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Evolution of an introductory undergraduate biology course through collaborative action research

Mahsa Kazempour [1*], Aidin Amirshokoohi [2], Lara Goudsouzian [2]

[1] Penn State University-Berks, Reading, PA, USA
[2] DeSales University, Center Valley, PA, USA
***Corresponding Author:** muk30@psu.edu

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ABSTRACT

Over the past few decades, we have witnessed an increasing emphasis on the significance of restructuring and revolutionizing undergraduate science education in achieving the goal of preparing a scientifically literate population and safeguarding our democracy and the future of STEM workforce. This paper reports on a collaborative action research conducted to reform and modify an introductory undergraduate biology course taught by the third author with professional support and feedback provided by the other authors. The findings will be discussed in the form of a case study focusing on the initial features of the course, continual feedback and professional growth, modifications to the course, and future plans for further revising the course.

Keywords: college science course, college science teaching, biology education, action research, course revision

INTRODUCTION

Over the past few decades, reform documents such as *From analysis to action* (National Research Council [NRC], 1996), *Shaping the future* (National Science Foundation, 1996), *Science teacher preparation in an era of standards-based reform* (NRC, 1997), *Reinventing undergraduate education: A blueprint for America's universities* (Boyer Commission on Educating Undergraduates in the Research University, 1998), and *College pathways to the science education standards* (Siebert & McIntosh, 2001) have underscored the significance of undergraduate science education in achieving the goal of preparing a scientifically literate population and safeguarding our democracy and the future of STEM workforce. There have been numerous calls for transforming undergraduate science courses and laboratory experiences from the traditional instructional approaches of lecture, teacher-directed activities, direct transformation of information, and passive student learning to student-centered and active learning experiences that allow for greater student engagement in the learning process and higher order thinking (Donovan & Bransford, 2005; Freeman et al., 2014).

Although there may exist various definitions and visions of what active learning in undergraduate STEM education may entail, all agree on certain features that distinguish this approach from the traditional, teacher-directed approach. In 2009, the American Association for the Advancement of Science (AAAS, 2009) published *Vision and change: Call to action,* which describes six core competencies central to student-centered undergraduate biology education, which include: applying the process of science, employing quantitative reasoning, using modeling and simulation, and focusing on the interdisciplinary nature of science and its interconnection with society. Similarly, Olson and Riordon (2012) recommended multiple changes to undergraduate STEM education including "the adoption of evidence-based teaching practices". All active learning approaches meet some criteria of either the cognitive (Piagetian) constructivist learning theory focusing on students' active and direct engagement with the subject matter or the social constructivist (Vygotskyian) lens, which also underscores the importance of actively engaging with other individuals for in-depth learning and construction of understanding to occur (Arthurs & Kreager, 2017; Freeman et al., 2014), The key distinction from the traditional framework lies in the active and interactive engagement of students in tasks that result in deeper cognitive and collaborative learning as opposed to a passive and disengaged learning process in the traditional approach (Chi, 2009; Chi & Wylie, 2014).

Benefits of more active and student-centered instruction include enhanced student performance, improved affect, decreased failure rates, and development of conceptual understanding and scientific thinking skills (Ballen et al., 2017; Eddy & Hogan, 2014; Crouch & Mazur, 2001; Freeman et al., 2014; Haak et al., 2011; Theobald et al., 2020). The advantageous effects have been shown to be greater among the most at risk and underrepresented student groups (Ballen et al., 2017; Beichner et al., 2007; Haak et al., 2011). Furthermore, meta-analysis by Theobald et al. (2020) and other research findings (Ballen et al., 2017; Eddy & Hogan, 2014; Haak et al., 2011) indicate increased diversification of STEM graduates, more equitable outcomes, and narrower achievement gaps for underrepresented students in STEM disciplines.

Despite the plentiful benefits of learner-engaged instructional approaches and the numerous efforts witnessed at various institutions of higher education to reform undergraduate science education (e.g., Baldwin, 2009; Kazempour & Amirshokoohi, 2013), the change has not been significant and widespread (Barr & Tagg, 2008; Brownell & Tanner, 2012). This is especially true for introductory courses that tend to be broader in scope and content and larger in class size. Such courses often serve as the initial and often sole opportunity to appeal to or deter students from pursuing paths in STEM fields as well as gain scientific knowledge and STEM related skills of problem solving, critical thinking, decision making, communication, and collaboration that are critical for achieving scientific literacy (AAAS, 2009; NRC, 2003; Seymour, 2002).

A key challenge to meeting the calls for undergraduate science education reform has been convincing science faculty that their instructional approach, which they witnessed during their own undergraduate experience and have utilized for years and even decades, may not be effective and require change (Brownell & Tanner, 2012). Three key factors of lack of training, time, and incentives have been identified as impeding faculty instructional change. Science faculty are often ill-equipped to modify their instructional approach due to lack of prior training and the consequent lack of pedagogical knowledge about teaching and learning theories, classroom management, enhancing student learning, motivation, and engagement, as well as evaluating student learning and engagement (Hativa, 1995; Hanson & Moser, 2003; Luft et al., 2004; Yarnall et al., 2007). Prior studies (e.g., Dancy et al., 2016; Smith et al., 2009; Stains & Vickrey 2017) have indicated that even when it comes to active learning strategies, instructors may implement such strategies differently than intended and that their instructional decisions may impact student learning in a significant manner. To address the issue with science faculty's limited pedagogical knowledge it is imperative to provide them access to formal training and ongoing professional development and continuing and iterative opportunities to apply and practice what they learn and evaluate the efficacy of the new approaches when implemented in the classroom (AAAS, 2009).

Research studies on undergraduate science education mainly focus on outcomes of revising science content courses, including student achievement, success or failure rates, student attitudes, and impact on achievement gap. However, the literature is devoid of studies focusing on the effects of the professional development experience on the faculty member's instructional behaviors and decisions. The nature and extent of revisions and modifications that are made to such courses are most often not reported. Therefore, it is critical to focus on evaluating the impact of training and professional development on instructional decisions and actions and disseminate description of such changes in order to encourage other science faculty to consider making similar changes and provide them beneficial examples that they may emulate in their own courses.

We conducted a multi-year collaborative action research study in an effort to reform and modify an introductory undergraduate biology course taught by the third author with professional support and feedback provided by the first two authors. In the current paper, we aim to discuss, in the form of a case study, our findings with respect to:

(a) the initial features of the course components of lecture, laboratory, and homework,

(b) initial feedback provided by the science educators,

(c) changes to course components after collaborative professional development, and

(d) additional recommendations and plans for the next phase of course revisions.

In another article (in review), we focus on the instructor's initial and evolving beliefs about science and science teaching, motivation to embark on a professional development and course revision, ongoing reflections on the professional development and course modification experiences, and barriers and concerns impeding possible changes in her instructional practice.

MATERIALS & METHODS

Context

This collaborative action research focuses on an introductory undergraduate science course at a Northeastern private university. The course, 'thinking and creativity' is one of the 'modes of thinking' natural science course options that must be taken by all students at this institution. The typical class size is approximately 40-45 students. The course includes a 50-minute lecture session twice a week with a two-hour weekly laboratory. According to the institutional course catalog, the course is described as one focusing on the "thoughts and methods of biologists" with the lecture component "centered on topics in human physiology, examining the scientific method and practical examples of its use" while the "laboratory component examines methods of obtaining scientific data, using the course participants as subjects." (course syllabus, p. 1). The student learning objectives include:

(1) describing differing levels of biological organization,

(2) explaining importance of DNA as molecule of heredity,

(3) demonstrating an understanding of human biology, including the anatomy and physiology of major organ systems, and

(4) designing and completing a research project that includes generating a scientific question, formulating a hypothesis, creating an experimental design, collecting and analyzing data.

The course instructor (third author) is an associate professor responsible for teaching intermediate and advanced molecular biology courses as well as cancer biology and biology courses for non-majors. She had taught the course of focus only once before initiating the study. At the time of the study, the second author was an associate professor of STEM education at the same institution and is mainly responsible for teaching science methods, math methods, STEM education, technology education, and designing instruction courses in the elementary education program. His areas of research include, among other things, pre-service teacher preparation focusing on both content and methods courses as well as teacher professional development. The first author is an associate professor of science education at a nearby public four-year university and is mainly responsible for teaching science methods courses for elementary pre-service teachers and environmental science and sustainability courses for non-science majors. She also focuses on pre-service teacher preparation and teacher professional development as part of her scholarly activity.

Collaborative Action Research

Action research involves a recurrent, systematic, and reflective process of planning, implementation, monitoring, evaluation, and reflection to allow for examination and improvement of instructional practices and contribute to the body of research on teaching and learning (Carr & Kemmis, 1986; Feldman & Minstrell, 2000) similar to ones conducted by other science educators (e.g., Capobianco, 2007; van Zee et al., 2003). We took a collaborative approach to our action research (Loucks-Horsley et al., 1998) by jointly embarking on a process of descriptive reporting, problem solving, critical reflection, collaborative discussion and support, and professional practice in order to improve the instructor's instructional practice in order to enhance students' learning experiences in the introductory science course. **Figure 1** summarizes four phases of action research process that will be described below.

This action research was initiated when the third author approached the first and second authors, both science and/or STEM educators, about her interest in discussing ways to improve the quality of her course instruction in order to engage students and fulfill the objectives of the course more effectively. Her interest in initiating this effort stemmed from her recent exposure to 'active learning' ideas as part of her involvement in the biology education community and participation in recent conferences. She had also come across the teaching and research work of the second author through cross departmental initiatives and teacher certification teaching, advising, and coordinating that the second author was responsible for. We decided that it would be most appropriate to begin with thoroughly examining the course content and instruction in its original format and provide feedback to the instructor and then re-examine the course instruction one year later once the instructor had the opportunity to modify the course based on the previously provided and ongoing feedback and resources.

In the first iteration of the study, the first and second authors began with an analysis of course instruction using the video recordings of the lecture sessions as well as examining syllabus and other documents such as assignment instructions and laboratory handouts. We provided the course instructor with thorough written feedback on her instruction for each class session as well as on the various homework assignments and laboratory instructions handouts. We also provided her with general overall feedback and suggestions in order to make her course more effective and inquiry-based. This was followed with several rounds of discussions of the feedback to clarify any areas that needed further explanation and ensure that the course instructor understood the feedback and ways to make the necessary changes in her course.

The following fall semester, the course instructor used the feedback to make some changes to the course before teaching it again in the spring. During this second iteration of teaching the course, the data collected and examined included video recordings of the class sessions, course instructor's reflections about changes made to each lecture and lab session and her thoughts and experiences throughout the semester, course assignment instructions and laboratory handouts, as well as post interviews with the course instructor to further discuss her thoughts and experiences throughout the process.

The instructor's reflections were read on a weekly basis and the other authors provided her with feedback and responded to questions or concerns mentioned by the instructor. The video recordings and assignment instructions handouts were examined and analyzed next.

Finally, a semi-structured interview was conducted to ascertain more information about the instructor's beliefs, experiences, and challenges or difficulties faced during the revision process. The data from the second phase of the research was cross examined with the initial set of data to explore similarities and differences and possible changes that may have occurred.

Data Collection & Analysis

As described in the above section, there were multiple forms of data that were collected throughout the various phases of the collaborative action research. These included:

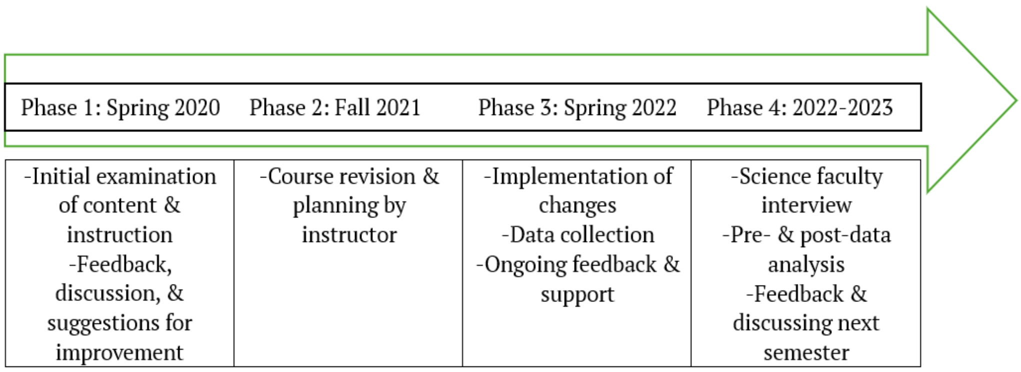

Figure 1. Four phases of action research process (Source: Authors' own elaboration)

(a) video recordings of the lecture sessions both before and after the changes,

(b) artifacts such as course syllabi, assignment instructions, homework assignments, laboratory handouts, and PowerPoint slides, and

(c) instructor reflections, email correspondence between researchers and instructor, and final instructor interview.

The video recordings of the lecture sessions as well as the associated presentation slides were analyzed by each researcher for the dual purpose of providing immediate or gradual feedback and comments to the instructor as well as identifying patterns in instructional approaches, strategies, and areas of strength and weakness for pre and post comparisons. Laboratory handouts and homework assignments were similarly analyzed for key features, areas requiring change, and possible evidence about the instructor's teaching decisions and actions as well as implementation of suggested revisions. Email correspondence between the instructor and researchers, the ongoing instructor reflections, the continual gradual feedback from the educator researchers, as well as the final instructor interview were content analyzed.

RESULTS

The findings will be discussed in the following sections:

(a) the initial features of the course components of lecture, laboratory, and homework,

(b) initial feedback provided by the science educators,

(c) changes to course components after collaborative professional development and initial feedback, and

(d) additional recommendations and plans for the next phase of modifying the course.

Original Course Features

The results of the initial phase of analysis focusing on the key features of the course as it was originally structured are described with respect to the course components of lecture, laboratory, and homework discussed in the below sections and summarized in **Table 1**.

Lecture Sessions

The instructor's lecture presentations had a few effective elements including the use of relevant and attention-grabbing images on the presentations slides as well as an effective narrative presentation format and use of analogies throughout the presentation. This combination of features allowed the lecture sessions to appear relatively engaging and the content simple to comprehend by the students. However, our observations of the lecture session revealed a number of areas that required modification. First, the lecture focused extensively on human biology with minimum attention to the process of science, with the exception of an initial session devoted at least partially to the discussion of the 'the scientific method'. There was little to no student exposure to and engagement in the process of scientific inquiry and the brief discussion of the scientific method model, early in the semester, did not include reference to other modes of investigation besides experiments. Additionally, the lecture sessions were too information-laden and focused on the coverage of content, which is the product of science, as opposed to the understanding of the process of arriving at that knowledge. This could potentially lead to multiple issues including student misconception about science being a large body of unrelated and trivial facts. Furthermore, instructor questions posed to the students were limited and often only served as quick review of content covered. Finally, most of the lecture sessions mainly consisted of instructor delivery of information with extremely limited, or even non-existent, peer discussion or collaboration among students.

Homework

There were 10 homework assignments distributed on an almost weekly basis throughout the semester. During our initial analysis of the existing homework assignments, we noted that they consisted of mainly lower-level thinking and simplified tasks, which included a limited number of questions that were mainly closed-ended in nature. Almost all the questions focused on simple information recall and knowledge of terminology rather than a deep understanding of concepts learned or addressed in lecture. The homework tasks did not consist of any critical thinking, problem solving, in-depth analysis, or communication and collaboration with peers.

Laboratory sessions

The laboratory handouts were mainly instructions for students to perform during the laboratory sessions. Nearly all of the handouts included information and description of content that were previously discussed in the related lecture session, including the explanation of the terminology and concepts that students should have already become familiarized with or been able to apply in the laboratory session. The laboratory instructions handouts included very

Table 1. Key features of initial course components

Course components	Key features
Lecture	▪ Information-laden–Focus on coverage of content (product of science) ▪ Focused extensively on human biology content with little/no exposure or engagement in process of scientific inquiry ▪ Questions limited and for quick review of content ▪ Limited peer discussion and collaboration
Homework	▪ Mainly simple, lower-level, close-ended questions/tasks ▪ Focused on information recall and knowledge of terminology ▪ No critical thinking, problem solving, analysis, communication
Laboratory	▪ Questions mainly included at end of handout ▪ Mainly simple, close-ended questions ▪ Information discussed in lecture re-explained on handout ▪ Inclusion of possible anticipated 'observations' or 'results'

few questions, which were mainly included at the end of the handout for students to respond to at the completion of the laboratory investigation. Similar to the homework assignments, questions included on the laboratory handouts were simple and closed-ended in nature. A few of the laboratory instructions handouts, such as the 'cells' lab, included some possible anticipated 'observations' or 'results', which inevitably meant that students were simply conducting the laboratory tasks and investigations to confirm or simply observe the expected outcomes and descriptions provided by the instructor. This implied that there was an expectation to obtain certain results that were deemed 'correct' and corresponded with what was previously discussed.

Initial Feedback

Upon completion of our initial observations, we communicated our feedback about the course and its components with the instructor and had numerous follow-up discussions with her to clarify areas that required further elaboration. As general feedback to the instructor we recommended that since the course is identified as a 'mode of thinking' natural science course for all majors, the focus should be on examining and employing science practices, critical thinking, problem solving, research, information literacy, and application of content to the real world. We argued that the course biology content should be treated as the 'context' for engaging students in understanding the scientific inquiry process and not the focus of the course itself. This would allow students to leave the course with an understanding of how scientists, in particular biologists, engage in scientific inquiry and what that process involves.

Lecture

With respect to the lecture sessions, we recommended structuring the lecture so that the focus would be on the process of scientific inquiry and allow the lecture session to serve as opportunities for students to think about and possibly engage in some aspects of the process of science such as using curiosity, inquiring, making observations and inferences, asking questions, analyzing evidence, discussing and communicating with peers, referring to literature, and recognizing the connection of science to real life as discussed in the nature of science and inquiry readings and supplemental materials. Furthermore, we emphasized the need for the lecture to address the cyclical and complex process of scientific inquiry (Understanding Science, 2022) illustrated in **Figure 2**, as opposed to the simplistic and linear scientific method model

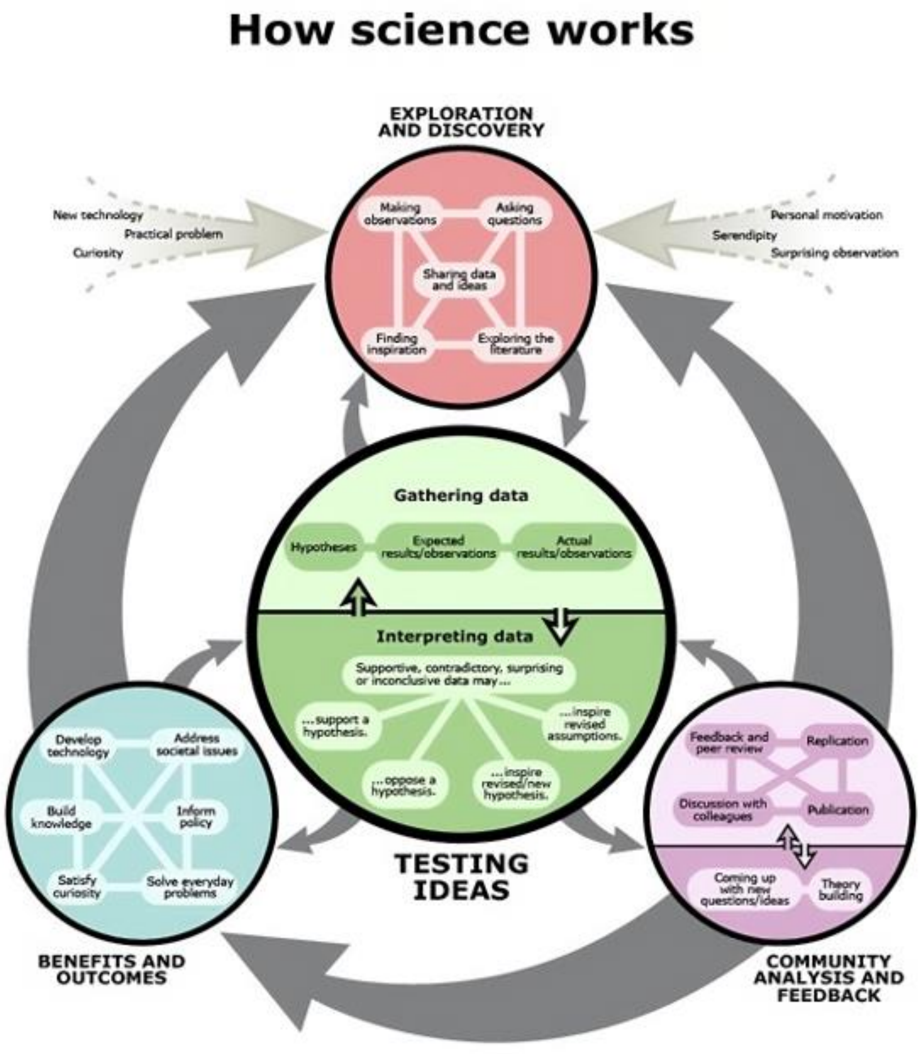

Figure 2. Complex science flowchart depicts a detailed view of iterative process of science (Understanding Science, 2022)

and shared several readings and resources with the instructor to clarify the distinction.

In line with that suggestion, we also discussed the importance of including various forms of scientific investigations, including descriptive, comparative, and modeling as the focus of lecture and laboratory sessions rather than only focusing on experimental investigations. We clarified our argument by providing multiple examples related to her lecture sessions including the following:

> The example of Jenner for the process of science discussion was good, but perhaps start with a brief video to expose the students to the story and then have them think about how it reflects the process of science before you discuss it. We would suggest allowing them to actually think as a small team before opening it up to class discussion. The story of Jenner actually lines up well with the science inquiry model because he did not start out with a question, and it was rather by serendipity and observations. Also, it would be effective to point out that his investigation was not an experimental one and that there was a societal context. Again, those are not reflected in the typically referenced scientific method model but clearly shown on the science inquiry model.

We also recommended that the lecture sessions be focused on essential questions, questions that drive inquiry and critical thinking, rather than merely meeting a list of objectives. Furthermore, we suggested shifting from 'telling' and 'teacher-directed instruction' to active, student-centered learning by utilizing the 5E learning cycle model (Bybee, 1997), which is based on the constructivist framework of learning. We explained that it is best to initiate the learning experience with an engaging introduction that captivates student attention and piques their interest and curiosity and provides them a problem, case, or scenario to think about and serve as the contexts for the discussion of the topic. Once engaged, students should be provided opportunities for initial exploration, analysis of evidence, peer discussion of cases, scenarios, and problems, and other collaborative tasks. This would then be followed with discussions of their findings and observations to introduce key ideas and concepts. To further elucidate our suggestions and feedback, we provided a number of examples including the following:

> For the discussion about carbohydrates and anabolic steroids, you could have provided a simple task such as giving students the structure of the different groups (carbs, proteins, lipids) and foods containing them and having them think about commonalities and differences among the categories. The questions you posed to them about carbs and body builders could also be provided for them to think about and discuss as part of this task or small discussions interspersed in the lecture.

Finally, we emphasized the importance of asking questions and class discussions in driving the lecture and similarly allowing students to be actively engaged in asking questions and inquiring about things in order to see the significance of questions in the process of scientific inquiry. The instructor inquired about further examples to help her implement the changes we had proposed and asked that we use the topic of 'digestion' as a sample topic to explain how we would suggest changing that component of the lecture. We provided her with a description of possible ideas that tied in with the various pedagogical suggestions we had recommended earlier.

Homework

In our initial feedback on the homework assignments, we discussed the need for allowing more opportunities for students to apply the content by incorporating questions and tasks that would require in-depth thinking of the content and applying their new understanding or the content addressed to new situations and examples. We also emphasized the importance of focusing on real-life connections and ensuring that students recognize the relevance of content addressed in the course. Finally, we stressed the need to create more meaningful homework assignments by incorporating appropriate questions that allow in-depth critical thinking, analysis, reasoning, problem solving, and some level of communication and collaboration with their peers.

Laboratory

For the laboratory instructions, we suggested that instead of including introductory explanations that mimicked what was previously discussed in lecture, to instead include questions that students would be required to think about and connect with the lecture material. We also advised the instructor to provide opportunities for the students to record observations, respond to questions, and make connections throughout the laboratory experience as opposed to only including questions at the end. For example, we pointed out that although the questions at the end of the 'circulation lab' were worded effectively, they would have been more valuable if asked throughout the various sections of the lab handout rather than all at the end or if in the form of concluding questions aimed at analyzing the results and writing a summary about the impact of the various factors on blood pressure. As was the case with the homework assignment instructions handouts, it was suggested that the instructor should include higher level, open-ended, critical thinking and analysis questions that would enable students to think more in-depth about the addressed content. Below is an excerpt of one of our suggestions on the 'germs' lab:

> The lab report questions should be asked as students complete the steps and not as an afterthought. So, first have them think about the question and hypothesis. Then, have them read through the procedures and summarize what they are asked to do in the lab write-up, and then have them collect data and graph it and finally draw conclusions. When the lab report components are included at the very end, students will often just do the procedure without much thinking.

Furthermore, it was suggested that the instructor ought to avoid providing information on possible or expected observations or results and instead allow students to make their own observations, gather and analyze their findings, and then make the necessary connection to lecture material by

Table 2. Effective course revisions & areas requiring improvement

	Revisions	Areas requiring improvement
Lecture	▪ Brief engaging demos & tasks ▪ Helium inhaling ▪ Voice box singing ▪ Pretzel chewing and swallowing ▪ More frequent & engaging discussions/questions for some topics	▪ Teacher directed quick reviews of previous material ▪ Few attempts to use cases, scenarios, & focusing essential questions to initiate a topic or provide context ▪ Some sessions partially/completely teacher directed ▪ Student tasks followed instruction rather than being exploratory ▪ Limited opportunities for collaboration, communication, & peer discussion
Homework	▪ Use of relevant text, cases, & scenarios ▪ Real-life connections ▪ Opportunities for critical thinking, problem-solving, & application of content	▪ Use of discussion forum to improve peer collaboration
Laboratory	▪ Questions throughout the handout ▪ More open-ended questions ▪ Effective connection to scientific inquiry model ▪ Use of real life & relevant examples as context for investigations ▪ Termite damage to buildings	▪ Some close-ended questions

explaining if and how their observations aligned or related to the content discussed. For instance, for the ‘cells’ lab, we pointed out that students should be asked questions about the various cell organelles, such as chloroplasts or vacuoles, rather than being given information about them. We also indicated that the task instructions for each station should be void of any reference to what students may actually observe in terms of the cell structures and instead ask them to draw and describe their observations and then make connections to the lecture or other resources to explain their observations.

Finally, similar to the lecture component, we emphasized the importance of focusing on the process of scientific inquiry, especially in the laboratory, which more considerably involves ‘doing’ science. It was suggested that student experiences in the laboratory should more closely reflect the various aspects of the interwoven and cyclical process of scientific inquiry. As part of this, we recommended that laboratory sessions, such as the ‘cells’ and ‘DNA’ labs, that were more in line with descriptive or comparative investigations be highlighted as such and emphasized just as important as laboratory investigations that involve setting up controlled experiments. For experimental investigations, we recommended that students be required to be cognizant of the scientific process they were involved with in various contexts and asked to identify the question of inquiry, the hypothesis, the different variables, and, when appropriate, even plan the investigation with respect to the control and experimental groups. For example, for the ‘germs’ lab, we suggested that students be instructed to identify the independent, dependent, and controlled variables or set up. Similarly, for the ‘circulation’ lab, we recommended having students think about the investigation question and hypothesis and identify the various components of the investigation, such as the different variables, as they proceed with the lab.

Post Observations

During the second round of observations, we identified a number of changes that had been made by the instructor to address previously discussed feedback. However, we agreed to continue the discussion and revision process by having her continue to reflect and inquire about questions or areas she needed further assistance or clarification and for us to provide additional ongoing suggestions and support to assist in further improving the course. The revisions made and areas still requiring further modification are discussed below and summarized in **Table 2**.

Lecture sessions

During the second iteration of teaching the course, the instructor continued to incorporate brief animations and videoclips that served as effective visuals and supporting resources during the lecture. For example, she showed a videoclip demonstrating how the heart works, another one showing the vocal cords in action during singing, and another one about eating lemons as part of digestion. She also incorporated engaging and relevant real-life examples and made connections with previously addressed concepts or students’ prior experiences. Examples included the discussions of possible reasons for vomiting, the history of lactose intolerance, the existence of battery acid in the stomach, reaction to ‘delicious’ versus ‘yucky/tasteless’ food and reasons for picky eating, and the connection between breathing at high altitudes and red blood cell counts with the use of a special mask, and the Lance Armstrong controversy.

Additionally, she began to incorporate brief, yet engaging, demonstrations and team tasks that created more opportunities for students to become interested and intrigued in the subject matter as well as actively involved in the exploration, close examination, and discussion of the concepts being addressed. Demonstrations included the helium inhaling demo followed by questions and discussion that students found interesting and intriguing. In discussing the larynx, students engaged in a brief task during which they attempted to say something while feeling their voice box, which got them engaged and sharing observations. In another example, the students did a quick pretzel eating task simulating the chewing and swallowing mechanisms, which was effective at engaging student interest and initiated discussion.

Finally, another important added component to the lectures was the incorporation of more frequent and engaging discussions and critical thinking questions for some of the topics. Examples included the questions and discussion about possible activities that alter the heartrate as an introduction to the heart's function, discussion question at the end of the respiration lecture about why athletes go to high altitudes for training, use of engaging image about damage to the heart followed by effective discussion about the impact of drinking and the connection with arteries, veins, and high blood pressure, as well as the effective questions and discussion about the role of the villi after sharing a brief example of the baby born without any villi.

Although there were some attempts to modify the lecture session, we discussed several additional changes that we deemed necessary or requiring further attention. For example, the beginning of most lecture sessions remained predominantly teacher directed and consisted of a simple and quick review and re-explanation of previously discussed material. We suggested that the review be done by engaging students in thinking about the material through questions and class discussion, which would also allow for assessing student understanding, confusions, and ability to make connections and apply the content.

Furthermore, other than the inclusion of occasional examples or scenarios, there were no attempts to use cases, scenarios, and problems/challenges and focusing essential questions to initiate a topic, provide context, set the stage, engage the students, and explore and discuss the content. Finally, on several occasions, there were examples or references, which may not have been familiar or relevant for some students. We discussed the need to consider students' prior experiences and familiarity, interests, challenges, limitations, and what they may find appropriate and avoid or clarify examples that they may not be familiar with or find inappropriate or unapplicable to them. For example, in one session, the Olympic game question about the athlete who had a certain blood condition was a valuable question; however, it would be engaging and suitable only if students are familiar with the particular winter Olympic game mentioned. We suggested that in such cases, playing a brief videoclip or showing an image or having students do a quick search on their digital devices would allow a certain level of exposure necessary before they can consider the question. In another similar case, the example of overdrinking or experiencing a hangover may either be inappropriate or not apply to all students who either do not engage in drinking or may have not experienced getting drunk or having a hangover.

Moreover, there were some lecture sessions that remained, either partially or completely, continuous instructor lecture with few to no questions or discussions in between. Examples included the cardiac lecture consisting of the coverage of content related to aneurysm and hemorrhage without any questions and the digestion lecture and the coverage of information about how food travels through the digestive system. The blood type discussion about the role of the receptors as well as the questions about the Rh factors and blood transfusion should have been done as team discussions and brief tasks instead of teacher-led discussions.

We recommended maximizing student engagement through the inclusion of more frequent questions, discussions, and brief collaborative tasks, to engage students in or at least allow them to be aware of the process of scientific inquiry. The timing and order or sequence of some of the questions, discussions, or quick tasks interspersed in various lecture sessions needs to be reconsidered to allow for maximum engagement, student thinking, and discussion and connection prior to the formal introduction of concepts. For example, during the circulation lecture, the instructor posed an effective question about fear and heartrate and had students pay attention to their heart rate as they watched a scene from a scary movie scene. However, she did so after her full explanation about the role of adrenaline and full description of the film scene, which minimized the suspense and surprise effect. Instead, she should have started with the movie clip and task of monitoring their heart rate in order to capture students' attention, pique their curiosity, and allow them to have experienced the fear, suspense, and heart rate increase themselves before discussing and introducing the content. In another instance, during the discussion about the genetics of hemophilia, the instructor first thoroughly explained genetic pedigrees and provided detailed information about who would be carriers or get the trait or disease rather than starting with students examining a sample pedigree and analyzing it for any patterns and possible explanations. During another session, the 'too much of a good thing' slide about the consequences of high levels of white blood cells was covered quickly by the instructor, whereas it should have instead been done by asking students to discuss what they noticed in the image and their thoughts about the possible consequences of too many white blood cells based on what they had previously learned about red blood cells.

Finally, in conjunction with the abovementioned observations and recommendations, we suggested more opportunities for student cooperation, collaboration, and discussion with their peers. Students often sat in individual seats and were never assigned to teams and seldom asked to work in groups. We discussed the need to either assign teams of two-four students or encourage sitting next to and working as a team with different students during each session to complete tasks and engage in discussions. During some of the sessions, class discussions were limited to only one or a few students responding to questions while others remained silent. We reemphasized the importance of engaging more students and introduced the instructor to the idea of 'wait time' when asking questions to allow more students to have a chance to think about the questions and be willing to raise their hand to respond to the questions as well as encourage other students to follow up with additional thoughts and ideas or to indicate their agreement or disagreement with the earlier responses. This would allow for productive dialogue as opposed to simply asking discrete questions. Furthermore, we highlighted the need to refrain from statements such as 'that's the correct answer I was looking for' or quickly accepting an 'accurate' response and proceeding to the next question or discussion of content because such actions emphasize the need to provide 'correct answers' rather than attempt to think critically and creatively and generate potential ideas.

Homework

The instructor made a noticeable and concerted effort to modify the homework assignments by using relevant text, cases, and scenarios for students to read, analyze, and critically think about in light of material discussed in lecture.

The revised homework tasks allowed students to realize the real-life context and relevancy of the material learned in the lecture and be able to think critically, apply their understanding, problem solve, as well as read and communicate effectively and reflectively. For instance, she created a case study homework assignment on osmosis, which related directly to the material discussed in lecture and required application of lecture material by thinking about a scenario about a woman who suffered a fatal case of water intoxication after entering a radio station contest. The instructor also developed similar case study assignments on radon's impacts on the lungs and the effects of nicotine on circulation. Early in the semester, she made extensive changes to an existing homework assignment focusing on the Tuskegee Syphilis Experiment. She provided students with the background on the origins and history of syphilis and included questions from another existing case study in order to engage the students and initiate their thinking before they watched a documentary film on the topic.

We only made a couple of minor suggestions for further improvements with respect to the homework assignments. First, we recommended possibly incorporating some of the questions, scenarios, or problems provided as part of the homework assignments into the lecture sessions to allow for discussion and exchange of ideas among students. To allow for some of the homework assignments to be more reflective or involve in-depth critical thinking, we suggested using the course discussion forum to allow students to post their responses and thoughts and be able to read and respond to their peers' posts. This would perhaps allow them to engage in further discussion and critical thinking and enhance their communication skills in the process.

Laboratory sessions

Several changes were made to some of the laboratory sessions. All the revised laboratory instructions incorporated questions for students to think about and respond to throughout the handout as opposed to only at the end. For at least some of the laboratory sessions, the instructions included more open-ended questions, effective connection to the scientific inquiry model, and use of real-life and relevant examples and framework to contextualize scientific investigations. For example, in the case of both the 'DNA' and 'germs' laboratory sessions, the instructor inserted effective questions throughout the handout and made clear connection to the scientific inquiry model. The 'nervous system' lab incorporated multiple activities that were effective both in terms of the instructions included as well as the incorporation of questions throughout the handout for students to think about, discuss, and respond to. Finally, the revised 'termites' lab provided a real life, relevant context about termite damage to buildings to contextualize the scientific investigation students were to embark on.

The main suggestion we made on the laboratory component of the course was for the instructor to reword and replace some of the remaining closed-ended questions with more open-ended ones. We reminded her to avoid yes/no or one-to-two-word response types of questions such as 'do you think …?' or 'Does the …?', which tend to not allow students to think in-depth or explain their responses thoroughly. Instead, we recommended such questions be re-worded into open-ended questions, such as 'how would you describe….?', 'explain whether or not …', 'compare and contrast the …', that provide students the opportunity to think and process the questions and the content more deeply and more thoroughly explain their thoughts and observations.

DISCUSSION

The current action research has proved to be an enlightening process that has enabled us to utilize a collaborative approach to explore, reflect upon, and improve the course focus and instructional practices. With just one round of full professional development and continual feedback the instructor was able to successfully initiate changes in the course.

The modifications were most evident in the homework assignments and the laboratory instructions handouts. The lecture sessions were slightly modified but there remained a number of issues that still require further attention and modification, including student evaluation and engaging students in collaborative tasks. There may be a number of possible reasons for the lack of more extensive changes, particularly with the lecture component, which consisted of the least modification. This may have partially been due to the fact that it involved the instructor's real-time actions, instructional decisions, and interactions with students, which are more difficult and challenging to revise. Such changes require time for advance planning, practice with implementation, continual self-reflection, and collaborative support. This is line with what has been reported in the literature. One of the main factors cited by science faculty for not implementing changes in their courses and adopting inquiry-based instructional approach is the lack of time to devote to making the necessary changes, implementing them, and evaluating them for the need for further revisions (Brownell & Tanner, 2012). Additionally, the literature on instructor's adoption of reform-based instructional approaches have further identified difficulty in convincing science faculty of the potential ineffectiveness of their teaching practices, which they have adopted based on their own academic experiences (Brownell & Tanner, 2012). This did not hold completely true for the course instructor in this study who expressed eagerness to engage in the collaborative professional development experience and becoming acquainted with effective and research-based strategies. However, she may have inadvertently, reverted to more traditional approaches at times, perhaps due to time limitation, insufficient practice with effective approaches, or lack of comfort and confidence in fully adopting these approaches, as suggested by previous studies (Hativa, 1995; Hanson & Moser, 2003; Luft et al., 2004; Yarnall et al., 2007).

Prior studies (e.g., Dancy et al., 2016; Smith et al., 2009; Stains & Vickrey, 2017) have indicated that instructors may implement research-based strategies differently than intended, which will consequently impact student learning in a significant manner. To address the issue with science faculty's limited pedagogical knowledge, it is imperative to provide them ongoing professional development and continuing and iterative opportunities to apply and practice what they learn and evaluate the efficacy of the new approaches when implemented in the classroom (AAAS, 2009). At this time, this course instructor's revision of her course has only been evaluated once. It is expected that, having experienced the first round of revising and teaching the course and receiving the in-depth feedback the subsequent iterations of the course are bound to include more comprehensive improvements. Because action research is an ongoing cycle, what we learn from the process will be utilized to continue the process of exploration, reflection, and improvement. In another article (in review), we focus on the instructor's initial and evolving beliefs about science and science teaching, motivation to embark on a professional development and course revision, ongoing reflections on the professional development and course modification experiences, and barriers and concerns impeding possible changes in her instructional practice. Prior studies have indicated that active and interactive engagement of students in tasks that result in deeper cognitive and collaborative learning as opposed to a passive and disengaged learning process in the traditional approach (Arthurs & Kreager, 2017; Chi, 2009; Chi & Wylie, 2014; Freeman et al., 2014). Future studies are necessary to explore the students' perspective and experiences in a course that has been revised to include active student engagement strategies and to examine the impact of such instruction on students' understanding of content, attitudes, and beliefs about science.

CONCLUSIONS

Over the past few decades, there have been numerous calls for undergraduate science courses to adopt instructional approaches incorporating student-centered and active learning experiences that allow for greater student engagement in the learning process and higher order thinking (Donovan & Bransford, 2005; Freeman et al., 2014). The current study aimed to address a gap in the literature that is considerably devoid of studies focusing on the effects of the professional development experience on the faculty member's instructional behaviors and decisions and lack of reporting on the nature and extent of revisions and modifications that are made to such courses. In sharing the collaborative action research process we embarked on, we hope that our reflections and the project findings may be insightful for other science educators and individuals responsible for teaching undergraduate science content courses. It is critical to continue exploring efforts to reform undergraduate science courses. It is equally essential to employ multiple and varied investigative approaches examining various components such as instructor beliefs and attitudes, instructional approach and motivation to change, changes in student beliefs, attitude, and understanding as a result of revised instructional approaches, and more. Conducting action research studies such as this one and disseminating the findings and lessons learned yield multiple potential benefits. On a more personal and individual level for the instructors, such action research allows for a unique opportunity for self-reflection and introspection, engagement in collaboration and professional development with science and STEM education professionals, and the experience of adopting research-based instructional practices. Additionally, there is a considerable added value of providing a unique context for merging theoretical research and instructional practice through the collaborative and recursive process of reflection, professional development, implementation, discussion, supportive coaching, modification, and so forth. This study will be of major interest and relevance to U.S. and international science educators and researchers interested in issues related to undergraduate science education and faculty professional development.

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