Modeling the Research Process: Authentic human physiology research in a large non-majors course

Anna K. Strain[1], Mary A. Williams[1] and Jane Phillips[1]*

[1] Department of Biology Teaching and Learning, University of Minnesota, St. Paul, MN

Abstract

Laboratory experiences in large-enrollment introductory science courses often utilize "cookie-cutter style" laboratory experiences due to the relative simplicity of setting up the lab stations, as well as a need to teach students particular course content. These experiences rarely offer insights into the way science is done in the research setting, resulting in a lack of understanding of the scientific process. In addition, students enrolled in non-majors introductory science courses often fail to see the relevance between what they are doing in the lab and what they are learning in the lecture portion of their course. To address this gap, we developed a laboratory module for a non-majors Human Biology course that provides students with a hands-on, authentic research experience using the iWorx software and hardware for human physiology. Weekly modules were designed to guide students through the major steps of the research process, including reading current scientific literature, developing a testable hypothesis, designing and performing a physiology experiment, analyzing data and presenting their findings to their peers. The described course framework encouraged students to participate in the scientific process, providing them with the opportunity to engage in an authentic research experience. The model described here could be adapted for use with introductory or advanced students, and could be modified to fit any research model available to the instructor. Utilizing the multi-week format described is recommended for students to gain the full benefit from the research-design-revise process.

Learning Goal(s)

Students will:

- Understand how science is done in a research setting, developing a deeper understanding of the scientific process.
- Demonstrate critical thinking skills.
- Appreciate how scientists study human physiological processes

Learning Objective(s)

Students will be able to:

- Read current scientific literature
- Formulate testable hypotheses
- Design an experimental procedure to test their hypothesis
- Make scientific observations
- Analyze and interpret data
- Communicate results visually and orally

Citation: Strain, A.K., Williams, M.A. and Phillips, J. 2014. Modeling the Research Process: Authentic human physiology research in a large non-majors course. *CourseSource.* https://doi.org/10.24918/cs.2014.12

Editor: Mary Mawn, SUNY Empire State College

Received: 3/03/2014; **Accepted:** 7/02/2014; **Published:** 12/01/2014

Conflict of Interest and Funding Statement: The authors are not aware of any conflict of interest. Anna K. Strain and Mary A. Williams were funded for their work on this project from an HHMI Grant for Undergraduate Science Education at the University of Minnesota.

Materials and Supplemental Materials: Table 1. Organization of the six-week research experience labs, including lab activities and assignments, and the recommended minimum time to spend on each activity. Table 2. Examples of the human physiology measurements our students could make using the iWorx equipment. Figure 1. Students were asked at the end of the Jigsaw activity to respond to the statement: "Please list one or two words that come to mind when you think about your upcoming experimental design". These responses were compiled and used to make the depicted WordCloud using Wordle (http://www.wordle.net/). Supplemental File S1: Jigsaw Activity Instructions, Supplemental File S2: Jigsaw Quiz and Key, Supplemental File S3: Introduction to Experimental Design, Supplemental File S4: Experimental Design Rubric, Supplemental File S5: Analyzing your Data, Supplemental File S6: Introduction to Excel, Supplemental File S7: Creating Presentations and Supplemental File S8: Research Team Presentation Rubric

***Correspondence to:** Jane Phillips, University of Minnesota, 123 Snyder Hall, 1475 Gortner Ave., St. Paul, MN 55108

INTRODUCTION

Origin of this Teaching Activity

Two of the authors (AKS, MAW) were funded by an HHMI Grant for Undergraduate Science Education to help create a new multi-week, inquiry-based science experiment module for a non-majors Human Biology course. In collaboration with the instructor for this course (JP), this lab module was developed and implemented in the spring semester of 2013.

The call has gone out to prepare scientifically literate students, and to engage them in the scientific process by providing them with authentic research experiences (1). Several studies have indicated that such an inquiry-based approach is an effective method for increasing student achievement in STEM (science, technology, engineering and math) majors (2-4). Recent studies suggest that inquiry-based laboratories help to promote student understanding of science concepts and enhance student confidence in science skills (5-8). Results from these studies indicate that allowing students to develop and test their own hypotheses encourages them to think critically and analyze data (5-8). The vast majority of these types of studies have been primarily focused on learning gains for science majors. To our knowledge, there is a decided lack of studies that specifically address non-majors courses in the context of experiential lab activities. We felt this goal of enhanced student achievement in science should apply both to students planning to continue in a STEM career and those who choose an alternate career path. These students will become the "general public" in the future and could play an important role in societal policy decisions. As such, they should have a basic understanding of the role of science in their lives and how science is performed. We chose to develop an authentic-research experience module for students enrolled in the Human Biology course at the University of Minnesota (UMN), a large-enrollment non-majors course with three class meetings and one two-hour lab session (multiple sections) each week. The laboratory portion of this course has traditionally been heavily focused on gross anatomy and dissections, with some microscopy using prepared slides to look at cellular structures. We wanted to get students actively involved in the scientific process, to ask questions and to do some hands-on physiology experiments. Our ultimate goals were to engage students in the scientific process, increase their scientific literacy, and to enhance their knowledge and comfort level with scientific concepts. Really, we wanted them to see that science can be fun and that it is not just all about memorization.

Intended Audience

The six-week research experience module described here is intended for first-year, non-biology majors in a Human Biology course, but the general concept could be used in any introductory biology course, whether for majors or non-majors. This is a large-enrollment course, typically with more than 240 students in two lecture sections. Students in the course enroll in one laboratory section with a maximum of 20 students per lab. Within their section, they are assigned to a team of four students with whom they will be working throughout the semester. This is their Research Team.

Learning time

This is a six-week laboratory module, designed to be used in a course that has lab sessions that meet once per week, lasting for two hours. The entire lab period is not required each week, and students completed other laboratory activities (e.g. dissections) while this module was implemented at the UMN. Please refer to Table 1 for detailed information about the amount of time involved each week for the described module. Modifications to the lab time can be made as needed to fit other courses; these are the minimum times recommended for achieving the learning goals.

Pre-requisite student knowledge

A basic understanding of how a scientific experiment is performed is beneficial; more detailed information is provided in the lesson and handouts. Additionally, the experimental questions described here are geared to utilize students' prior knowledge of topics covered in the course, in this case, knowledge of the cardiovascular and nervous systems. Modifications can be made to meet individual course needs.

SCIENTIFIC TEACHING THEMES

Active learning

- *Outside of class:* Students read a scientific article about recent research in human physiology, answering questions about the study design to prepare them for in-class activities. Students read materials on experimental design, data analysis and oral presentations. Student Research Teams develop experimental designs, analyze data and prepare oral presentations.
- *Inside class:* Students participate in a Jigsaw activity to present to their Research Team the article that they read. Students discuss experimental design strategies. Students develop hypotheses on how physiological measurements could be altered, and design experimental strategies to test their hypotheses using the iWorx (or similar) system. Students perform their experiments, collect and analyze data, and present the results to their peers.

Assessment

- Student learning is measured by instructors through questions on a lab quiz after the Jigsaw activity (Supplemental S2), to determine their understanding of the basic aspects of the scientific process. Student learning is assessed through rubrics used to assess their experimental design and final presentations (Supplementals S4 and S8, respectively). Pre- and post-quizzes may be given to assess learning gains related to the scientific skills and processes.
- Students self-evaluate their learning through the development and revision of the experimental design. This portion of the activity is done in two parts, with students bringing in a rough draft of the experimental protocol that is refined after discussions with the laboratory teaching assistant.

Inclusive teaching

- This six-week module allows students to determine and develop their own experimental question(s).
- All students are able to participate in both the experimental design and data collection; Research Teams are able to tailor their questions to accommodate students of all abilities.
- Experimental questions raise issues of diversity as the experimental results may depend on a variety of factors. Students must decide which factors play a role in any conflicting results, and come to an understanding of the role of participant criteria in human studies.

Teaching Assistant Training

This large-enrollment course involves over 240 students, divided into at least twelve lab sections with 20 students each. It would not be possible for a single instructor to be present at all lab sections, as well as teach the three lectures per week in two different lecture sections of the course. As such, we rely on our teaching assistants (TAs) to take the lead in providing the laboratory-based components of the course. The TAs for our course were either upper level science majors at the top of their class in academic ranking, or graduate students hired as teaching assistants. In either case, the TAs must have successfully completed an anatomy and physiology course and show competence in anatomy and physiology. In addition, our TAs typically have at least one semester of research experience.

For this module, although two of the authors (AKS, MAW) sat in on two laboratory sections throughout the six week activity, we felt it was important to allow the TAs to continue to have the leadership role in their sections. This six-week module had the added benefit of allowing the TAs an opportunity to further develop their science teaching skills.

Given our use of TAs in the laboratory, it is important that they have appropriate training to address any questions or problems that might arise in the process. As a part of TA training, TAs completed a weeklong training session with the course instructor and lab manager prior to the start of the semester. During the semester, they attended weekly training meetings lead by an experienced head TA who had been involved with the course for two years. These meetings included discussions of upcoming activities, the potential for any problems and how to deal with issues that may arise. These weekly meetings were also an opportunity for the TAs to share their insights and suggestions with one another.

In the weeks prior to the start of the six-week module described below, training was provided for the TAs on the iWorx equipment. Several of the TAs had used the equipment previously, and for those TAs it was a chance to refresh their skills and to test the iWorx tutorial we had developed for use by the students. This preparation provided the TAs a level of comfort with the iWorx equipment but did not necessarily make them an expert in all aspects of the equipment. For troubleshooting technical problems that the TAs were unable to handle themselves, senior lab staff was always available during laboratory sections to lend assistance.

For the purpose of this activity, we specifically instructed the TAs to troubleshoot experimental problems only at the general level (e.g. helping students to think about how they would quickly attach electrodes to a research participant after an aerobic activity), but not to predict results or to say that an experiment was not worth doing. We wanted to allow students the freedom to propose and execute experiments even if we knew it was unlikely that the students would observe a difference between treatment groups. We did not intentionally want experiments to fail, but this failure was a potential part of the experimental design process. The research was still new for the students, and they were able to perform simple statistical analyses with their data. For issues relating to experimental design or hypothesis development, students and TAs could consult with the instructor or post-doctoral fellows, as well as any of the TAs or support staff. Although this additional support was not always physically present in the labs, one or more individuals were available in nearby rooms if needed during the labs.

LESSON PLAN

This module is structured over a six-week period, with the basic activities scheduled as indicated in Table 1. When we first implemented the module, we began the six-week arc in week six of the semester, which allowed time for instructors to introduce students in the class to looking at and thinking about scientific data and concepts, and for students to familiarize themselves with the laboratory setting The first activity in the research experience module is a Jigsaw activity. Following this activity, the research experience module guides students through the process of designing an experiment, collecting and analyzing data, and presenting the results of their hypothesis testing. An overview of the schedule of activities is provided in Table 1 (on page 4). We did not use a set script for each week, however, an overview of the weekly activities is provided below.

Week 1- Reading the scientific literature for experimental ideas

This activity will take up about half of one lab session (60 minutes), and should be introduced the week before students participate in the Jigsaw.

Teacher and teaching assistant preparation: You may want to read the Jigsaw Activity Instructions (Supplemental File S1) if you have never done a jigsaw activity before. Even if you have, it would be good to familiarize yourself with the unique aspects of this activity. The purpose of this jigsaw activity is to introduce students to reading the scientific literature and to give them a feel for how physiology experiments are designed and performed. Based on our previous experiences, we set the following criteria for our article selection: the articles must 1) be readable by a non-scientist, 2) provide ideas for student experiments, and 3) be well-designed so that students understand the components of good experimental design. Because our students were going to be using the iWorx software and hardware system to perform their experiments, we chose articles that related to the measurements that they would be able to perform. The types of measurements we allowed students to select from the first time we ran this module are listed in Table 2.

Table 1: Modeling the Research Process-Teaching Timeline

Topic	Assignment for upcoming week	Description of relevant in-lab activity	Approximate time (of 2 hour weekly meeting)
Week 0			
	Read: Jigsaw handout, assigned jigsaw article	Introduction by TA of iWorx; small group discussion of project ideas	15-20 min in class
Week 1			
Reading the scientific literature	**Read:** Introduction to Experimental Design **Think About:** Developing a research plan	**Do:** Jigsaw activity **Discuss:** Limitations of research activities in class setting	60 min
Week 2			
iWorx Tutorial	**Develop:** Experimental design **Read:** Experimental Design Rubric	**Do:** iWorx Tutorial	90-120 min
Week 3			
Experimental Design and Data Collection Trial	**Read:** Analyzing Your Data	**Do:** Revise and refine experimental design with TA	60-90 min
Week 4			
Testing your hypothesis (day 1)	**Read:** Presenting Your Research **Skim:** Presenting Your Research Rubric	**Do:** Conduct experiment and collect data	120 min
Week 5			
Analyzing and Understanding Your Data	Work on data analysis and presentation	**Do:** Day 2 of data collection (if needed), Data Analysis; Work on presentations	60-90 min
Week 6			
Presenting Your Research		Group presentations (5-10 min per group)	40 min (depends of number of groups)

Strain, A.K., Williams, M.A. and Phillips, J. 2014. Modeling the Research Process: Authentic human physiology research in a large non-majors course. *CourceSource*.

Table 2. Modeling the Research Process-Examples of human physiology measurements our students could make using the iWorx equipment

System/Process	Measures
Human Circulation	
Blood Pressure	Pulse, blood pressure and heart rate
ECG	Saturated oxygen levels and electrocardiogram (ECG)
Pulse	Vascular tone, arterial stiffness, pulse and blood pressure
Human Heart	
Diving Reflex	Pulse, then correlates to breathing and diving reflex
ECG	Pulse, ECG and heart rate
Human Muscle	
EMG	Electromyogram (EMG)
EOG	Electrooculogram (EOG-elecrical activity from eye muscles)
Human Nerve	
Achilles	EMG and reflex conduction time
Auditory	Reaction times with visual and auditory cues
Patellar	EMG and reflex conduction time
Human Psychophysiology	
EEG	Electroenecephalogram (EEG)
Spirometry	
Breathing	Lung volume

Strain, A.K., Williams, M.A. and Phillips, J. 2014. Modeling the Research Process: Authentic human physiology research in a large non-majors course. *CourceSource.*

The week before the jigsaw activity, the teaching assistants (TAs) who lead the laboratory sections introduced the research experience module by describing some of the measurements and capabilities of the iWorx equipment. This introduction is intended only as a highlight, to encourage students to start thinking about what types of measurements they can make with the equipment. The TAs also have students begin to discuss possible project ideas. Before students leave, the TAs should assign the Jigsaw Activity Instructions to students (Supplemental File S1). The assignment includes a handout explaining what will happen during the jigsaw activity in the lab, guiding questions about the assigned research article that students must respond to before the following lab period, and the assigned research articles. The TA should assign each member of a student Research Team to a different paper. We found the easiest way to assign students to a paper was to tell them that they were assigned to "Group Bernardi", for example, which corresponded to the first author of the research paper. The articles we assigned can be found in Supplemental S1. Because many of our students are not used to reading the scientific literature, we also provided some guidance for reading a scientific research paper in the Jigsaw Activity Instructions (Supplemental File S1). The instructors and TAs should be familiar with each of the articles assigned; we found it helpful to compile a key for each article in order to address any student questions or misunderstandings during the activity.

Student preparation: In preparation for the jigsaw activity, each student needs to read their assigned research article and the handout describing the jigsaw activity, then answer the questions about the research article provided in the Jigsaw Activity Instructions (Supplemental File S1). Students will discover that each member of their Research Team has been assigned to a different research article and, in reading the Jigsaw handout, will discover that they need to be the expert in their team on their assigned paper. Students need to have completed the reading and answered all of the questions about the paper before coming to class in order to be able to participate in the jigsaw activity. We found that students did not want to let down their peers, so we had little difficulty enforcing this requirement.

During Class: During class, students show their responses to the guiding questions to their TAs as their "ticket for admission" to the jigsaw activity. They then find the other members of their lab section that read the same paper that they read and discuss their responses to the guiding questions. This part of the activity should take about 10-15 minutes to ensure that all students agree on the answers. Students are asked to determine the general structure of their research paper, the main questions being asked by the researchers, why anyone should care about the answers to those questions, what the researchers' hypothesis is and how they went about testing their hypothesis. Students then go over the experimental design in detail, determining the take-home message and conclusions of the research, and deciding whether or not they agree with the authors' conclusions. Once the student "experts" have agreed on their responses, they return to their Research Team and present their research paper to the other members of their team. This should then lead into a discussion within the Research Teams about the types of experimental questions they want to ask and how they might use some of the techniques they read about to answer those questions. We took this opportunity to discuss the limitations of research activities in a teaching lab setting, and research ethics that should apply in the lab setting. Students were not allowed to propose experiments that could cause bodily harm or could be considered unethical.

Assessments: After completing the jigsaw activity, students were given a short quiz on reading scientific literature and the components of experimental design. For consistency with other lab quizzes, this was given as a multiple choice quiz, representing foundational level Bloom's skills. The questions we asked are provided in Supplemental File S2, along with the answer key. These questions could be modified as needed to fit the research model used in the class setting. As a formative assessment for how students were feeling about the research experience at this point, we also asked students to provide a response to the following statement: "Write one to two words that come to mind when you think about designing your own experiment". We compiled student responses from each lab section into one document and created a WordCloud using the online software tool available at wordle.net. The results of this impromptu survey, shown in Figure 1, were shared with the students at the next lab session.

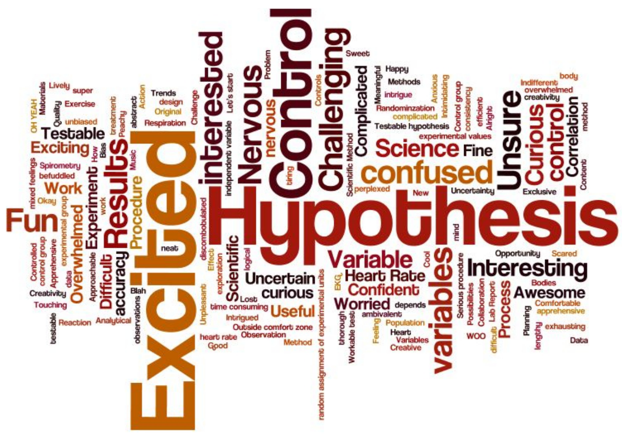

Figure 1. Modeling the Research Process-Wordcloud of experimental design

Week 2- Introduction to physiology measurements: the iWorx tutorial

Students are introduced in this week to the iWorx equipment and software, giving them hands-on experience with the equipment. In the first iteration of this module, we had all students work through a tutorial on how to record measurements of an electrocardiogram (ECG), which was a slightly modified version of the tutorial provided by the manufacturer. Once they felt comfortable with that tutorial and were able to produce an ECG, they were able to test out some of the other equipment available with the iWorx machinery, if their experiment involved some other physiological measurement (see Table 2 for details on the equipment available for students at UMN). For example, some students were interested in measuring brain activity while multitasking, and so they did an additional tutorial on how to record and assess electroencephalogram (EEG) measurements. This entire lab period was devoted to learning the iWorx so that students were comfortable working with the equipment to collect the data they needed.

Teacher preparation: Familiarize yourself with the iWorx equipment and manufacturer's tutorial to be prepared to help troubleshoot any technical problems. Provide one set of iWorx equipment for each student team to use.

Student preparation: Before coming to class, students read the Introduction to Experimental Design handout (Supplemental File S3). This document provides guidelines for the components of a good experimental design, as well as worksheets for them to begin drafting their team experiment plan.

During class: Students should have the entire lab period this week to work through the iWorx tutorial, learning how to use the program software, practice applying the electrodes to the skin, practice taking measurements and begin to work with the type of data they will be collecting. This process should not be rushed, as the students need to feel comfortable enough with the equipment so that they can trouble-shoot their experimental design in the next lab period. We used this week to encourage students to continue thinking about their experimental design, and remind them that they need to come to lab the following week prepared to do a trial run of the experiment. Before leaving, students should be reminded that they need to develop their experimental design for the next class period, and should look over the Experimental Design Rubric (Supplemental File S4) to help guide their designs. In the next lab period, each Research Team will work with the TA to be sure they have a workable experimental design, but they should begin this process in this second lab period so that they have additional opportunities to refine their procedure.

Week 3- Introduction to experimental design and data collection

Teacher preparation: Teachers and TAs need to be prepared to answer questions about experimental design and how to use the iWorx equipment to collect the measurements students need to address their hypotheses. Primarily, the preparation is the same as for week 2: Familiarize yourself with the iWorx equipment and manufacturer's tutorial to be prepared to help troubleshoot any technical problems. Provide one set of iWorx equipment for each student team to use.

Student preparation: Research Teams should prepare a working outline for their experimental plan and be prepared to take test measurements of their experiment. Students should familiarize themselves with the Experimental Design Rubric (Supplemental File S4) so that they understand how their experimental plans will be assessed. They will go over their experimental design with the TA during lab time, but they need to have worked through the Experimental Design worksheet (Supplemental File S3) prior to coming to lab.

During Class: Although students likely will not appreciate this week, it is a key part of the research experience arc. This week they will test out their experimental plan, making sure that they know how to take measurements under the conditions they are planning in their experimental design. This process may seem to students to be a repeat of the activities during week 2, or it may make the data collected in week 4 feel less "real". However, it is important to remind them that this trial run will help them assess where they may have difficulties in the data collection, what they may need to prepare for, and to determine the best way to perform their experiment to collect the data that they want and not have errors due to technical difficulties. For example, they may discover that the recordings they want to take cannot be measured in a loud classroom but instead require a quiet environment. If so, students were able to arrange a time to come in outside of standard lab time to take those types of measurements. Before students leave lab today, provide them with the "Analyzing Your Data" handout (Supplemental File S5), explaining that data analysis is a key component of experimental design. Knowing what you are going to do with your collected data is as important as knowing how to collect your data, and is an aspect of experimental design that is not always well understood by young researchers. This was also an excellent opportunity to remind them of the importance of controls in any experiment, and for the teams to ensure they had considered these aspects of their experimental design. Students were given about 60-90 minutes of the class period this week to go through their experimental designs, receive feedback, and make revisions. Assessments: By the end of this lab period, student teams had a chance to work through their experimental protocol and to receive feedback on their protocol from their TA. The Experimental Design Rubric provided in Supplemental 4 was used by the TAs to evaluate the experimental protocols. This assessment correlates with application and creation level Bloom's skills, as students were required to apply the knowledge and skills gained during the first two weeks of the module, as well as create their own hypothesis to test.

Week 4- Testing your hypothesis

Teacher preparation: As with week 3, little additional preparation is required. Teachers and TAs need to be prepared to help troubleshoot equipment problems or data collection issues, be prepared to participate as a research subject, and lend general support. As for weeks 2 and 3, the lab should be set up to provide general equipment for each student team. Any supplemental equipment should be provided by the student (unless other arrangements have been made).

Student preparation: Working with the feedback from their TA and their experiences from week 3, students should revise their experimental plan so that they are prepared to do the actual measurements during the lab period this week. They should provide any outside materials needed for their experiment, and ensure they have arranged for the appropriate number of volunteer subjects so that they are able to perform statistical analyses on the data they collect. Students should read Supplemental S5, "Analyzing Your Data", prior to coming to the lab. We also provided a basic guide to using Excel for students that did not have previous experience using Excel for data analysis (Supplemental File S6), and recommended they read that handout if needed before class.

During Class: This week is the most exciting week, in our experience: hypothesis-testing week. Students should be encouraged to collect as much pertinent data as they can during this lab period. This reminder is especially important if you are not able to extend the data collection period beyond this one two-hour lab session. We were able to make some adjustments for our students, providing them with opportunities to come into the lab during non-class times, but this is not always possible. If students were able to complete all their data collections in this time period, we invited them to begin analyzing their data while the TAs and instructors were available to help if they had questions about their data analysis.

Week 5- Analyzing and Understanding Your Data

Teacher preparation: Minimal preparation is required on the part of the instructor this week. The task at hand will be ensuring that students are analyzing their data in an appropriate way, and answering any questions related to the data.

Student preparation: Student teams should begin analyzing their results before coming to lab to verify that they have all the necessary data. Students should read Supplemental Files S7 and S8 prior to the lab session, "Presenting Your Research", and the "Research Team Presentation Rubric".

During Class: This lab session is divided between data collection, if any data points are missing, data analysis and some time for student teams to begin working on their presentations. Ninety minutes were set aside for students to work on these components during the lab time, with time left over for students to work on other course material. We encouraged students to ask all of their questions about the presentations and analysis phase at this point, as the following week of lab class is team presentations.

Week 6- Presenting your research!

Teacher preparation: Be sure that students have either a flash drive or a way to upload their presentation files to a course management system for ease of access for the presentations.

Student preparation: Student teams must complete their data analyses and presentations prior to coming to the lab period. Presentations should be practiced so that all members feel comfortable with the presentation.

During Class: Student teams are introduced individually and provided with seven minutes to present their research question, hypothesis, experimental design, results, and conclusions. Students who were not presenting were encouraged to ask questions, with about three minutes allowed for the question and answer session. Once the question ball got rolling, it was often difficult to get it to stop. Because the students all had experience designing physiology experiments at this point, they were very interested in the experimental designs that others had come up with.

Assessments: The culmination of this six-week module is the creation of oral presentations by individual Research Teams to present their research findings. Most students chose to use PowerPoint as their presentation platform, although this was not a requirement. Presentations were evaluated by TAs using the grading rubric provided in Supplemental File S8. We measured application and analysis level Bloom's skills, assessing the ability of students to apply the knowledge learned throughout the module in order to collect and analyze data. Students were also expected to synthesize and evaluate their data and experimental design, to determine whether their hypothesis was supported by the data collected.

To assess learning gains on scientific process skills, we administered a pre/post-survey using questions derived from the TOSLS assessment tool (9). This assessment was done during the lecture portion of the course. The survey was administered one week prior to and one week after completing the six week laboratory module. The survey was presented in a multiple choice format, measuring foundational knowledge as well as the ability to analyze graphical data.

TEACHING DISCUSSION

The goals of this activity were to provide students with the opportunity to fully engage in a research experience as a scientist would. This engagement included reading primary literature to develop experimental questions, formulating testable hypotheses, designing and implementing an experimental procedure to test their hypotheses, and collecting, analyzing and reporting their data to their peers for consideration. These goals align with the UMN Council on Liberal Education (CLE) guidelines for non-majors biology courses, which aim to promote biological literacy among non-scientists (10). Our learning goals do not focus on material retention but rather on understanding how science is done, including why data is important to biologists, how to collect and analyze data, and how biologists communicate with one another. For most of our learning goals (understanding the elements of research design, understanding and interpreting basic statistics, and ability to create graphical representations of data), student performance on an assessment of science process skills improved after the six-week module (unpublished data). In addition, student confidence in their scientific abilities increased after the six-week lab module (unpublished data).

When we began developing this module, we hoped that students would develop their science process skills and improve their confidence in their science skills. An outcome that we had not anticipated was that students and instructors would actively enjoy participating in the module. One TA indicated that "all the students were very enthusiastic and excited to gather data." Student buy-in on the experimental design was very high, although there was some confusion in the beginning about the specific weekly requirements. For example, one TA whose class met earlier in the week indicated that only one of her student Research Teams came with a fully detailed experimental design for week three. The remaining teams only had outlines sketched out. However, by the end of the lab period each team had workable experimental plans with appropriate controls and replicates planned.

While the majority of responses to the activity were positive, we did receive some negative comments when we solicited feedback from students and TAs at the end of the module. Most of the negative comments were in reference to the iWorx equipment and software, not to the research activities. In addition, a few students indicated they had already learned the scientific method in high school and therefore this type of laboratory experience was not needed. Given these responses, we modified some of the procedures as described below.

The key factor in the success of this module is good communication. Providing students with a clear timeline for when different components are due, as well as being clear in the expectations for participation in the activity resulted in a rewarding learning activity for all. Several TAs and students indicated it was "the most fun" they had experienced in a science lab.

Finally, while we did not formally measure the impact of the module on science teaching skills in our TAs, we saw clear improvements in the ability of the TAs to critically evaluate student work and progress throughout the module. TAs who continued working with this course the following fall semester had become more adept at guiding students to testable hypotheses and away from inappropriate analyses and conclusions.

Suggestions for modifications: Based on our experiences implementing this module in the spring semester of 2013, the following modifications were suggested and implemented for the fall semester. To respond to student comments indicating some frustration with trying to learn multiple components of the iWorx equipment, we chose to restrict students to ECG measurements for their experimental designs. This helped the TAs feel more comfortable with troubleshooting any experimental difficulties, as they did not have to first determine which experimental measurements were being taken. It also streamlined the tutorial process; students did not need to learn two different tutorials before deciding on their experimental questions. In addition, one of our TAs substantially revised the iWorx tutorial to provide a more student-friendly and activity-focused format.

SUPPLEMENTAL MATERIALS

- Table 1. Modeling the Research Process-Organization of the six-week research experience labs, including lab activities and assignments, and the recommended minimum time to spend on each activity.
- Table 2. Modeling the Research Process-Examples of the human physiology measurements our students could make using the iWorx equipment.
- Figure 1. Modeling the Research Process-Students were asked at the end of the Jigsaw activity to respond to the statement: "Please list one or two words that come to mind when you think about your upcoming experimental design". These responses were compiled and used to make the depicted WordCloud using Wordle (http://www.wordle.net/).
- Supplemental File S1: Modeling the Research Process-Jigsaw Activity Instructions. This supplement outlines the jigsaw activity done by the students to prepare them for thinking about and designing their own experiment. We purposefully chose research papers that would be understandable by non-majors and also would give some idea of the kinds of questions they could ask that would lead to their testable hypothesis.
- Supplemental File S2: Modeling the Research Process-Jigsaw Quiz and Key. This file contains the quiz with answers that we used to assess whether students understood some basics of reading scientific literature and the components of experimental design after doing the jigsaw activity.
- Supplemental File S3: Modeling the Research Process-Introduction to Experimental Design. This document provides guidelines for the components of a good experimental design, as well as worksheets for them to begin drafting their team experiment plan.
- Supplemental File S4: Modeling the Research Process-Experimental Design Rubric. This rubric is used to grade the Research Team's experimental designs. Allowing the students to see the rubric as they are writing their designs helps them include all important elements.
- Supplemental File S5: Modeling the Research Process-Analyzing your Data. This supplement helps those students with less background in data analysis to be better prepared for data collection.
- Supplemental File S6: Modeling the Research Process-Introduction to Excel. This introduction was written for students unfamiliar with Excel for data analysis, a common problem in non-majors courses.
- Supplemental File S7: Modeling the Research Process-Creating Presentations. Along with Supplemental File S8, this helps Research Teams prepare their presentations so that all the important elements are included.
- Supplemental File S8: Modeling the Research Process-Research Team Presentation Rubric. This rubric is used to grade the Research Team's presentations.

ACKNOWLEDGMENTS

We would like to acknowledge the help of Sarah Borgen and Sandra Stroup with helping to prepare the iWorx tutorial and equipment for the course. We also thank Judi D'Aleo from iWorx for her help with the software. In addition, the TAs in the Human Biology labs were key to the success of this module. Without their help, this would not have been possible. Special thanks to Tatyana Berkhina, Sarah Campbell and Ben Swart, who allowed us to sit in on their lab sections

and watch them work their magic, in addition to providing constructive suggestions for improvements to the module.

REFERENCES

1. **Woodin T, Carter VC, Fletcher L.** 2010. Vision and change in biology undergraduate education: a call for action-initial responses. CBE Life Sci Educ. 9:71-73.
2. **DiPasquale DM, Mason CL, Kolkhorst FW.** 2003. Exercise in inquiry. J Coll Sci Teach. 32:388-393.
3. **Myers MJ, Burgess AB.** 2003. Inquiry-based laboratory course improves students' ability to design experiments and interpret data. Adv Physiol Ed. 27:26-33.
4. **Michael JA, Wenderoth MP, Modell HI, Cliff W, Horwitz B, McHale P, Richardson D, Silverthorn D, Williams S, Whitescarver S.** 2002. Undergraduates' understanding of cardiovascular phenomena. Adv Physiol Educ. 26:72-84.
5. **Mitchell BF, Graziano MR.** 2006. From organelle to protein gel: a 6-wk laboratory project on flagellar proteins. CBE Life Sci Educ. 5:239-246.
6. **Brownell SE, Kloser MJ, Fukami T, Shavelson R.** 2012. Undergraduate biology lab courses: comparing the impact of traditionally based "cookbook" and authentic research-based courses on student lab experiences. J Coll Sci Teach. 41:36-45.
7. **Rissing SW, Cogan JG.** 2009. Can an inquiry approach improve student learning in a teaching laboratory? CBE Life Sci Educ. 8:55-61.
8. **Gasper BJ, Gardner SM.** 2013. Engaging students in authentic microbiology research in an introductory biology laboratory course is correlated with gains in student understanding of the nature of authentic research and critical thinking. J Microbiol Biol Educ. 14:25-34.
9. **Gormally C, Brickman P, Lutz M.** 2012. Developing a Test of Scientific Literacy Skills (TOSLS): measuring undergraduates' evaluation of scientific information and arguments. CBE Life Sci Educ. 11:364-77.
10. **University of Minnesota.** 2010. Guidelines for proposing a liberal education course. University of Minnesota <http://cscl.umn.edu/assets/doc/__CLE_Guidelines.pdf>. Accessed 2014 May 9.