Training TAs in scientific teaching for the human physiology and anatomy laboratory

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SCIENTIFIC TEACHING (ST) is a method developed nearly a decade ago by Handelsman and colleagues (2) in which instructional practice in undergraduate science is based on current educational research findings and established best practices. The ST approach uses a process in which all students, especially those in courses with large enrollments, are more actively engaged in learning compared with traditional lecture-based courses.

Unique to ST is an active learning and inquiry-based framework that aims to ensure that the needs of students with diverse learning styles and backgrounds are addressed. Furthermore, students’ ongoing progress toward achieving the course learning goals can be assessed dynamically (e.g., via in-class responses while students are engaged in the process of learning) and at higher cognitive levels (e.g., beyond rote memorization), as demonstrated by Bloom’s taxonomy of learning domains (1). When integrated into a curriculum, ST methods have been shown to improve student knowledge retention because participation in these structured activities and group discussions has been shown to facilitate the identification of misconceptions, construction of new knowledge, and development of critical-thinking skills (9). Implementation of a variety of structured activities also appeals to a broader variety of learning styles (9).

In 2010, we incorporated the ST approach into the lecture portion of our Enhanced Human Anatomy and Physiology course at the University of Connecticut. Because this approach is particularly well suited to the laboratory classroom setting where an interactive approach is much more easily implemented, in 2011 we also adopted the ST approach into the laboratory component of our course. To facilitate this process as well as to extend the impact of an individual instructor, we trained a cohort of graduate students from diverse science backgrounds (e.g., biology, engineering, and allied health). The structure of the course is shown in Fig. 1.

To introduce the principles and utility of scientific teaching, at the beginning of the semester, TAs attend a 2-day on-campus workshop featuring learner-centered approaches. The 2-day TA training curriculum is modeled on The National Academies Summer Institutes on Undergraduate Education in Biology, created by The National Academies and Howard Hughes Medical Institute (6). During training, TAs learn ST principles about how people learn and how to use a variety of teaching methods to engage students and assess their learning progress. For example, participants in the 2011 training session learned how to design lectures from well-defined learning goals and objectives, a process described by Wiggins and McTighe as “backward design” (8). They also learned how to choose from various activities to engage students and discussed diverse types of learners and how different teaching approaches might be applied to engage learners with various social and ethnic background and learning approaches; topics such as formative assessment, summative assessment, and metacognition were also introduced to help participants refine their teaching approaches.

After completion of the workshop, ST-trained TAs meet weekly to discuss instructional plans for the following week. To prepare for each meeting, a pair of TAs develops a “teachable unit,” an instructional segment that appeals to a broad range of learning styles, for the upcoming laboratory (Table 1). With assistance from course instructors, the TA pair identifies the most confusing aspects of their topic, articulates clear student learning objectives that are closely tied to lecture objectives, and plans learning activities (e.g., concept map, drawing, think-pair-share, and brainstorming) that directly align with the learning objectives and also serve as formative assessment. The TA pair presents their teachable unit for critical peer evaluation during our weekly TA meeting. Most importantly, all TAs are required to work together to revise the final teachable unit to ensure consistent delivery to >20 laboratory sections.

Evaluation of ST-Trained TAs in the Physiology Laboratories

To evaluate the efficacy of this curriculum innovation, we recruited a comparison class from the Human Anatomy and Physiology course. The structure of this comparison course is shown in Fig. 1. TAs recruited to teach this course have
backgrounds similar to those who teach the Enhanced Anatomy and Physiology course. TAs in the comparison class receive an orientation that does not include any ST-related curriculum. The formats of the weekly training for both TA groups are very similar. For example, in the comparison class, a pair of TAs also prepare the teaching PowerPoint presentation with the course instructors ahead of time and all TAs work together to revise the final PowerPoint presentation during the weekly TA meeting. Both groups of TAs were asked to explicitly describe their learning goals and learning objectives. In the ST-focused weekly TA meetings, we emphasized principles of backward design and higher levels of interactive teaching. Despite the different pedagogical approaches, the laboratory curricula for the two courses (i.e., laboratory resources, technology involved, experiments, and assignments) are similar. Moreover, the laboratory activities are almost identical: half of the laboratories for both courses are inquiry based or have significant inquiry components.

At the end of the semester, we invited students in the Enhanced Human Anatomy and Physiology course to fill out a student assessment of their learning gains (SALG) survey (5) about their learning experience in our anatomy and physiology laboratory course. The identical survey was administered in the comparison course, Human Anatomy and Physiology.

We compared student responses to the SALG instrument based on the type of laboratory they were in (standard vs. ST influenced). For the present analysis, we focused on only the laboratory-related SALG items in accordance with the recommended analysis for the SALG instrument (5). This resulted in the identification of six SALG-defined categories, including: increase in skills, impact on attitude, integration of learning, laboratory instructional approach, lab activities, and individual support scores.

To ensure that the items in the present data set conformed to the validated SALG instrument’s category structure (5), an exploratory factor analysis for the items within each category was conducted. For each SALG category, e.g., integration of learning, when all participants’ data were considered, each associated exploratory factor analysis had a single factor (eigenvalue > 1) with the percentage of total variance accounted for ranging from 60% to 84% and factor loadings for each item of >0.70 (with only two exceptions). Thus, the present data set’s items conformed with the SALG instrument’s predetermined categories. In addition, exploratory factor analysis was conducted for each class separately. The analyses were largely the same, with two exceptions. For the comparison class, there were two SALG categories that had two factors (i.e., each with an eigenvalue > 1): lab activities and, separately, individual support. It is also the case that the items making up these two SALG categories are most directly related to the students’ laboratory environment, and, given the

Table 1. Example of a laboratory teachable unit developed by a work group

<table>
<thead>
<tr>
<th>Learning Goals</th>
<th>Learning Outcomes</th>
<th>Activities</th>
<th>Engagement Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understand the experimental setup</td>
<td>Explain how to calibrate a force transducer; demonstrate the use of a force transducer to record isolated frog gastrocnemius muscle activity with a stimulating electrode</td>
<td>Discuss what is being recorded and the necessity to calibrate the force transducer</td>
<td>Movie; brainstorming</td>
</tr>
<tr>
<td>Understand how skeletal muscle changes its contractile force</td>
<td>Define muscle recruitment; explain the relationship between increasing stimulus intensity on muscle contraction; explain the effects of increasing stimulus frequency on muscle contraction; differentiate among twitch, summation, tetanus, and fatigue; predict the changes of Ca²⁺ and ATP/ADP when different stimulus frequencies are applied; interpret recorded data</td>
<td>Propose how muscle can contract at different forces when the action potential is all or none.</td>
<td>Think-pair-share; diagram interpretation; case study; group work</td>
</tr>
<tr>
<td>Understand the length-tension curve</td>
<td>Describe the effects of stretch on contractile force; interpret recorded data; diagram the length-tension curve; predict how contractile force changes when the organization of skeletal muscle is modified (e.g., myosin or actin).</td>
<td>Predict the change of the length-tension curve when myosin heads were modified</td>
<td>Think-pair-share; draw diagram; clicker</td>
</tr>
</tbody>
</table>
two different approaches to lab work, these differences are to be expected.

For each of the six laboratory-related SALG categories, the means of the ST-influenced and comparison classrooms are shown in Fig. 2, and the sample sizes, means, and SDs are shown in Table 2. The items included in each category are shown in Table 3. We report only general response trends without tests of statistical significance due to the pilot, exploratory nature of this study. More specifically, students in the scientific teaching laboratory and the comparison group laboratory were not randomly assigned, and, given the limitations of the present data set, we were unable to account for the “nested” nature of the two classrooms using hierarchical mixed modeling.

Acknowledging these constrains, we explored the overall grade point averages (GPAs) and course grades for students in these two classes. We found no significant differences in cumulative GPAs ($P = 0.32$) and number of credits earned overall ($P = 0.57$). We found a difference in course grades, with a higher average in the standard classroom than the experimental classroom (mean: 2.94 vs. 2.57, $P = 0.02$). The significantly higher course grade averages for the standard laboratory class could be attributed to the courses being taught by different faculty members with different grading criteria or different exam structures.

As shown in Fig. 2 and Table 2, students taught in a ST-influenced laboratory environment reported overall higher perceived levels of learning gains. In addition, for the integration of laboratory learning to course content SALG category, ST-influenced students perceived to be influenced somewhat more. For all SALG categories related to student laboratory experience, this preliminary evidence shows that students perceived more learning gains in a laboratory curriculum that is structured within the ST framework.

Discussion

Our ST-trained TAs were specifically charged with engaging all learners and welcoming questions, doubts, and curiosity. The pilot study data suggest that students in this type of environment feel more comfortable revealing what they know and what they do not know and feel more comfortable and willing to seek help. We believe that this pattern of differences in attitudes shown through the SALG instrument is partially due to more structured and engaging group work: specifically, in the laboratories with TAs trained in ST, group work is required not only when conducting experiments but also during various instructional activities, such as developing hypotheses, solving problem sets, and analyzing case studies. Thus, students have more opportunities to work with peers and deal with group dynamics as well as the question itself.

Complementing the well-established and highly-regarded “inquiry-based” laboratories, which aim to engage students in the thinking processes of scientists (7), we believe that implementing principles of ST offers faculty members methods to further improve the laboratory atmosphere and encourage student participation by targeting the design, implementation, and assessment of active learning strategies. The ST approach provides an opportunity for both the instructors and students to frequently reflect on and assess the progression of learning and, therefore, enhances metacognition. It is particularly well suited for laboratory teaching that is traditionally delivered by lecturing.

Limitations. The most notable limitation in this study is that the two courses differ in a number of ways. The “treatment” course, Enhanced Human Anatomy and Physiology, is intended for biology and physiology/neurobiology majors and takes both a more quantitative and more investigative approach. Students have typically completed at least 1 yr of chemistry and are in the organic chemistry sequence. Lectures include primary literature source material, including discussions of appropriate experimental techniques used in understanding physiological phenomena.

Table 2. Six laboratory-related SALG categories responses from students in the standard laboratory sections and ST-influenced laboratory sections

<table>
<thead>
<tr>
<th>Category</th>
<th>ST-influenced Laboratories</th>
<th>Standard Laboratories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase in skills</td>
<td>3.67 (0.96)</td>
<td>2.59 (1.11)</td>
</tr>
<tr>
<td>Impact on attitude</td>
<td>3.36 (1.03)</td>
<td>2.68 (1.03)</td>
</tr>
<tr>
<td>Integration of learning</td>
<td>3.18 (0.96)</td>
<td>2.86 (0.99)</td>
</tr>
<tr>
<td>Help learning: class activities</td>
<td>3.67 (0.96)</td>
<td>3.07 (0.99)</td>
</tr>
<tr>
<td>Individual support</td>
<td>3.60 (1.14)</td>
<td>2.90 (1.17)</td>
</tr>
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</table>

SALG, student assessment of their learning gains.

Fig. 2. Six laboratory-related student assessment of their learning gains (SALG) category responses from students in the standard laboratory sections and scientific teaching (ST)-influenced laboratory sections. Responses were scored on a scale from 1–5, where 1 = no help, 2 = a little help, 3 = moderate help, 4 = much help, and 5 = great help. The response numbers, means, and SDs for each SALG category are shown in Table 2.

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ing, dietetics, and some biology or molecular and cell biology majors. The course accommodates a variety of backgrounds and levels of preparation, ranging from sophomore nursing students who have had one semester of chemistry plus freshman biology to senior premedical students who have taken advanced chemistry and additional biology courses. The emphasis of this course is on thorough coverage of each organ system to prepare for future professional school courses. These two courses are also taught by different faculty members, who do not use similar exams and grading scales.

It is possible that the differences we observe in our two groups of TAs are partially due to the initial workshop/orientation they receive at the beginning of the semester. The ST-influenced initial workshop is designed to create a framework for ST and provide tools to execute it. Instead of using a lecturing approach, the initial ST workshop aims to create a learning-centered environment and provides many opportunities for activities and discussions.

We have informally observed that ST-influenced TAs are more aware of common misconceptions that exist among their students; they are more ready to use various formative assessment tools to facilitate the learning process, and they do not give up easily when an activity does not appear to work initially. The TA workshop also promotes dialogues and discussions about the best practice of enhancing student success. During weekly TA meetings, there are more creative ideas on discussions about the best practice of enhancing student success.

As a result of your work in this class, what gains did you make in integrating the following?

<table>
<thead>
<tr>
<th>SALG Category</th>
<th>Items Included in Each Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increases in your skills</td>
<td>Identifying patterns in data; recognizing a sound argument and appropriate use of evidence; developing a logical argument and working effectively with others</td>
</tr>
<tr>
<td>Class impact on your attitudes</td>
<td>Enthusiasm for the subject; interest in discussing the subject area with friends or family; interest in taking or planning to take additional laboratories in this subject; confidence that you understand the material; your comfort level in working with complex ideas; your willingness to seek help from others (teacher, peers, and teaching assistants) when working on academic problems</td>
</tr>
<tr>
<td>Integration of your learning</td>
<td>Connecting the laboratory experience with key lecture ideas; applying what I learned in this laboratory in other situations; using systematic reasoning in my approach to problems</td>
</tr>
<tr>
<td>The class overall</td>
<td>The instructional approach taken in this laboratory</td>
</tr>
<tr>
<td>How much did the following aspects of the class help your learning?</td>
<td>Specific laboratory activities; participating in discussions; listening to discussion during the laboratory; the topics covered in the discussion; doing hands-on laboratory activities</td>
</tr>
<tr>
<td>Support for you as an individual learner</td>
<td>Interacting with the teaching assistant(s) during the laboratory; interacting with the teaching assistant(s) during office hours; working with the course instructor regarding laboratory topics; working with peers outside of the laboratory (e.g., study groups)</td>
</tr>
</tbody>
</table>

**Conclusions.** Interpretation of our initial promising findings on ST-influenced laboratories and perceived student learning gains should be viewed within the limitations just stated and considered pilot in nature. We expect that a more rigorous experimental design would support our hypothesis that the ST approach can further improve the already hands-on and engaging laboratory setting, yet this needs to be empirically tested.

**DISCLOSURES**

No conflicts of interest, financial or otherwise, are declared by the author(s).

**AUTHOR CONTRIBUTIONS**

Author contributions: X.C. conception and design of research; X.C. and K.K. performed experiments; X.C., J.F., and M.J.G. interpreted results of experiments; X.C. and M.J.G. prepared figures; X.C., K.K., J.F., and M.J.G. drafted manuscript; X.C., K.K., J.F., and M.J.G. edited and revised manuscript; X.C., K.K., J.F., and M.J.G. approved final version of manuscript; M.J.G. analyzed data.

**REFERENCES**