct” outcome for each lab exercise.

In the new cardiovascular lab, the students are first taught the basics of blood pressure regulation in lecture and in a short lab introduction. The goal of this introduction is to provide the students with a framework for thinking about the relevant physiological processes. In this case, the students are taught the relationships between cardiac output (CO), total peripheral resistance (TPR), and mean blood pressure (MBP; MBP = CO × TPR). The specific situation relevant to the laboratory is not discussed (the effect of exercise on CO, TPR, and MBP). Students are then taught how to measure CO (from heart rate measured using MacLab and a table of body size and exercise effects on human stroke volume), MBP (using a sphygmomanometer), and TPR (calculated from TPR = MBP/CO) on a human at rest. Students are then asked to predict how they think exercise on a bicycle ergometer will affect the experimental variables and to explain the basis to their predictions. Before conducting the experiment, the students are required to write out their hypothesis, defined as an explanation of
causal linkages in the system. For example, a common student hypothesis is that “Due to greater oxygen need by the muscles during exercise, CO must increase to allow more blood and oxygen delivery. The rise in CO causes MBP to increase because the blood pumped by the heart pushes on the walls of the arteries. TPR will be constant because the diameter of arterial walls will not change appreciably.” Students design an array of experiments and write out specific predictions that follow logically from their hypothesis. The most straightforward experiments simply examine several levels of steady aerobic exercise on CO, MBP, and TPR. In this case, a common student prediction would be that increasing exercise intensity will raise CO and MBP but have no effect on TPR. Some students choose to focus on issues such as

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FIG. 2. Schematic of the floor layout of the renovated lab room showing the arrangement of the lobular tables and the open central region for cadaver dissections.
sprint exercise, non-steady-state conditions, or effects of differences among subjects in conditioning and generate different hypotheses and predictions. Although there are almost always problems with the experimental designs (mostly due to time constraints), in most cases the students gain considerable appreciation for both cardiovascular physiology and the scientific method. As noted earlier, most students expect MBP to rise in a manner similar to CO with exercise. The cognitive dissonance they experience as their data contradict this prediction is perhaps the most pleasing thing about this lab from an instructor’s viewpoint. This result helps the students learn to trust their data and logical implications of that data, rather than an untested mental model.

ASSESSMENT OF THE RENOVATION

Overall consequences of the renovation. One method we used to assess the effect of the renovation on student satisfaction was to use a 13-question survey provided at the end of two semesters during years before and after all the renovations were completed. Students answered each question on a Likert scale with 1 = best and 5 = worst. Students were also encouraged to write an explanation of their rating. In each year, these surveys were answered by ~140 students, divided among three teaching assistants, each of whom had two lab sections. We pooled results from the two sections for each teaching assistant but present the results for each teaching assistant separately to illustrate the variation among instructors. We tested for an effect of the lab changes by ANOVA.

The overall summary question was “Did you learn a lot in this lab?” Student answers to this query improved by ~0.5 units on a 1–5 scale (Fig. 3; before all changes: $\bar{x} = 2.24$, SE = 0.07; after all changes: $\bar{x} = 1.76$, SE = 0.12; ANOVA, $P < 0.01$). We interpret these results as indicating that the renovation strongly improved student satisfaction with the lab, improving it in their perception from a “B” to an “A–” lab. The written comments confirm that many of the “post-renovation” students found this to be one of their best lab experiences at the university.

Students were also asked to “Rate the anatomy labs.” This was an overall rating of all the anatomy labs, which covered half the semester. There was no significant change in the student evaluations of the anatomy labs (Fig. 4; before all changes: $\bar{x} = 2.26$, SE = 0.11; after all changes: $\bar{x} = 2.34$, SE = 0.15; ANOVA, $P > 0.05$). Examination of the written responses suggests that pre- and post-renovation students identified different problems with the anatomy labs. Pre-renovation students complained that the fetal pig dissections were not relevant to humans and noted the difficulty of the dissections. Post-renovation students complained about the lack of reality of the computer animations and the difficulties of sharing two cadavers. We interpret these conflicting comments as reflecting a trade-off between the advantages and disadvantages of these two methods of teaching. We suspect that the students trained post-renovation would fair better if tested for their anatomical knowledge on human subjects (as will be done by future classes and job experience for these allied health students).

Student rating of the cardiovascular physiology lab improved significantly (Fig. 5; before all changes: $\bar{x} =$
2.31, SE = 0.12; after all changes: x̄ = 1.85, SE = 0.14; ANOVA, P < 0.01). Similar significant increases of ~0.5 rating units were found for all of the individual physiology labs (data not shown). The consistent improvement in the ratings of the physiology labs suggests that changes in the physiology labs were a major factor in the overall improvement in student satisfaction.

Testing for an effect of new equipment on student satisfaction. The improvement in student ratings for the overall lab and for the physiology labs could be due to a number of factors, including the use of the new equipment, the curricular changes, and changes in the physical space and furniture. We conducted an experiment to test the hypothesis that the use of the new equipment (computers, MacLab, ADAM, etc.) would improve student satisfaction independently of the other factors. For one semester, we had completed the curricular changes and obtained the new equipment but did not have access to the physically renovated space or furniture. During this semester, two anatomy labs and two physiology labs were selected for focal comparisons to test the effect of equipment on student satisfaction. For the “old” anatomy labs, students dissected fetal pigs, whereas for the “new” anatomy labs, students used ADAM (cadavers were not available). For the old physiology labs, students collected data using Gilson duographs and chart recorders, whereas MacLab was used for the new physiology labs. The curriculum was as identical as possible for the old and new labs, with a critical inquiry approach used throughout the physiology labs. Each teaching assistant taught both old and new labs, and each student experienced two old and two new labs. At the end of each lab, the students took a 5-point quiz on the scientific material relevant to that lab and completed a 12-question survey (rated on a 1–5 scale) that assessed their satisfaction with the lab. Data were analyzed with a two-way ANOVA, with equipment age and teaching assistant as factors.

There were no significant differences in the results of the postlab scientific content quizzes between students with the old and new equipment (Fig. 6, ANOVA for all comparisons with P > 0.05). It should be noted that the questions were designed to be relevant to the anatomical material presented. For example, students who dissected fetal pigs were
tested on fetal pig anatomy, whereas students who studied with ADAM were tested on ADAM. For the physiology labs, the protocols, topics covered, and questions were virtually identical except for the particulars of the data acquisition equipment. So perhaps it is not surprising that the equipment itself did not seem to affect the rate of learning.

Student attitudes were also little affected by the use of old vs. new equipment. For all seven survey questions, there were no significant differences in student responses for the two anatomy labs examined (Table 1). The use of fetal pigs vs. ADAM did not appear to influence how the students felt generally about the lab, the usefulness of the lab, or the ease of conducting the lab. For the two physiology labs examined, 4 of the possible 14 lab/question combinations did differ significantly between the old and new labs. In response to the statement “I think that I’ll be able to use information and/or thinking skills from today’s activities in future classes,” significantly better scores (~0.3 units) were given to the old labs. Similarly, students rated the old respiratory physiology lab better in response to the statement “This lab activity helped me better understand lecture material.” The old cardiovascular physiology labs also fared significantly better in response to the statement “I felt pressed for time in completing the lab activity.” Along with student comments, we interpret the tendency for the lower rating of physiology labs using MacLab to difficulties the students were having with learning the software and their perception that computer difficulties impeded the learning of anatomy and physiology. This was the first semester in which MacLab (and a great deal of new equipment) was used in

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Results of student attitude surveys</th>
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<tr>
<td>Cardiovascular</td>
<td>Respiratory</td>
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<tr>
<td>Physiology</td>
<td>Physiology</td>
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<tr>
<td>I would recommend that this lab activity be used in next year’s A and P class.</td>
<td>NS</td>
</tr>
<tr>
<td>I felt pressed for time in completing the lab activity.</td>
<td>new &gt; old*</td>
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<tr>
<td>This lab activity helped me better understand lecture material.</td>
<td>NS</td>
</tr>
<tr>
<td>I felt that I needed more assistance and guidance in completing today’s lab activity.</td>
<td>NS</td>
</tr>
<tr>
<td>I think that I’ll be able to use information and/or thinking skills from today’s activities in future classes.</td>
<td>old &gt; new*</td>
</tr>
<tr>
<td>It was clear how to work with the lab equipment and materials.</td>
<td>NS</td>
</tr>
<tr>
<td>This lab activity helped me improve my ability to think scientifically.</td>
<td>NS</td>
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Labs had identical curricula but different equipment. Table compares student attitudes for labs using old equipment (Gilson duographs) vs. new equipment (computers, MacLab) for 2 physiology labs and for using fetal pig dissections vs. ADAM computer animations. *Significance by ANOVA ($P < 0.05$). NS, nonsignificant. Error degrees of freedom ranged from 85 to 94.

![Graph showing average scores on scientific content quizzes for labs with identical curricula but differing in equipment.](image-url)
Biology 202. We suspect that these results occurred mostly due to the extensive time necessary for the instructors to learn how best to teach the use of all the new equipment and software. In subsequent semesters, we have learned to simplify software use by the students by using setup programs that minimize the need for the students to customize MacLab.

CONCLUSIONS

Student ratings indicate that the curricular and physical renovation conducted on this undergraduate anatomy and physiology lab significantly improved student learning, as judged by student perceptions (Fig. 3). The cost of this improvement was relatively small when expressed on a per student basis over the expected duration of use. However, the initial costs were considerable. We feel that the results of this assessment support the benefit of such investment in our students.

The specific components of the physical and curricular renovation that were mostly responsible for the improvements in student ratings of the course are somewhat unclear. One clear trend is that improvements in the physiology labs seemed to be more important than improvements in the anatomy labs (Figs. 4 and 5). The lack of a strong student preference or achievement difference between fetal pig dissection and computer animations was supported in our study of labs differing only in this variable (Figs. 6 and 7, Table 1). The improvement in student ratings of the physiology labs occurred despite a tendency for the students to find use of computerized data acquisition systems more difficult, at least in the first semester they were used (Fig. 7, Table 1). This finding highlights the need for further improvements in the student interface for such data acquisition systems. Because the newer equipment was not preferred by the students (Table 1) and student satisfaction increased for the physiology but not the anatomy labs (which had similar physical environments), we suspect that the most likely explanation for the improvement in ratings of the physiology labs is the use of the critical inquiry approach. Student written evaluations suggest that these open-ended labs tend to be more interesting and informative. However, we lack quantitative data in support of this interpretation.

Another likely contributor to the improvements in the overall ratings of the lab is the change in the physical space. Student surveys suggest that the physical renovation reduced glare and improved visibility and improved student circulation in the lab (4). Preliminary data on space use in the new and old laboratory rooms indicate that group work and student interactions are better facilitated in the new lab (8). Student written comments also suggest that just being in a new lab with new equipment and comfortable chairs makes a tremendous difference to their perception of the relevance and worth of the course. At least in the initial years after a renovation, most students feel lucky and positive to be the beneficiaries of such an investment.

The methods by which we measured the benefits of the renovation were imperfect. A better approach would be to evaluate learning by the use of a common set of assessment questions. In the future, it would be useful to define, a priori, the goals of the course, allowing common questions to be asked before and after a reno-
vation. In retrospect, we may have been able to argue that a focus on human (rather than fetal pig) anatomy was more justified for this course, and we may have found a way to test this before the availability of cadavers. Similarly, the push for more understanding of the methods of science is a strong trend in education today. Evidence from a broad variety of science courses suggests that use of an inquiry approach facilitates development of student reasoning skills and understanding of science (6), and, therefore, we could have justified testing whether students could generate hypotheses, experiments and predictions, and interpret data. On the other hand, with every gain, there is a loss. Students using computers and cadavers lose the hands-on dissection experience that prior students had with the fetal pigs. Cookbook labs and demonstrations allow a larger number of physiological topics to be covered in a 3-hr lab and, perhaps, allow greater time for discussion of theoretical aspects of physiology (7). If we judge the benefits of a renovation by only using a priori questions (such as on human rather than fetal pig anatomy), we risk missing such losses. Student attitude surveys seem less likely to suffer such problems. Another cost associated with generating common, unbiased assessment questions is the time required for both the instructors and the students. However, we feel that justifying the large initial costs of lab renovations will be aided by more rigorous assessments.

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