Action Research: Using a 5E Instructional Approach to Improve Undergraduate Physics Laboratory Instruction

By Ozden Sengul and Renee Schwartz

A physics laboratory instructor used action research to effectively implement a 5E instructional approach, which incorporated scientific practices. The instructor explored how to integrate the instructional approach into practice, challenges present in the implementation, and students’ learning experiences. The data were collected during three consecutive semesters through instructor and student reflections, weekly lesson plans, and lesson artifacts. These qualitative data sources were analyzed for emergent codes to develop categories. The results indicated that the instructor’s reflections helped to appropriate the existing physics laboratory curriculum into the 5E model and support the curriculum with additional formative assessment tasks. The instructor also explored students’ experiences in engaging in scientific practices. Students’ reflections and lesson artifacts revealed their challenges in scientific explanations, experimental design, use of models, and measurements, which guided the instructor to modify the instruction.

The American Association of Physics Teachers (AAPT) made recommendations for the Physics Laboratory Curriculum (PLC) to foster the development of 21st-century skills, which engage students in authentic science learning experiences (Kozminski et al., 2014). The PLC addressed the incorporation of scientific practices into instruction, including designing and carrying out experiments, collecting and analyzing data, using and developing models, arguing from evidence, and communicating information in an iterative process, all while aligning with the Next Generation Science Standards (NGSS) (Kozminski et al., 2014; Lewandowski & Finkelstein, 2015; NGSS Lead States, 2013). The Structured Quantitative Inquiry Labs (SQILabs) (Holmes & Bonn, 2015) and the Investigative Science Learning Environment (ISLE) (Etkina, 2015) have adopted the PLC’s approach to incorporating scientific practices into instruction. These laboratories demonstrated evidence of this approach’s effectiveness in improving students’ knowledge and competencies in constructing new understandings, applying these understandings into new situations, and evaluating their own learning through active participation and reflection.

Despite the reported benefits, adopting the AAPT’s suggestions for the PLC has been difficult for undergraduate physics instructors (Roseler, Paul, Felton, & Theisen, 2018). This difficulty arises from the way undergraduate instructors teach physics concepts. Instead of engaging students in scientific processes, instructors prefer lecturing or laboratory investigations that reinforce or confirm lecture content (Holmes & Wieman, 2018). They may have been taught physics through traditional (direct instructional) methods, may not be aware of all innovative strategies, or they may be unsure of how to incorporate scientific practices into their instruction in less prescriptive ways. A lack of training, institutional support, instructional resources, and time may contribute to their inability to integrate reform-based strategies into physics instruction (Henderson, Beach, & Finkelstein, 2011; Henderson & Daney, 2007). These instructors need to modify their physics instruction; they should focus on supporting knowledge construction, designing and using innovative resources, and creating active learning environments instead of transferring knowledge (Crawford, 2014; Taylor, Fraser, & Fisher, 1997). Action research is one research method that can be used to promote these changes in instructional practices (Altrichter, Feldman, Posch, & Somekh, 2013).
The research method: Action research

Action research, as a practitioner-oriented inquiry, seeks to change instructional practices through planning the lesson, teaching the lesson plan, observing the implementation of the lesson, and reflecting on the teaching experience (Altrichter et al., 2013). Teachers-as-researchers ask questions, collect, reflect on, and evaluate data in ongoing cycles to better understand how they teach and how effectively their teaching methods help their students learn (Altrichter et al., 2013). Although action research methodology has the potential to change teaching practices, it has rarely been used in undergraduate science education (Raubenheimer & Myka, 2005). This paper investigates the experiences of an undergraduate physics laboratory instructor as she uses action research while implementing an instructional approach that incorporates scientific practices into students’ learning process.

The instructional approach: 5E model

The new instructional approach implemented in this study aims to address the goals of teaching undergraduate physics courses and to revise physics laboratory instruction according to the recommendations of the AAPT. The 5E instructional model is an effective way to create lesson plans and embed scientific inquiry into instruction by providing a structure that encourages students to engage with, explore, explain, elaborate on, and evaluate scientific processes while engaging in laboratory activities (Tanner, 2010). The 5E instructional model is a learning cycle based on a constructivist approach and promotes a conceptual-change model of learning (Bybee, et al., 2006). This learning cycle fosters active student participation and guides students to be critical of their existing ideas and to apply their understandings into new situations (Posner, Strike, Hewson, & Gertzog, 1982). Therefore, this study’s instructional approach incorporates scientific practices into the 5E inquiry model during physics laboratory instruction.

Purpose and research questions

In this study, the authors explore the experiences of the instructor, who engages in action research on her teaching and students’ learning processes while embedding scientific practices into the 5E instructional model. The instructor used the innovative instructional resources from the suggestions of the AAPT community that require students to work in groups, to develop a method to collect and analyze data, to use models and argumentation, and to communicate information. This study uses action research to examine the implementation of the 5E instructional approach, with the intention of identifying learning challenges and successes during the implementation.

The study is guided by two research questions:

1. What experiences does a physics laboratory instructor have while implementing the instructional approach?
2. What challenges do the students of the physics laboratory instructor experience while learning through the instructional approach?

Method

Context and participants

This paper is written by two authors: a science educator and an instructor-as-(action) researcher. The participant of the study was the instructor-as-researcher (first author), who was a graduate student in science education and taught undergraduate physics laboratory students as a teaching assistant in an urban university in the southeastern region of the United States. This action research focused on the physics laboratory instructor’s experiences in her classroom and demonstrated how the instructor brought about a change in the pedagogical practices while integrating the 5E model. The role of the science educator was to act as a mentor and provide suggestions and resources during the action research process. Additionally, a total of 60 students participated in the study. These students attended three separate classes, averaging 20 students per class (students’ demographic information is available at https://www.nsta.org/college/connections.aspx). The research was conducted in one class each semester across three consecutive semesters. The 60 students attended the laboratory component of a mandatory physics course for science and engineering majors, which included separate lecture and laboratory sections. Each week, students met for three hours and worked in groups of two or three during a 60-minute tutorial followed by a two-hour physics lab experiment. Students had to attend and complete the work for at least eight physics labs of a twelve-week laboratory component to pass the physics course. The lab portion of the course consisted of three parts: tutorial (5%), physics lab (15%), and tutorial homework (5%), which was worth 25% of the overall grade. Seventy-five percent of the course grade was for the lecture component of the physics course.

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Data sources and analysis

Different forms of qualitative data were collected during three semesters including three cycles of action research to document the experiences of the instructor and her students. The data collected in each cycle followed the plan, act, observe, reflect sequence. The data collected during the first cycle were used to revise the lesson planning for the second cycle; the data were collected and analyzed in the second cycle to change the instruction in the third cycle. (The timeline for action research is available at https://www.nsta.org/college/connections.aspx.)

The data sources were the instructor and student reflections, weekly lesson plans, and lesson artifacts (tutorial and physics experiment worksheets). The instructor wrote pre- and postlesson reflections to demonstrate her mental processes before and after teaching each lesson. The instructor’s reflections focused on what the instructor planned and accomplished based on students’ learning and what the strengths and weaknesses of the lesson were before and after the implementation (Etkina, 2010). The instructor used her reflections to make modifications to her pedagogical acts while implementing the instructional approach across different cycles. In addition, students’ written reflections were collected at the end of each laboratory section, and these reflections focused on the strengths and weaknesses of the lesson, students’ learning difficulties, and instructional strategies. Students’ reflections provided feedback about the instructor’s teaching and their learning process. Moreover, the instructor developed weekly lesson plans to integrate scientific practices into the 5E instructional model for physics laboratory instruction. These lesson plans, instructor and student reflections, and lesson artifacts were used to explain how the instructor integrated the instructional approach into undergraduate physics laboratory instruction.

Inductive data analysis was conducted through identifying emergent codes and developing categories in an iterative process (Merriam, 2009). The instructor’s reflections were analyzed in order to explore the instructor’s experiences and pedagogical decisions related to the implementation of the instructional approach. Lesson artifacts and students’ reflections were also analyzed in order to examine students’ strengths and challenges during the learning process. The lesson plans were also reviewed in order to understand how the instructor modified her teaching strategies according to her and her students’ reflections.

Results

Cycle 1: Integrating the instructional approach

The research started with the physics instructor’s identifying a problem in the laboratory component of a physics course. The instructor was teaching the three-hour laboratory part of a physics course including a one-hour tutorial session and a two-hour laboratory session. Students had to work on the weekly assigned chapters from *Tutorials in Introductory Physics* (McDermott, Shaffer, & Physics Education Group, 1998) in the tutorial session. Then, in the laboratory session, students had to work on the assigned inquiry-based experiments. The research started with the instructor’s dissatisfaction with the effectiveness of her instructional practices. In her prestudy reflection, she stated,

Students are expected to learn the fundamental concepts during the lecture portion. Some physics experiments are not parallel to what students are taught in the lecture, so I have to cover the concepts before they start to do the experiment, but I feel I am lecturing to help students get the expected results from the experiment.

The instructor observed students focusing on the completion of the assignment rather than developing an understanding of the scientific processes enacted within the assignment. In order to overcome this problem, the instructor wanted to integrate innovative teaching strategies rather than follow the physics laboratory curriculum verbatim. The recommendations of the physics education community and national education documents also encouraged the instructor to move beyond traditional teaching methods (e.g., Kozminski et al., 2014; NGSS Lead States, 2013). As a starting point, she asked the following questions:

How can I understand students’ thinking and reasoning in the physics laboratory? How can I help them understand scientific concepts while conducting physics experiments? How does my teaching influence their learning?

To answer these questions, the instructor attempted to modify various aspects of the curriculum and set clear objectives for addressing learners’ needs during laboratory instruction. She believed that the instruction should be student-centered and promote students’ engagement in scientific practices beyond completing the assignment. She aimed to use the 5E instructional model to engage students in different scientific experiences to realize what they know, and
enable them to explore, and to construct their understanding of science concepts in an ongoing cycle.

However, the physics department required all students who were taking this physics course to work on the same physics laboratory curriculum. To meet this requirement, the instructor had to cover the assigned tutorial chapter and physics experiment each week. The instructor realized that meeting these departmental requirements while incorporating the new instructional approach within the time limits of the class would be challenging, so she asked herself the following question: How should I implement the instructional approach that I feel provides a better learning opportunity? She needed to plan the instruction by integrating the required laboratory curriculum into the 5E instructional model.

First, she examined the tutorials and physics experiments to identify which scientific processes they emphasized. She realized that the physics laboratory curriculum included activities that required students to make observations, collect and analyze data, use models, and construct explanations. She conjectured that students could start to explore the concepts in the tutorial session and then extend their understanding and skills while they worked on the physics investigations. Therefore, she used the tutorial part as the exploration phase and the experiment part as the elaboration phase.

However, the laboratory curriculum required students to follow specific procedures to accomplish the expected results without the explicit goal of developing students’ higher-order thinking. The required laboratory curriculum did not provide opportunities for students to ask questions and define problems; plan and carry out investigations; engage in argument from evidence; or obtain, evaluate, and communicate information. This observation encouraged the instructor to focus on answering the following question: “How can I incorporate additional activities that can enhance students’ scientific experiences?” She aimed to support the required physics laboratory curriculum with formative assessment tasks that would help to make smooth transitions across the phases of the instructional approach and gather evidence of students’ learning in a continuous process.

The instructor integrated these formative assessment tasks in the engagement, explanation, and evaluation phases. For the engagement phase, she aimed to elicit students’ prior knowledge through open-ended questions, quizzes, group problems, and using or developing models. For example, the instructor prompted students to argue for the validity of different claims about the electricity and magnetism concepts or discussed the real-world examples for the types of waves. For the explanation phase, the instructor aimed to promote class discussions about what students had done during the exploration phase and connect their understanding to the topics to be covered in the physics experiment through questioning and use of visual representations. For the evaluation phase, the instructor planned not to use the tutorial homework and instead evaluated students’ learning of concepts through multiple-choice questions or engaging them in different scientific practices. For example, the instructor asked students to design a method for making a magnet by using a nail, copper wire, and a battery or to manipulate the mathematical formula that students derived during the experiment to solve a problem. In all phases of the instructional approach, the instructor aimed to promote peer instruction and small-group or class discussions to support the social aspect of learning (example lesson plan is available at https://www.nsta.org/college/connections.aspx).

The instructor observed and reflected on the influence of enacted activities on student learning in different phases of the 5E instructional model. Students’ responses to the formative assessment tasks allowed the instructor to explore what students learned and the effectiveness of her teaching. Summary of cycle 1 is presented on Table 1. For cycle 2, she aimed to modify her lesson plans based on her reflections and students’ learning experiences from cycle 1. As a result of her experiences in the first cycle, the instructor was interested in a new question, “How can I promote better learning for my students, specifically for higher levels of thinking?”

**Cycle 2: Exploring students’ experiences**

The instructor’s reflections and lesson plans from the first cycle informed her planning during the second cycle. She also reviewed the student-created artifacts such as students’ tutorial and physics experiment worksheets, formative assessment task responses, and their postlesson reflections to identify their learning challenges and make modifications in the instruction accordingly.

First, the instructor observed the ineffectiveness of using multiple-choice questions to understand the rationale of students’ thinking. In her prelesson reflection, she stated:

> When I looked at students’ previous papers, I realized that I should not ask multiple-choice questions. They did a good job
and provided the correct answer. They could answer where the image of an object appeared. However, they did not know how to find the image of a nail in the mirror with a hands-on experiment. I made a mistake that I focused on whether students could answer a question. They should be engaged in the process, not finding the right answers. I should integrate activities that could promote students’ thinking to explore the concepts.

The instructor changed the multiple-choice questions to open-ended questions. However, students tended to provide short, simple answers rather than detailed explanations of their reasoning. For instance, when the students were asked, “What happened to the image position as the object distance was increased?” they provided a one-word response, such as “decreasing.” The instructor incorporated writing frames into the questions to encourage students to give more evidence-based explanations, such as “My idea is that …, my reasons are that …, the evidence I would use to convince somebody is that …” (Osborne, Erduran, Simon, & Monk, 2001).

Furthermore, the tutorial and physics experiments promoted students’ engagement in the use and development of models, but students had difficulty in drawing or explaining the visual representations in physics. The instructor aimed to integrate learning tasks that could guide students toward thinking about different types of models (e.g., visual, qualitative or quantitative) while predicting and explaining scientific phenomena across different cycles of the 5E instructional approach (an example activity is available at https://www.nsta.org/college/connections.aspx). The result was a noticeable increase in students’ interest and curiosity. Instead of seeking to only provide the correct answers, they tried to understand the meaning and real-world applications of concepts. They were still puzzled during the engagement phases, but higher-level questions and an increased level of interest in the use of models started to appear. The following excerpt from the instructor’s postlesson reflection illustrates a student’s attempt to ask a question about his prediction of a physical model:

I asked a very easy question, whether or not capacitors could have different shapes, and most of the students said, “Yes! They can have different shapes.” However, one student asked if we could have a capacitor like a hollow cylinder. It was a higher-level question; in physics lessons, students learn hollow cylinder for integral calculations. Although I considered that this question was easy and did not make students think, it made a student consider a different representation of the concept.

The instructor felt she successfully fostered students’ engagement with using models and asking questions; however, she was still concerned about students’ attitudes toward participating in group or class discussions. The instructor aimed to encourage students to communicate their ideas to both their group and the entire class. She provided two competing theories on “light rays” concept (Osborne et al., 2001) during the engagement phase. By introducing these two competing theories, the instructor hoped to open a discussion about how light travels through a

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**TABLE 1**

**Action research sequence in cycle 1**

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<tr>
<th>Focus</th>
<th>Timing</th>
<th>Action research</th>
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<tr>
<td>How to implement 5E model</td>
<td>First semester January–May 2015</td>
<td><strong>Plan</strong></td>
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<tr>
<td></td>
<td></td>
<td>• Changing her teaching practices</td>
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<td></td>
<td></td>
<td>• 5E model</td>
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<td></td>
<td></td>
<td>• Emphasizing scientific practices</td>
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<tr>
<td><strong>Act</strong></td>
<td></td>
<td>• Conducting action research</td>
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<td></td>
<td></td>
<td>• Preparing lesson plans</td>
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<td></td>
<td>• Analysis of tutorials and physics labs</td>
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<td></td>
<td></td>
<td>• Using activities for engagement, explanation, evaluation phases</td>
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<tr>
<td><strong>Observe</strong></td>
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<td>• Restrictions of physics department</td>
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<td></td>
<td></td>
<td>• How laboratory curriculum emphasized the scientific practices</td>
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<tr>
<td></td>
<td></td>
<td>• Students’ difficulties with science concepts and practices</td>
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<tr>
<td><strong>Reflect</strong></td>
<td></td>
<td>• Using tutorial and experiment in 5E model</td>
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<td>• Connecting the tutorial concepts to physics labs</td>
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<td></td>
<td></td>
<td>• Other scientific practices</td>
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<td>• Modifying activities</td>
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Students were introduced to the claim-evidence-reasoning-rebuttal components (Berland & McNeill, 2010) to develop their arguments. During the group and classroom discussions, students had high interest in the question; they were puzzled and enthusiastic to discuss their ideas, and they showed academic interest in each other’s arguments. Their verbal explanations allowed the teacher to better understand students’ prior conceptions (a sample class discussion is available at https://www.nsta.org/college/connections.aspx). In the postlesson reflection, the instructor stated:

… I began to introduce the argument structure as the claim-evidence-reasoning-rebuttal components while teaching in the laboratory. I was afraid that students would not be interested. But they said, “Are we doing philosophy?” and they developed a high interest in providing the evidence-claim pairs while discussing the question. I utilized one of the frameworks created for argumentation: competing theories. Students began to discuss with their group members and other groups. I observed that utilization of argumentation by introducing the argument structure caused the academic interest of the students to increase. As students became puzzled, they asked higher-level questions and made explanations in their groups and during the whole-class discussion.

Summary of cycle 2 is presented in Table 2.

### Cycle 3: Confidence in the implementation

Through reflection, the instructor was able to identify the strengths and weaknesses of the implementation and act upon them. In the first and second cycles, she could incorporate the scientific practices that helped students work collaboratively, engage in argumentation, use and develop models, and ask questions. Her role as a teacher changed from helping students to get the expected results of the experiment to promoting students’ scientific experiences. She felt more confident and received good evaluations from students about her teaching and their learning experiences.

One student said,

She explains what to do very thoroughly. When we need help on a problem, she does not just tell us, but makes us work for them. She gives us hints and makes us look at problems in a different way to try to come up with our answer.

The instructor had the lesson plans with the suggestions from previous cycles, and in the third cycle, she felt confident enough to make slight modifications in the required physics laboratory curriculum to address students’ common challenges. For example, one student stated, “Conveying instructions and understanding what the question is asking seemed difficult for most of the students at times.” Another student stated, “You should post a video on how to set up the experiment and how to do the lab, so students understand what to do visually ahead time before the lab.” Therefore, she revised the questions on the physics laboratory curriculum. She changed procedural instructions into questions that guided students to design and carry out the experiments collaboratively. Additionally, the instructor also observed that

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<td><strong>Action research sequence of cycle 2</strong></td>
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<th>Focus</th>
<th>Timing</th>
<th>Action research</th>
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<tr>
<td>Exploring students’ experiences</td>
<td>Second and third semesters June–September 2015</td>
<td><strong>Plan</strong>&lt;br&gt;• Modifying the activities appropriately for the purpose of the phase&lt;br&gt;• Making conceptual links across the phases</td>
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students had large measurement errors; therefore, students were encouraged to evaluate the accuracy of their measurements. For example, after the data collection and analysis, the instructor asked, “What limitations of the equipment and method created the uncertainty in the results? What can you do to improve your results?” These questions guided students to evaluate the investigation process and engage in further data collection to improve their results. The summary of cycle 3 is presented in Table 3.

**Discussion and implications**

The purpose of the study is to present the experiences of a physics laboratory instructor while integrating a new instructional approach using action research. Through continuous reflection on her practice and students’ learning, the instructor was able to examine her own challenges and students’ learning experiences. Consequently, she was able to make sense of and act on these experiences through iterative rounds of lesson adjustments and reflections. Furthermore, the instructor could identify a problem in her practice; she was able to take targeted action to collect data about the details of the teaching and learning experiences in her classroom and create opportunities for resolution. Her reflective journey helped to recognize her challenges as chances for teacher learning and improvement in practices.

The instructor faced many challenges when determining how to incorporate the 5E model. The instructor had difficulties with lesson planning. She had to appropriate the existing physics laboratory curriculum into the instructional approach and support the curriculum with formative assessment tasks in ongoing cycles. Additionally, the instructor used students’ reflections and lesson artifacts to identify their learning experiences based on their engagement in scientific practices, which helped her to design new pedagogical moves and understand the effectiveness of her instruction toward meaningful learning. In her classroom, students experienced challenges related to the experimental design, use of models, doing accurate measurements, and engaging in argumentation. The formative assessments, integrated in different phases, helped to address these challenges.

This study provides the results of a physics laboratory instructor’s practice-oriented experiences while incorporating the 5E instructional model in the laboratory portion of a mandatory physics course. Other studies have focused on exploring students’ scientific abilities (Etkina, 2015), enhancing their quantitative critical thinking skills (Holmes & Wiemann, 2018), and engaging in scientific practices (Kozminski et al., 2014) while working on physics experiments. Little research exists on how physics laboratory instructors attempt to integrate scientific practices and how they reflect on and change their practices to enhance students’ engagement in scientific processes. The findings showed that reflective teaching assisted the instructor in challenging and refining students’ ideas and in promoting authentic learning through active participation. Over three semesters, the instructor made adjustments in the curriculum, assessments, and instructional elements to improve physics learning experiences through 5E lessons that included scientific practices. Through purposeful and focused cycles of reflection and action, the physics laboratory instructor-as-researcher designed instruction relevant to students’ needs, which enhanced their critical voice.

The authors think action research is a viable way to modify teaching

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<td><strong>Action research sequence of cycle 3</strong></td>
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<th>Focus</th>
<th>Timing</th>
<th>Plan</th>
<th>Act</th>
<th>Observe</th>
<th>Reflect</th>
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<tr>
<td>Confidence in implementation</td>
<td>Third semester October–December 2015</td>
<td>• Integrate PowerPoint presentations</td>
<td>• Modifying the tutorial and physics experiment</td>
<td>• More confidence in teaching</td>
<td>• Modifying the questions were helpful</td>
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<td>• Revise the experimental worksheet</td>
<td>• Using activities to improve measurement skills and student questioning</td>
<td>• Enhanced student participation</td>
<td>• Positive impact of taking an action to make changes</td>
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<td>• Guidance in the design of experiment</td>
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<td>• Students’ positive reflections</td>
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practices toward adopting the suggestions of the AAPT for physics laboratory curriculum. This study can motivate other college physics instructors and teaching assistants to identify problems with their teaching and move toward resolution. Further research is needed to examine how physics instructors attempt to change their practices in light of the AAPT’s recommendations. Encouraging and supporting instructors to become reflective practitioners and participate in action research can serve as a guide for promoting changes in their teaching and students’ learning experiences.

References

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