Fostering improved anatomy and physiology instructor pedagogy

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Mattheis, A., Jensen, M. Fostering improved anatomy and physiology instructor pedagogy. Adv Physiol Educ 38: 321–329, 2014; doi:10.1152/advan.00061.2014.—Despite widespread calls for reform in undergraduate science, technology, engineering, and mathematics education, effecting lasting change in instructor practice is challenging to achieve. This article describes the results of a 2-yr research study that involved efforts to develop the pedagogical expertise of a group of anatomy and physiology instructors at the college level. Data were collected through a series of individual interviews that included the use of the Teacher Beliefs Inventory questionnaire (23) along with observations onsite in participants’ college classrooms and at process-oriented guided inquiry learning (POGIL) curriculum writing workshops. Findings indicated attitudinal shifts on the part of participants from teacher-centered to more student-centered pedagogy and supported the benefits of long-term professional development for instructors. Here, we documented the successful progress of these professors as they participated in a curriculum development process that emphasized student-centered teaching with the goal of promoting broader change efforts in introductory anatomy and physiology.

undergraduate education; professional development; introductory anatomy and physiology; instructional change

Many introductory biology courses at postsecondary institutions are taught by scientists with a great deal of content knowledge and professional background but little formal education in instruction. This can often lead to teaching that prioritizes memorization of facts rather than conceptual understanding and higher-order thinking, a situation common to many such courses (26) but out of step with contemporary best practices in science education. A good deal of research has focused on the impacts of curricular change and teaching practices on students, but fewer studies have examined the impact on the instructors themselves. Investigating the process by which teachers learn about, adapt, and even resist instructional change is necessary to promote best practices and increase the quality of teaching in science, technology, engineering, and mathematics (STEM) fields. Allendoerfer et al. (2) also proposed that examining the practice of faculty members associated with STEM courses “can offer unique insight into what it takes, at a broad systemic level, to catalyze a shift from teacher-centered to student-centered instruction.” This article describes a study that sought to improve instruction in the field of undergraduate anatomy and physiology by involving a group of professors in 2 yr of professional development focused on the writing of a set of curriculum modules following the process-oriented guided inquiry learning (POGIL) approach.

Broad agreement exists in the field of science education that more engaging pedagogies benefit students in introductory classes (see, e.g., Refs. 7, 28, and 38). In one experiment in a large enrollment course that tested the effect of decreasing time spent on lecture and increasing cooperative group activities, Knight and Wood (20) found that students showed gains in both learning and responsibility. Similarly, Luckie et al. (22) reported that students dedicated additional time to more cognitively demanding tasks (based on Bloom’s taxonomy) in a physiology laboratory course after revisions to a curriculum that focused on increasing collaborative learning activities. Other work has served to explore particular pedagogical interventions designed to encourage more active and engaged science classrooms, including problem-based learning, POGIL, and peer-led team learning (13). Research specific to anatomy and physiology includes studies of internet-assisted learning in an undergraduate physiology course for nonmajors (21), case studies in an online graduate physiology class (8), distance learning using two-way live video in a high school pharmacology class (31), and integrated multimodal multidisciplinary teaching in anatomy for medical students using lecture, dissection, problem-based learning, and computer-assisted learning (18), to name just a few. Hoskins and Stevens (17) presented a “less is more” approach in an article identifying particular classroom tools that can be used to increase student engagement, develop scientific thinking skills, and deepen understanding rather than cover a wide range of detailed information in cell biology and physiology courses.

Effecting broader change in the way that introductory science is taught remains difficult to achieve, however, and instructors who are open to moving away from lecture-based teaching require support, both institutional and curricular, to do so. Allen and Tanner (1) noted that faculty members who want to adapt their approach are “often faced with the need to develop new curricula to supplement or replace a reliance on textbooks, a task for which she or he may have received little prior training.” In his book What the Best College Teachers Do, Ken Bain (4) described how superior professors are able to combine expertise in a particular field with knowledge of human learning and development to build student understanding. Unfortunately, most STEM instructors tend to teach as they were taught (in a lecture-based format) and have received little formal training in effective teaching techniques (5). Many experienced science educators have also become accustomed to lecture as the “typical” way to teach, counter to research demonstrating its ineffectiveness as an instructional strategy. Knight and Wood (20) described this situation as one in which “we as instructors must face up to the common pedagogical misconception that students will learn effectively only what we tell them in class.” Brainard (6) also noted that liberal arts colleges have been quickest to embrace new teaching methods, but that research universities, which grant the majority of
degrees in STEM fields, have been the most resistant. Our project was unique in approach as we simultaneously sought to provide in-depth pedagogical development and curricular writing support while engaging instructors from a range of institutions and departments in ongoing dialogue about teaching and learning.

Most introductory anatomy and physiology courses are taught by instructors who have achieved advanced degrees in their field of scientific study but who are likely to have little to no formal teacher education. In a review of challenges faced by new K–12 science teachers, Davis et al. (11) identified key areas of understanding that are expected of these educators: “the content and disciplines of science, learners, instruction, learning environments, and professionalism.” This list also reflects general expectations of college and university science professors. Successful professional development for these professors must address their needs as learners as well as teachers. In a project that involved instructors and graduate assistants in improving instruction in introductory anatomy and physiology laboratory classes, Chen et al. (9) emphasized the development of reflective practice and formative assessments. These metacognitive processes have been shown to be key to long-term learning and changes in attitude and understanding.

Henderson et al.’s (15) expansive review of the literature on change in undergraduate STEM education revealed four main research themes: disseminating curriculum and pedagogy, developing reflective teachers, enacting policy, and developing shared vision. In a related work, Henderson and Dancy (16) emphasized that knowing what works in STEM classrooms is only one aspect of reforming education; such efforts must be accompanied by spreading the use of strategies that are effective. Guskey (14) described teachers as attracted to professional development that offers specific, concrete, and practical ideas and strategies tied to enhanced student learning outcomes and successful professional development programs as those that provide ongoing support and evaluation and the opportunity to adjust practice as needed. Our project met Henderson and Dancy’s (16) suggestions for involving faculty members in the reform process in a meaningful way by providing a model for material development (the POGIL approach), focusing on the dissemination of educational research ideas in addition to curriculum (prioritizing student-centered instruction) and emphasizing personal connections (connecting instructors and providing ongoing opportunities for interactions).

The instructors who participated in this project engaged in a long-term collaborative inquiry activity focused on improving their instructional practice; this experience served to model the collaborative inquiry process for concept understanding emphasized by POGIL curricular modules. Activities that follow the POGIL model apply constructivist learning cycle theories and focus on developing process skills through a guided inquiry of particular content knowledge and ideas (27). Such an approach also mirrors Tanner and Allen’s (33) application of the understanding by design (37) approach to examine biology teaching for a focus on deep, multidimensional understanding rather than superficial knowledge. Several aspects of the POGIL model as we have applied it to introductory anatomy and physiology lecture courses fit Wood’s (38) “research-based promising practices” and present obvious needs for shifts in instructor practice: content organization (formulate specific student learning objectives), student organization (most student work is done cooperatively in small groups), feedback (feedback to instructor and students provided continually through in-class formative assessments), in-class learning activities (all students spend most of all class time engaged in various active-learning activities facilitated by instructors and teaching assistants), and student-faculty interactions in class (instructor explains the pedagogical reasons for the structure of course activities to encourage student buy-in and explicitly and frequently communicates the course learning goals to students).

As described in a 2006 article published in this journal, Silverthorn et al. (32) stated that “instructors who do decide to change how they teach must step out of the comfortable role of a lecturer disseminating content to students and instead learn to guide students as they take responsibility for asking questions, engaging in logical reasoning and problem solving, and discussing scientific concepts and processes with their peers.” In their study of the implementation of a new approach to physiology education, these authors (32) noted several challenges to successful use of the Integrative Themes in Physiology curriculum module project, one being “insufficient time to develop a mindset for change.” The design of the project described here was mindful of this challenge in developing a 2-yr process of observing instructor practice and examining attitudinal shifts. We have reported the curricular development process and student impacts in a separate article and here focus on the pedagogical change and development aspects of the project (A. Mattheis and M. Jensen, unpublished observations).

The instructor experience in the POGIL curriculum development project described in this article was modeled according to the National Research Council’s (7) suggested framework for supportive learning environments as learner centered, knowledge centered, assessment centered, and community centered. Beyond the development of a set of classroom activities, the overall project was designed to promote student-centered teaching philosophies and improve participant abilities to provide instruction aligned with such approaches. The research question that guided this aspect of the project was as follows: to what extent does the development of student-centered curricular materials (POGIL modules) promote change in the teaching philosophies of the instructors?

MATERIALS AND METHODS

The overall study design used a mixed methods approach (10, 19, 34), and appropriate modes of data collection were selected according to the setting and type of information gathered. The data presented here are predominantly qualitative in nature, in keeping with the research goal of developing deep understanding of instructors’ individual experiences. Data were collected over 2 yr between July 2011 and June 2013 by the two authors of this article. Figure 1 shows an overview of the timing of data collection over the course of the project.

Description of participants. A group of eight focal participants were recruited from a variety of college and university settings in the upper Midwest. Each of the instructors was a permanent full-time employee of their educational institution and had a PhD in a field related to anatomy and physiology. Table 1 shows an overview of the location and years of experience of each instructor as well as information about their reported knowledge of POGIL before and after participation in the project. One of the original participants was replaced 6 mo into the project due to increased professional commitments but remained involved in the process of piloting of the draft POGIL activities.

Data collection and analysis. Data were collected through the use of semistructured interviews with each of the participants at three
points during the study, observations of their classroom practices using the reformed teaching observation protocol (RTOP) (30), and pre- and postsurveys. In addition, informal observations of participant behaviors and interactions during the curriculum development workshops were used to contexturalize the data collected through other means. These in-person meetings allowed the researchers to clarify their understanding of each participant’s pedagogical approach and observe any potential changes over the course of the study. All data were collected with informed consent of the participants.

Interviews. Semistructured, responsive interviews (29, 36) were conducted with focal participants at three points during the study: by phone before the first POGIL workshop in July 2011 and in person during the January 2012 and August 2012 workshops. Interviews were conducted one on one during the professional development workshops, but questions were not specific to the workshops. All interviews were digitally recorded, transcribed verbatim, and ranged in length from 10 to 45 min. These transcripts were then analyzed using an interpretive approach (25) constructed around an initial framework of codes based on the interview protocols with additional themes identified inductively during the coding process. The qualitative analysis software Dedoose (12) was used to record codes, organize data, and uncover additional patterns.

The Teacher Beliefs Inventory questionnaire (23) was used as a key tool to track instructor attitudes and pedagogical philosophies over time. The wording of the instrument was modified very slightly with permission of its developers to focus on the experiences of postsec-

Table 1. Participant characteristics

<table>
<thead>
<tr>
<th>Instructor Name</th>
<th>Institution Type</th>
<th>Years of Teaching Experience</th>
<th>Prior Experience With POGIL</th>
<th>Perceived Level of POGIL Expertise at the End of the Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Margaret</td>
<td>Private college</td>
<td>39</td>
<td>Had tried POGIL before</td>
<td>Confident implementing POGIL in class and writing new activities</td>
</tr>
<tr>
<td>Kate</td>
<td>Public state university</td>
<td>14</td>
<td>Limited experience</td>
<td>Confident implementing POGIL in class and writing new activities</td>
</tr>
<tr>
<td>Frances</td>
<td>Community college</td>
<td>16</td>
<td>Limited experience</td>
<td>Confident implementing POGIL in class but not confident in writing new activities</td>
</tr>
<tr>
<td>Melissa</td>
<td>Community college</td>
<td>20</td>
<td>Limited experience</td>
<td>Confident implementing POGIL in class and writing new activities</td>
</tr>
<tr>
<td>Craig</td>
<td>Public state university</td>
<td>19</td>
<td>Limited experience</td>
<td>Confident implementing POGIL in class and writing new activities</td>
</tr>
<tr>
<td>Henry</td>
<td>Private college</td>
<td>11</td>
<td>Limited experience</td>
<td>Confident implementing POGIL in class and writing new activities</td>
</tr>
<tr>
<td>Patricia</td>
<td>Public state university</td>
<td>14</td>
<td>Limited experience</td>
<td>Confident implementing POGIL in class and writing new activities</td>
</tr>
<tr>
<td>Robin</td>
<td>Community college</td>
<td>9</td>
<td>Had tried POGIL before</td>
<td>Confident implementing POGIL in class and writing new activities</td>
</tr>
</tbody>
</table>

The instructor names used are pseudonyms. The years of teaching experience indicates the years of experience reported at the beginning of year 1. For prior experience with process-oriented guided inquiry learning (POGIL), the data reported here are from responses to a multiple-choice question that asked “Prior to your participation in this project, how familiar were you with using POGIL in your classes?” and provided the following options: 1) I had limited understanding of the POGIL approach, 2) I had observed another instructor use POGIL or attended a workshop but had not used it myself, 3) I had tried POGIL activities in my classroom at least once, and 4) I regularly use POGIL activities in my classroom. For perceived level of POGIL expertise at the end of the study, the data reported here are from responses to a multiple-choice question that asked “How would you describe your current familiarity and expertise with POGIL?” and provided the following options: 1) I have limited understanding of the POGIL approach, 2) I have a strong understanding of the POGIL approach but do not feel confident implementing POGIL activities in my classroom or writing new POGIL activities, 3) I have a strong understanding of the POGIL approach and feel confident implementing POGIL activities in my classroom but do not feel confident writing new POGIL activities, and 4) I have a strong understanding of the POGIL approach, feel confident implementing POGIL activities in my classroom, and feel confident writing new POGIL activities.
ondary-level anatomy and physiology instructors. The list of interview questions and associated coding framework, both based on the work by Luft and Roehrig (23), are included in the APPENDIX. This adapted framework was reviewed and approved by one of the original authors of the inventory (personal communication). Other interview questions were related to teacher background and preparation, classroom experiences and practices, and overall teaching philosophy. Much of the data shown in Table 1 and all participant quotations shown in Figs. 2–4 were drawn directly from these interviews.

Surveys. All attendees of the initial workshop in July 2011 completed a 21-item survey that collected data about educational and professional background, current teaching responsibilities relative to anatomy and physiology, and familiarity with a variety of pedagogical strategies. A second 12-item survey was administered to only the focal participants in May 2013. This survey included an additional administration of the eight questions from the Teacher Beliefs Inventory as well as questions about previous professional development experiences and overall impressions of participation in the project.

Classroom and workshop observations. Each instructor was observed on site at least once during the course of the project. Classroom observers used RTOP (30) to collect information about instructional behavior and approach. RTOP was used as a formative assessment tool by the research team to gain familiarity with instructors’ instructional practice and plan workshops accordingly. Furthermore, these observations served to correlated instructor reported behaviors in interviews and surveys with their classroom practices. The principal investigator and research associate conducted joint observations three times during years 1 and 2 and compared notes and ratings as an internal validity check. No significant differences were found in observational assessments between the two researchers. The initial professional development workshops were designed to familiarize all participants with the design of POGIL activities and their implementation in the classroom. Later workshops focused specifically on developing models and writing questions for use in specific activities and on the review and editing of draft activities.

How do you decide what topics to concentrate on in your A&P classes?

| TRADITIONAL | I use the textbook Essentials of Human A&P by Marieb, and I cover every chapter in there except special senses. (Margaret) |
| INSTRUCTIVE | I look at what interests me and try to find something that interests students...mostly to keep myself interested and be knowledgeable. (Craig) |
| TRANSITIONAL | I tend to cover the ‘standard’ topics described by HAPS and topics that students show a particular interest in. (Patricia) |
| RESPONSIVE | I have gotten somewhat of a feel for the areas where students struggle, and try to focus on those, providing them information and readings for things I think they can understand [independently]. (Melissa) |
| REFORM-BASED | I rely a lot on real life events (because) all my students are going into something medical. I like to do case studies and give them a patient...because a textbook does not tell you what you really need to know when you go and do this as a profession. (Frances) |

More Teacher-Centered
More Student-Centered

Fig. 2. Sample responses from TBI question 1. A&P, anatomy and physiology.

How do you describe your role as a teacher?

| TRADITIONAL | My first job is to say ‘what in this textbook is the most important information...and the second part is to facilitate their learning by coming up with outstanding lectures...by helping them learn the fundamentals. (Henry) |
| INSTRUCTIVE | I’m there to help the learner learn. I can’t make them learn it, they have to learn it themselves. But my job is to...break it down and I guess also entertain, so make it fun, which is how I model my life. You can make anything fun. (Robin) |
| TRANSITIONAL | I would hope to be more of a coach than someone who funnels information into [students]. I try to teach them ways of thinking and organizing their thoughts....I do lecture a fair amount but I have at least one thing [in class] where they get up and are active. (Melissa) |
| RESPONSIVE | I think of myself as a helper T-cell. I am there to stimulate the student’s interest in the topic and to provide them with the knowledge and resources to learn the topics presented. (Patricia) |
| REFORM-BASED | I really feel my role is a facilitator of not only content but how to approach content. Students need to have ownership in their education...I try to give them a framework to start with, some study skills, some background information, and then we start the exploration. (Frances) |

Focus on information and structure
Focus on providing experiences
Focus on teacher / student relationships or student understanding
Focus on collaboration between teacher and student
Focus on mediating student prior knowledge and the knowledge of the discipline

More Teacher-Centered
More Student-Centered

Fig. 3. Sample responses from TBI question 3.
Challenges and limitations. Perhaps due to the frequent level of feedback and contact from the principal investigator’s research office and receipt of a modest honorarium, attrition of participants was not a problem in this study. One of the original focal instructors, however, chose to participate as a volunteer rather than an official member of the group after phase 1. This participant was replaced by an experienced instructor in January 2012. The original participant continued to work on the piloting and development of POGIL activities and the instructor approach aspect of the project, but data collected from this participant were not included in the final results. Conducting classroom observations was challenging due to the large distances between institutions involved in the study and frequently hazardous winter weather. The two instructors who were located farthest from the principal investigator’s location were observed only once, during year 2. All other instructors were observed at least twice across the 2 yr of the study.

Institutional Review Board approval. The research reported in this article was conducted with the approval of the University of Minnesota Human Subjects Institutional Review Board (study number 1101S95097).

RESULTS AND DISCUSSION

Following the qualitative approach to research used in this aspect of the project, much of the data collected were used for formative assessment and to prepare for the professional development workshops. In this section, we report interpretive findings from summative analysis of the data collected and discuss meanings for participant attitudes and teaching practices in the context of professional development for instructional change.

Instructor attitudes. Using the coding framework based on the Teacher Beliefs Inventory (see the APPENDIX), the responses of each of the eight focal instructors collected at three points in the study were coded and examined for patterns particular to each individual. Figures 2–4 include sample teacher responses to questions 1, 3, and 6 that show how answers were coded along a spectrum of instructional approaches ranging from traditional to reform based. These quotations are not phase specific; they were selected to include feedback from all of the eight focal instructors and provide examples for readers.

The Teacher Beliefs Inventory is a semistructured interview protocol that was developed to examine how instructors’ epistemological beliefs about teaching and learning shift during professional development experiences and how these beliefs are linked to behavior (23). Responses are coded into categories that represent teacher-centered beliefs (traditional and instructive) and student-centered beliefs (responsive and reform based) with a transitional stage that reflects a combination of focus on behaviorist beliefs with a move toward a focus on students’ cognitive development. Of the three questions selected for display in this article, questions 1 and 3 reflect teachers’ attitudes about the transmission of content knowledge in the anatomy and physiology classroom and question 6 provides insights into how they view the learning processes. Figure 2, which shows selected participant responses to the question “How do you decide what topics to concentrate on in your anatomy and physiology classes?,” shows how Margaret’s reliance on a particular textbook to guide course curriculum reflects traditional belief systems, whereas Frances’ incorporation of health career case studies specific to the professions sought by her students demonstrates a reform-based attitude. Patricia’s response, coded as transitional, shows a movement in her understanding of the value of student-centered approaches but a reliance on teacher-centered practice. Melissa’s transitional response shows a movement in her understanding of the value of student-centered approaches but a reliance on teacher-centered practice. Patricia and Frances’ quotations are coded as more student centered because they emphasize the role of the instructor as a facilitator of students’ interactions with information rather than delivery of content. Figure 4, which shows answers to the question “How do you know when learning is occurring in your classroom?,” shows the contrast between...
traditional approaches that reflect teacher observation of students as opposed to reform-based practices that emphasize the facilitation of learning processes. The more student-centered responses describe the importance of hearing students work together and dispute and discuss class content, whereas teacher-centered beliefs are reflected in the responses that focus on instructor behaviors.

As evidenced by participant reports in interviews and workshops, the process of developing POGIL activities, which emphasize students working cooperatively in groups with the instructor serving a facilitator role, pushed them to think about transmitting content knowledge in a more student-centered way. There were obvious differences in how receptive the different professors were to this mode of planning and writing curricula at the beginning of the project but repeated interactions with this particular model of teaching appeared to help shift even the most “traditional” instructors away from a strictly teacher-centered approach. Our data suggest that the engagement with this type of curricular planning in addition to professional development of pedagogical methods was key to the success of this project because instructors were immersed in a particular instructional philosophy and provided with a supportive peer network. Wood’s (38) schematic comparison of standard course planning to a backward design is a useful complement to the Teacher Beliefs Inventory (which provides a coding framework for assessing attitudes) in demonstrating the differences between instructor-centered and student-centered practices. Wood describes instructor-centered course planning as beginning with textbook selection, followed by syllabus writing, preparation of lectures, notes and Powerpoint presentations, and finally assessed with homework and exams; student-centered course planning begins with the formulation of broad learning goals and setting of specific learning objectives followed by the design of formative and summative assessments, with learning activities prepared after these steps are completed (38). POGIL activity modules focus on student-centered activities and beliefs. In interpreting instructor attitudes, identifying specific reported behaviors as instructor centered or student centered was key in coding participants’ responses to the Teacher Beliefs Inventory questions. Figure 5 shows the number of responses coded in the categories of traditional, instructive, transitional, responsive, or reform based from each administration of the set of questions to each participant across phases of the project. Overall, a general trend toward more student-centered beliefs was demonstrated in the pattern of responses across all participants. These interpretive data were supplemented with survey responses, classroom observations, and additional interview questions to confirm or adjust the degree to which each of the eight focal participants used instructional strategies from a more teacher-centered or student-centered perspective.

The participant who showed the least movement across the spectrum was Frances, who already demonstrated a student-centered approach at the beginning of the project. Unique among the participants was this instructor’s role as a professor at two different institutions with different student populations. She had spent several years working as a healthcare professional before beginning her teaching positions. In interviews and conversations, she expressed a strong understanding of the need to make specific links between theory and concepts in coursework to “real-world” experiences. Interestingly, at the end of the study, Frances was the only participant to report feeling confident implementing POGIL activities in her class but not in writing new activities (see Table 1). Because other feedback from this instructor indicated a high degree of reflexivity in terms of practice and assessing her own abilities, her response may in fact suggest that other respondents are overestimating their own expertise. The fact that all participants reported feeling confident implementing the activities in class, however, suggest that the ongoing support and repeated review of the POGIL approach was successful in preparing instructors to have confidence in their own capacities and likely led to more successful experiences leading such activities with stu-
udents. These findings also support Allendoerfer et al.’s (2) call for research to focus on underlying teacher beliefs and not just their classroom practice if lasting change is to be implemented.

Importantly, our data suggest that participation in professional development experiences that link instructors with a network of their peers and provide ongoing support can shift the pedagogical approach of even very experienced professors, like Margaret, who was entering her 40th year of teaching at the completion of the study. In two conversations with the project research associate, Margaret talked about collaborating with a junior faculty member at her institution to make other, broader shifts in the curriculum of the life sciences program, and the off-campus experiences she had with other peers through this POGIL project may have further influenced her decision to embrace changes rather than rely on past practice.

Robin, the instructor with the fewest years of teaching experience, showed the most rapid change in terms of the Teacher Beliefs Inventory scale. This finding was supported by her enthusiasm for exploring instructional improvement; at the beginning of the study, she reported a desire to make her classes more active and inquiry based but also felt unsure of the best way to do so. Being able to use POGIL activities in a systematic way appeared to increase her confidence in organizing group work and encouraging greater student involvement in the learning process. Luft and Roehrig’s work (23) suggests that interviewees who show movement from teacher-centered to student-centered beliefs on at least three of the seven Teacher Belief Inventory questions can be considered stable shifts in attitude. The results shown in Table 2 demonstrate strong evidence that the changes in belief demonstrated by the participants in this project are likely to reflect permanent adoption of more student-centered approaches.

It is important to note Henderson et al.’s (15) caution that without system-changing efforts to complement faculty development, our findings will not be generalizable to unsupportive institutional settings. In comparing our experience with the results of Silverthorn et al.’s study (32) of the implementation of the Integrative Themes in Physiology curriculum module project, however, we acknowledge similar challenges but report a successful project that took their cautionary tale into account. We had a smaller focal group, a longer-term implementation plan, and took care to maintain contact with the participants. Only one participant noted the modest honorarium provided to the focal instructors as a key incentive to participate, but being paid for their time was appreciated by all and may have helped maintain participation for the entire length of the study.

Importantly, the pedagogical intervention aspect of this project was implemented concurrently with the development of new curricular materials, collection of attitudinal data from students, and collaboration across campuses, in keeping with Henderson and Dancy’s (16) suggestions for implementing lasting change.

Conclusions. The opportunity to challenge themselves to adjust their individual pedagogical practice while also networking with other instructors focused on improved student experience emerged as a primary benefit provided by the experience. When asked what had been the best part for them of participating in this 2-yr project, the focal instructors shared the following responses:

- “Collaboration with other committed science educators.” (Craig)
- “Interacting with other professionals, sharing ideas, and having intellectual discussions about various concepts.” (Kate)
- “Developing resources that I believe will be helpful to students.” (Henry)
- “Getting feedback from colleagues on the team and from [other] teachers who had used my POGIL activities.” (Margaret)
- “Learning about POGIL [and] discussing anatomy and physiology teaching and learning.” (Patricia)
- “I am quite happy how [POGIL] gives [my students] confidence and practice with understanding difficult concepts. I very much enjoyed the chance to get together with other biology educators, listen to their approaches, concerns, and differences of opinion.” (Melissa)
- “I really liked the interaction with the other faculty, the sharing of ideas and viewpoints. It was a learning experience for me—I was somewhat out of my comfort zone and I think that is a good thing.” (Francis)
- “Working with other faculty—having the intellectual and collaborative environment.” (Robin)

Such responses are in keeping with research that emphasizes the importance of teachers learning from and with each other (28). The effective development of a cross-institutional network for the sharing of resources based on teaching and learning best-practices research is also significant in addressing barriers to professional development that may exist at particular colleges or universities. The absence of broad efforts to implement widespread change in STEM education at many institutions presents a challenge for isolated educators interested in adapting their own teaching (5). Our results show that instructors benefit from opportunities to engage in long-term professional development and interaction with job-like peers at other institutions to develop solutions for problems of practice. To avoid what Baldwin (5) described as “the lone wolf approach to improving STEM undergraduate education,” it is our hope that involving these same participants in future projects to extend the POGIL model to anatomy and physiology labs as well as upper-division lectures will maintain their involvement and allow them to recruit colleagues to join these efforts.

Finally, this project also helps to extend the research literature on teacher professional development for undergraduate STEM education specifically to the introductory anatomy and physiology classroom and has been part of our efforts to meet the call put forth in the American Association for the Advancement of Science Vision and Change report (3): “All members of the biology academic community should be committed to creating, using, assessing, and disseminating effective practices in teaching and learning and in building a true community of scholars.” In this article, we presented evidence that involving professors in conversations centered on both content and pedagogy is effective for promoting change in instruction. The adaptability of our findings for other groups of instructors lies in demonstrating the success of a professional development endeavor characterized by the long-term involvement of participants and consistent use of a particular curricular model. Our efforts demonstrate success in encouraging introductory anatomy and physiology educators to act less like the prefrontal cortex of the classroom and more like (as Patricia put it)
Table 2. Overview of the Teacher Beliefs Inventory framework

<table>
<thead>
<tr>
<th>Question 1: How do you decide what topics to concentrate on in your anatomy and physiology classes?</th>
<th>Traditional</th>
<th>Instructive</th>
<th>Transitional</th>
<th>Responsive</th>
<th>Reform Based</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic description</td>
<td>Focus on information, transmission, structure, or sources</td>
<td>Focus on providing experiences, teacher focus, or teacher decision</td>
<td>Focus on teacher/student relationships, subjective decisions, or affective responses</td>
<td>Focus on collaboration, feedback, or knowledge development</td>
<td>Focus on mediating student knowledge or interactions</td>
</tr>
<tr>
<td>View of science</td>
<td>Science as rule or fact</td>
<td>Science as rule or fact/science as consistent, connected, and objective</td>
<td>Science as consistent, connected, and objective</td>
<td>Science as a dynamic structure in a social and cultural context</td>
<td>Science as a dynamic structure in a social and cultural context</td>
</tr>
<tr>
<td>Teacher or student focused?</td>
<td>Teacher focused</td>
<td>Teacher focused</td>
<td>Teacher focused</td>
<td>Student focused</td>
<td>Student focused</td>
</tr>
<tr>
<td>Decision guided by adopted curriculum or other school factors</td>
<td>Decision based on teacher focus or direction</td>
<td>Decision in which some modification is based on student feedback</td>
<td>Decision based on student feedback and other possible factors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Question 2: How do you decide to move on to a new topic in your classroom?</td>
<td>Directed by teacher</td>
<td>Directed by teacher, based on basic student understanding of facts and concepts</td>
<td>Teacher decision based on limited student feedback or ability of their teacher</td>
<td>Decision based on student feedback that potentially involves revisiting concepts</td>
<td>Decision based on an ongoing evaluation and considers student abilities to demonstrate understanding in different ways. May involve the modification of lessons</td>
</tr>
<tr>
<td>Question 3: How do you describe your role as a teacher?</td>
<td>Focus on information and structure</td>
<td>Focus on providing experiences</td>
<td>Focus on teacher/student relationships or student understanding</td>
<td>Focus on collaboration between teacher and student</td>
<td></td>
</tr>
<tr>
<td>Question 4: How do your students learn best about anatomy and physiology concepts?</td>
<td>From the teacher</td>
<td>By mimicking the teacher</td>
<td>By using procedures/guidelines</td>
<td>By encountering and interpreting phenomena</td>
<td>By eliciting, encountering, and constructing their ideas about phenomena</td>
</tr>
<tr>
<td>Question 5: How do you know when your students understand?</td>
<td>When they receive the information</td>
<td>When they can reiterate or demonstrate what has been presented</td>
<td>When they give an explanation or response that is related to the presented information</td>
<td>When they can use the presented knowledge</td>
<td>When they can apply knowledge in a novel setting or construct something novel that is related to the knowledge</td>
</tr>
<tr>
<td>Question 6: How do you know when learning is occurring in your classroom?</td>
<td>Determined by actions of students during instruction. Emphasis is on order and attention as related to the student</td>
<td>Determined through measures given by the teacher. Emphasis is on the correctness of the student response to the measure</td>
<td>Determined through subjective conclusions about the student</td>
<td>Students interact with their peers or the teacher about the topic. Responses are limited or preliminary</td>
<td>Students initiate significant interactions with one another and/or the teacher about the topic</td>
</tr>
<tr>
<td>Question 7: How do you maximize student learning?</td>
<td>Teacher provides information in a structured environment</td>
<td>Teacher monitors student actions or behaviors during instruction</td>
<td>Teacher creates a classroom environment that involves the student</td>
<td>Teacher designs a classroom environment to enable students to interact with each other and their knowledge</td>
<td>Teacher depends on student responses to design an environment that allows for individualized learning</td>
</tr>
</tbody>
</table>

Table and questions were adapted from Table 1 and Fig. 1 in Luft and Roehrig (23); modifications were approved by these authors.

a helper T cell in an interdependent and complex system of learning and teaching.

APPENDIX

Table 2 shows an overview of the Teacher Beliefs Inventory framework.

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DISCLOSURES

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

AUTHOR CONTRIBUTIONS

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

REFERENCES

FOSTERING ANATOMY AND PHYSIOLOGY INSTRUCTOR PEDAGOGY

How We Teach: Generalizable Education Research

nrs.fs.fed.us/environmental_literacy/local-resources/downloads/Vision_and_Change_report.pdf [3 November 2014].