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The Effect Of 7E Model Inquiry-Based Labs On Student Achievement In Advanced Placement Physics: An Action Research Study

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THE EFFECT OF 7E MODEL INQUIRY-BASED LABS ON STUDENT ACHIEVEMENT IN ADVANCED PLACEMENT PHYSICS: AN ACTION RESEARCH STUDY

by

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DEDICATION

For Duncan, who can always make me smile.

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ABSTRACT

This dissertation involved an action research study of the effects of 7E Model inquiry labs in Advanced Placement (AP) Physics on students' performance on AP exam inquiry lab-based questions. The study, which is described in detail, employed a one-group, pretest-posttest design to answer the research question regarding the effects of the inquiry-based AP Physics labs on students' achievement on AP exam inquiry lab questions as measured by unit assessments. Data collection and analysis strategies are also discussed. Sources of data included a pretest, lab reports, and a posttest. The data were analyzed using descriptive statistics, specifically a t-test comparison of pretest and posttest results. Reflection upon the data and formation of an action plan after its analysis were the last steps in the action research process. Through this process, it was demonstrated that the 7E Model inquiry labs did have a positive effect on student achievement on AP inquiry lab questions.

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CHAPTER 1: BACKGROUND

Implementation of inquiry labs is not new to the science classroom. Since the 1940s, many science educators have called for the use of inquiry to further science education and to help the United States to maintain its status as a leader in science and technology (Spring, 2014). From the 1950s through the 1980s, the era of the Cold War, efforts to surpass the Soviet Union caused federal funding of science education skyrocket (Chiappetta, 2007). U.S. government-sponsored textbooks were better than commercial ones, and they advocated that science be taught as inquiry (Chiappetta, 2007).

Even today, inquiry continues to play a large role in science education. In 2013, in an effort to maintain American competitiveness in an ever-expanding global market, the National Research Council furthered the understanding of inquiry with release of the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013). The NGSS provided a framework for describing behaviors in which scientists engage and set out to explain better what is meant by the term “inquiry” (NGSS Lead States, 2013).

Most recently, in 2014, the College Board has adopted a newly-revised curriculum for Advanced Placement (AP) Physics that includes inquiry as a standard. In order to clarify the new inquiry recommendations, the Board has developed Science Practices (SPs). These SPs “align to the . . . curriculum framework to capture important aspects of the work that scientists engage in, at the level of competence expected of AP Physics students” (College Board, 2015, p. 28). Inquiry has now become more than just an idea to include. It is a standard and requirement of the AP Physics curriculum, with as much value as much of the content knowledge of the course.

Statement of the Problem of Practice

The College Board has recently introduced a new form of the AP exam that requires students to design and evaluate inquiry-based physics labs. The 7E Model (Eisenkraft, 2003) has been the basis for the inquiry labs suggested by the Board. The identified problem of practice (PoP) for the present action research study involved Advanced Placement (AP) Physics at the teacher-researcher's high school, where typically students have scored well on the traditional AP exams. With the introduction of new inquiry-based lab questions, however, students found it difficult to maintain their levels of achievement. The teacher-researcher also needed to develop the pedagogical skills to conduct the labs successfully for the students in the class. In order to prepare students for the new exam, she implemented 7E Model structured inquiry labs in her two AP Physics sections in the fall of 2017. The impact of the inquiry labs on the exam performance of the students in these classes was the focus of the study.

The AP development committee based the new AP Physics inquiry labs on the 7E model (College Board, 2015). This model or learning cycle consists of seven stages: elicit, engage, explore, explain, elaborate, evaluate, and extend (Eisenkraft, 2003). It allows teachers to present lessons that incorporate inquiry labs and activities into their curriculum in a cycle that promotes a student-centered classroom (2003). The research-based 7E model employed a constructivist approach to challenge students' misconceptions through activities that access students' prior knowledge (Bybee, 2014).

The teacher-researcher was concerned that a lack of exposure to the new 7E model inquiry labs would hinder her students' success on the AP physics exam. It would be unfair for the students not to participate in the inquiry labs in contravention of the new College Board learning objectives. She was also concerned that, even though her students may have known the content, they would be unable to communicate their knowledge to an AP exam grader appropriately. Traditionally, AP Physics students in the teacher-researcher's classes have been very strong in mathematical skills but weaker in their ability to explain concepts and other processes involving scientific communication.

Because few of their previous courses included inquiry labs, which are time-consuming and complex, most students entering AP Physics had had little actual experience with them. They expected lab experiences to involve following a set of directions prescribed by the teacher in order to arrive at an expected result. Owing to this lack of experience with inquiry labs, the behavior, participation, and techniques of the students needed to be observed during them. Students may have shown positive attitudes toward inquiry labs, but if they were observed exhibiting poor behavior and techniques, then the full purpose of the labs would not have been achieved.

An inquiry lab is a challenge in itself; in addition, students must communicate procedures, analyses, and conclusions clearly. In most of their previous science classes, many students had only been asked to write to demonstrate knowledge gained through short-answer and essay-assessment questions (Yore, Bisanz, & Hand, 2003). With the new AP revisions, students had not only to become proficient in problem-solving for lab procedure development but also to improve their scientific communication skills in terms of writing, explaining, and justifying their procedures and conclusions in their lab reports and on the AP exam inquiry lab questions.

This teacher-researcher began to wonder whether there was a connection between 7E Model inquiry labs and the development of scientific communication skills, that is, whether students, by participating in the labs, could strengthen and improve their scientific communication skills. Further, it seemed students' skills in and familiarity with inquiry labs could improve their achievement on AP inquiry lab-based exam questions. Given that students can earn college credit for passing AP exam scores, doing well on these exams can save them money by reducing the number of college courses required to obtain a degree. Beyond the test score, developing the problem-solving skills used in inquiry labs can help students to be successful in future endeavors, when as adults they find themselves able to use prior knowledge to develop a plan to solve problems that they encounter. Effective communication is also crucial for any person, scientist or otherwise. By increasing their proficiency in problem-solving and communication skills, then, students can be better prepared for future careers and educational pursuits in science and technology.

The teacher-researcher was discouraged by the predominantly white and male make-up of her classes and sought to use 7E model inquiry labs to encourage more students from traditionally underrepresented groups, such as female students, to take AP Physics and succeed. The aim was for the make-up of the classes to mirror more closely the demographics of the school. The teacher-researcher worked to diversify her curriculum through the use of 7E model inquiry labs so that the class and its curriculum would be more accessible to all students while still adhering to the standards of achievement.

Research Question

This action research study sought to discover the effect of the newly-developed 7E Model inquiry labs on student performance on lab-based AP exam questions. The research question (RQ) was accordingly framed as follows: What are the effects of 7E Model inquiry labs in Advanced Placement (AP) Physics on student achievement on AP exam inquiry lab-based questions as measured by unit assessments?

Purpose Statement

The primary purpose of the present study was to determine the effect of 7E Model inquiry labs on the performance of two sections of AP Physics I students on AP exam inquiry lab-based questions. The secondary purpose was to devise an action plan for improving the effectiveness of AP teachers in the context of the unique location and population of high-level science students at the teacher-researcher's school.

Brief Overview of the Methodology

The current inquiry was conducted as an action research study to answer the research question regarding the effects of 7E Model inquiry labs on the performance of AP Physics students on AP exam inquiry lab-based questions. Action research can be defined as cyclical or spiral paths that a teacher-researcher takes and reflection on those paths (Elliot, 1988). In each cycle, the teacher-researcher identifies a practical problem to be solved, develops strategies to address the problem, implements the strategies, and reflects on the results, which reflection may reveal other problems to be addressed (Dana & Yendol-Hoppey, 2014). The present study was conducted using action research because this methodology allowed the teacher-researcher to carry out the work in her own classroom. Action research is not meant to be generalized to a larger population, but addresses a specific problem in a particular location (Mertler, 2014), and it served as a means for this teacher research to explore her own classroom and better understand her students in relation to the research question.

After identifying a broad PoP, the teacher-researcher narrowed it to a specific research purpose. Through a review of relevant literature, the topic was further refined and the research question determined. During the acting phase, the teacher-researcher conducted a pretest, implemented the 7E Model inquiry labs, collected data, and concluded with a posttest. The data were then analyzed using a t-test to determine whether the 7E Model had an effect on student achievement. The t-test was conducted using Excel. The percentage correct from the pretest was compared with that from the posttest. Based on the data analysis, the teacher reflected on the study to determine its effectiveness, problems in implementation, modifications to be made, and need for future study. The teacher-researcher also included the subject participants, i.e., her AP Physics 1 students, in the reflection process to understand better the strengths and weaknesses of the study design and the 7E Model. After reflection, the teacher-researcher developed an action research plan to implement the findings of the study in her own classroom. The current action research study was informed by a conceptual framework (Appendix A) discussed in detail in Chapter 3.

The action research study, then, was of a one-group, pretest-posttest design. Two sections of AP Physics 1 served as the experimental group, participating in the 7E Model labs. A comparison of pretest and posttest scores for each group served to determine whether the 7E Model inquiry labs affected student performance on lab-based inquiry exam questions.

Significance of the Study

This action research study was designed to contribute to the body of research on the 7E Model and inquiry-based labs. Of the many studies consulted in the review of the literature, none seemed to focus on groups similar to the population of high school AP Physics 1 students examined here. Thus much of this work involved college or middle school students or was conducted in a country other than the United States.

In fact, most of the research on the effectiveness of the 7E Model has been conducted in Turkey, which adopted a constructivist approach to science curriculum development and education in 2005 (Balta & Sarac, 2016). The current action research study therefore serves to increase understanding of the effect of the 7E model on U.S. students. Further, many of the Turkish studies (Duran & Duran, 2004; Acisil & Turgut, 2011) involved only the 5E (as opposed to 7E) Model with the inquiry labs.

Other work on inquiry and learning cycles in physics labs has focused on populations that differ significantly from the one studied for the present research. Thus the Investigative Science Learning Environment (ISLE) developed at Rutgers University showed positive results with inquiry in a physics lab, but the relevant study was conducted in a university setting rather than a high school classroom (Etkina, Karelina, Ruibal-Villasensor, Rosengrant, Jordan, & Hmelo-Silver, 2010). The ISLE study also did not employ the 7E Model specifically as the learning cycle.

The present study, by contrast, involved use of the 7E Model with inquiry labs in a high school AP Physics 1 course. The College Board’s largest change for the course in its 2014 guidelines was the introduction of Science Practices (SPs; Appendix G), which included inquiry-based labs based on the 7E Model (College Board, 2014a). Through the inquiry labs, students were asked to develop procedures, analyze data, and form conclusions based on the evidence. A key facet of these skills is the ability to communicate what has been done and learned in the inquiry labs effectively and in a scientifically appropriate way. A study was accordingly required to determine whether these changes did in fact improve student's performance on the AP inquiry lab-based questions.

Rationale for Action Research

In science education, action research has been conducted at many levels for the purpose of "advancing knowledge about how science teachers teach and what students learn in science" (Capobianco & Feldman, 2010, p. 911). Capobianco and Feldman (2010) argued that action research in the science classroom can serve as a way for science teachers to maintain a capacity for change; they must adjust to ongoing changes in education, and action research can serve as a mean to address and embrace these changes. In the context of the evolving AP science curriculum, this teacher-researcher aimed to use action research as a means to investigate changes in her current classroom and lab practices, since the action research study of 7E Model inquiry labs in her own classroom had the potential to enhance instructional practices for her students.

The action research, then, offered to the teacher-researcher the opportunity to improve her classroom practice by gaining more insight into 7E Model inquiry labs and facilitating scientific communication. She hoped to receive feedback from the data gathered and to use it in helping her current and future students. Helping students better their education, as always, is the main objective, and it was felt that any insight gained through this research would improve the current classroom situation.

Summary of the Findings

Students were given a pretest at the beginning of the study and a posttest after completing four 7E Model inquiry-based labs for which they submitted written lab reports. A t-test determined that scores had significantly increased between the pretest and posttest. The t-test results and observations made from the lab reports indicated that the 7E Model inquiry-based labs did indeed contribute to an increase in performance on AP inquiry lab-based type questions.

Limitations of the Study

This action research study was limited by the small number of student participants ($N = 37$); for while the group of AP Physics 1 students was larger than most of the teacher-researcher's previous classes, it was still too small to be widely generalizable. The study was also constrained by a short research period (approximately six weeks). Through the use of an extended research period and a larger and more diverse sample of participants, a study similar to this one could provide more information concerning the impact of 7E Model, inquiry-based physics labs on students' performance on AP lab-based questions.

Dissertation Overview

This first chapter of the dissertation has provided an overview of the current problem of practice, the pertinent background information concerning the problem, and the research question. Chapter 2 provides a review of relevant literature focused on the topics of science reform, inquiry and learning cycles in physics, and changes to the AP exam. Chapter 3 describes the action research methodology used, the role of the teacher-researcher, and details regarding the setting and participants. The data are analyzed and discussed in Chapter 4. In Chapter 5, the results are discussed and avenues for future research are suggested. An action plan is also proposed in the final chapter describing the teacher's plans to implement the findings in her future classes.

Keyword Glossary

7E Model

Developed by Eisenkraft (2003) as an expansion of the 5E Model, the 7E Model is a learning cycle composed of seven steps, namely elicit, engage, explore, explain, elaborate, evaluate, and extend (2003). The model was used by the College Board (2015) to develop inquiry labs for AP Physics.

Action Research

This kind of research is conducted by teachers for their own use, helping them to assess their instructional practices (Mertler, 2014).

Advanced Placement (AP) Physics

These high school physics courses were developed by the College Board to focus on topics typically included in the first and second semesters of an introductory college-level physics course (College Board, 2014a). Students generally take a standardized, cumulative exam at the end of the school year, their score on which can earn college credit at some colleges and universities.

Advanced Placement (AP) exams

These standardized, cumulative exams are administered at the end of an AP course. They are developed by the College Board and consist of multiple choice questions and free response questions. Again, a student may earn college credit with a passing score.

College Board

This organization is responsible for developing the AP curriculum, and it designs and assesses the AP exams. The College Board also develops and administers the Scholastic Assessment Tests (SAT).

Inquiry lab

This is a guided inquiry activity in which the teacher provides a question and the students design the procedure, develop explanations, and communicate their results to answer a provided question (Miranda & Hermann, 2012).

Inquiry lab-based question

A multiple-part question on either a teacher-designed assessment or a part of an AP exam developed by the College Board that requires a student to develop a procedure, analyze lab results, and/or evaluate possible sources of error in addressing a given lab-based problem. On the AP exam, such questions appear in the free response section of the exam.

Science inquiry

This term refers to science taught by means of a learner- or student-centered approach (Chiappetta, 2007). Students construct scientific knowledge through an “active process of investigation” (2007, p. 21).

Science Practices (SPs)

These practices involve AP Physics objectives designed to promote students’ participation in aspects of scientific work at an appropriate level (College Board, 2014a).

Integration of these practices by teachers throughout the AP Physics curriculum is intended to facilitate students' efforts to connect content learning objectives with inquiry and reasoning skills (Appendix G).

Traditional lab

Traditional labs involve predetermined steps and expected outcomes. They are often communicated in list form, much like a recipe, which is why they are sometimes called "cookbook labs." Such labs are generally not accepted as a part of student-centered learning.

CHAPTER 2: THEORETICAL FRAMEWORK

Constructivism

Constructivism is a learning theory that developed in response to behaviorism and cognitivism (Keser & Akdeniz, 2010; Harasim, 2012) during a recent period of educational reform in the United States. Drawing on the research of Piaget, Bruner, Goodman, and Vygotsky (Ertmer & Newby, 1993; Harasim, 2012), constructivism was founded on the notion that learners create or construct meaning from experience (Ertmer & Newby, 1993; Colburn, 2000). Every learning situation is viewed through learners' previous learning and knowledge (Ertmer & Newby, 1993). Students take responsibility for their own learning, that is, for constructing the knowledge required in various situations (Altun & Yucel-Toy, 2015). Thus teachers, rather than controlling and directing the learning environment, serve as coaches or facilitators (Keser & Akdeniz, 2010), supporting students so that they can discover and interpret knowledge on their own (Altun & Yucel-Toy, 2015). Constructivist activities in the classroom involve problem-based learning, inquiry labs, dialogues with fellow students and teachers, usage of multiple sources of information, and various ways in which students can demonstrate diverse understandings (Windschitl, 1999).

Vygotsky furthered this approach with his theory of social constructivism; according to which students construct meaning about ideas and concepts through interactions with others (Singer, Marx, & Krajcik, 2000). Ideas are explored and examined in the context of a social event, with each participant reflecting on and making sense of what is being communicated (Lederman & Abel, 2014). The four main features of social constructivism are active construction, situated cognition, community, and discourse. Active construction requires students to become immersed in a given context (Singer et al., 2000), to construct knowledge by explaining, gathering evidence, generalizing, applying concepts, and representing things in various ways (Singer et al., 2000). When students are able to construct their own understanding of a subject actively, they are more likely to develop a deeper understanding of it (Singer et al., 2000). Situated cognition requires that students be immersed within the context of a subject so that new learners can grow through social and intellectual support. Support can only come through a community of people practicing and learning a given discipline. Discourse provides the community with opportunities to exchange ideas, learn what counts as evidence, and develop in the language of the subject (Singer et al., 2000).

A constructivist perspective may at first seem ill-suited to teaching science. In practice, though, when students construct their own knowledge, the role of science teachers is to facilitate the acquisition of the particulars of a certain concept in a manner that is in line with scientific principles (Mulhall & Gunstone, 2012). Thus constructivism in the science classroom does not mean a free-for-all with a multitude of student understandings. Rather, it is the role of science teachers to link students' construction of meaning with scientific knowledge and the nature of science; thus they must be introduced to the "physics way of knowing" and thereby provide opportunities for students to discuss their ideas about physics (Mulhall & Gunstone, 2012).

Social constructivism can allow students to move away from their own understanding of a concept and toward the ways in which a scientist would understand it through discourse with fellow students and questioning from the teacher (Colburn, 2000; Mulhall & Gunstone, 2012). Cooperative learning and questioning are major tenants of social constructivism; for when students explain their viewpoints to others, they may become aware of problems with their explanations, such as lack of sufficient information (Colburn, 2000). Posing challenging questions to one another during a lab experience which may be a less threatening experience for students than responding to the same questions posed by a teacher (Colburn, 2000). If students are to learn how physics is practiced in the real world, they must be given access, not just to physical experiences, but also to discussion of the concepts with their peers and teachers (Driver, Asoko, & Leach, 1994).

In creating constructivist classrooms, teachers follow five basic principles: (1) pose interesting questions, (2) use key concepts to construct learning, (3) incorporate student viewpoints, (4) adapt the curriculum to correct students' misconceptions, and (5) evaluate learning based on subject matter context (Altun & Yucel-Toy, 2015). Teachers must ask questions that spark students' interests and thoughts, and activities should be based around key concepts and involve diverse ways to evaluate student viewpoints (Altun & Yucel-Toy, 2015). Student misconceptions should be addressed within the structure of classroom activities, and assessments should be evaluated in a way that is consistent with the purpose of the lessons (Altun & Yucel-Toy, 2015). By participating in such activities, students are socialized into knowing the ways of school science (Driver, Asoko, & Leach, 1994) as they develop the necessary critical perspective on science and its culture. In order to accomplish this, students must be made aware of the many purposes of scientific knowledge, limitations encountered in science, and the reasons why scientists make certain claims (Driver, Asoko, & Leach, 1994).

So that their lab activities support constructivist principles, science teachers are urged to provide lab activities before discussing the expected results with students (Colburn, 2000). In other words, students benefit by participating in labs before receiving lectures on the topics covered. Thus, for example, rather than being given data tables, they can be encouraged to create their own ways of organizing information (Colburn, 2000). So also students can be encouraged to invent a procedure to answer a question posed at the beginning of a lab, during which they can debate findings, discuss outcomes, and share findings in a group context (Colburn, 2000). Throughout a lab activity, teachers can use a questioning strategy to help students demonstrate their thoughts (Colburn, 2000). After an understanding has been developed, then mathematical problem solving and reasoning can begin (Mulhall & Gunstone, 2012).

Dewey

John Dewey based his theory of experience on the principles of continuity and interaction (Dewey, 1938). From this perspective, a student's past experience influences her present, interacting with the present moment. The present experiences must allow students to grow and develop in their learning, and teachers, serving as guides, must be aware of their previous knowledge in order to help them connect the past with the present situation. The teacher helps students to create new knowledge, but cannot do the learning for them, since this involves making connections with their past experiences (Dewey, 1938).

Prior to entering AP Physics, the majority of students at the researcher's school had only participated in traditional, "cookbook" labs, which Dewey would not have supported. These traditional labs give students step-by-step instructions and have a known outcome. Deficiencies occur because students do not have opportunities to connect prior knowledge to the present. Although traditional labs do involve student movement, of which Dewey would approve, they do not allow the students to create their own context for learning. Because every step is already predetermined, with no room for creativity or individual experiences, students tend to miss basic concepts, fail to develop a sense of the scientific process, and often are unable to apply what they learn to different situations (College Board, 2015). Students in traditional labs are merely told the right answer, which impedes construction of their own knowledge. When students do not create a personal connection to learning, it has no meaning for them, and they have difficulty communicating what they have done or why they did it.

In an AP Physics inquiry lab, a question or problem is posed to students, who are asked to develop a solution to the problem or an answer to the question using physics principles that they have learned through lecture, reading, or prior experience. There are often numerous ways to answer a question. Consistent with Dewey's theory of experience, students connect prior knowledge to the present situation in order to answer the question posed in the lab, which would occur in the "engage" and "elicit" stages of the 7E model (Eisenkraft, 2003).

Dewey believed that scientific inquiry carried out without consideration of prior experience, knowledge, and misconceptions could not lead to problem-solving or the development of effective solutions (Harris, 2014). Misconceptions are not usually well addressed in traditional physics instruction or introductory physics textbooks (Dykstra, Boyle, & Monarch, 1992). Logical arguments about Newtonian mechanics presented by a teacher, for example, do not encourage conceptual learning when the reasoning makes little sense to students in the context of their current views, which means that the traditional teaching of physics is not effective in facilitating students' understanding of the concepts taught in class (Dykstra, Boyle, & Monarch, 1992). By leveraging their prior knowledge through the use of learning cycles, students can construct their own conceptual framework, which is necessary if they are to leave a physics course having been disabused of their misconceptions (Dykstra, Boyle, & Monarch, 1992). Dykstra et al. (1992) argued that effective physics instruction emboldens students to learn in a way that promotes conceptual understanding whereby the individual constructs knowledge. Classrooms must be structured to facilitate students' development of physics concepts for themselves, and, in order for this to happen, teachers need to recognize students' prior knowledge (Dykstra, Boyle, & Monarch, 1992).

As a progressivist, one of Dewey's main goals was to "enrich and expand everyday experience" (Pugh, 2011, p.107). As in Dewey's Lab School, students in AP Physics inquiry labs are often given real-world problems to solve. The physics inquiry lab can thus provide a transformative experience through which the student can integrate school learning with everyday experiences (Pugh, 2011). The problems given to students in the Lab School were often associated with work (Dewey, 1938). Many AP Physics students wish to pursue careers in science in which they will be presented with questions and problems to solve. Inquiry labs can help prepare them for future work by promoting the development of effective problem-solving, communication, and team building skills, in like manner as Dewey sought to prepare his students for their future work. AP Physics inquiry labs are designed to help students develop scientific communication and problem-solving skills. For whether or not students actually become scientists, they need to know how to approach problems through an experimental or scientific process, again as urged by Dewey (Harris, 2014).

In the lab, an AP teacher ensures safety when equipment is used and answers basic procedural questions. Dewey (1938) suggested that teachers should not provide answers pertaining to a lab but should instead offer guidance regarding resources that students can use to develop their own solutions. Because the teacher administers not just the labs but instruction for the entire course, she is aware of her students' background with the material in other contexts. This awareness helps her to facilitate the students' connections between prior knowledge and the current lab.

Through the use of Dewey's principles, this action research project sought to improve students' true science practices, which help to develop their epistemic basis for science and its processes (Osborne, 2014). During activities, including those elaborated for the new AP inquiry-based labs, students ask questions and define problems, develop and use models, plan and carry out investigations, use mathematical thinking, construct explanations and solutions, engage in arguments from evidence, and communicate information (Osborne, 2014). According to Osborne (2014), science practices help teachers to clarify goals for their students' experiences and learning during labs and to develop professional language for communication. Through science practices in the AP inquiry labs, students can connect previous knowledge to a current situation; therefore, they should be able to develop their own procedures to answer a given problem. By creating their own context, students should then be better able to communicate their procedures and findings and thus to be more successful when reporting their inquiry labs and writing answers on the AP exam.

Piaget

Piaget characterized intellectual development in terms of four stages, namely sensory-motor, preoperational, concrete, and formal thought (Driver, Asoko, & Leach, 1994). During sensory-motor stage, occurring from birth to age two, a child's thinking is exhibited by such actions as reaching and sucking (Karplus, 2003). From ages two to seven, children begin to develop language and to describe their feelings (Driver, Asoko, & Leach, 1994). AP Physics students are in last two stages which deal directly with secondary students; in the third, concrete thought stage, which generally occurs between the ages of seven and twelve, a child begins to think more logically, but may be still tied to concrete ideas (Karplus, 2003). During the final, formal thought stage, individuals aged twelve and up use logical and formal thinking, which can include forming and testing hypotheses (Karplus, 2003).

Many current learning cycles and inquiry models are based on the work of Piaget. In order to move from one stage to the next, students must mature in their views and have experience with their physical environment (Karplus, 2003) through processes of assimilation and accommodation (Driver, Asoko, & Leach, 1994). During assimilation, students interpret new information within their own cognitive structure, while accommodation occurs when students adapt or reconstruct new information to make sense of it (Driver, Asoko, & Leach, 1994).

Piaget's theory of how students construct their knowledge has influenced many scholars working on conceptual change and student conceptions (Driver, Asoko, & Leach, 1994). Karplus (2003) suggested that science teachers can benefit from applying Piaget's theory in moving students from concrete to formal thought; however, teachers must focus on student reasoning patterns and must not expect each student to engage easily or entirely in either. When learning physics, students must begin to acquire formal thought, especially when designing lab experiments. Lab designs during inquiry activities or on lab-based exam questions are not concrete. When teachers work with students to help them move their ideas of the natural world relating to physics principles to the formal stage, the students enjoy greater success on inquiry labs and the AP exam.

Vygotsky and Social Constructivism

Unlike Piaget, who saw the construction of knowledge as an individual pursuit, Vygotsky recognized that learning can involve a transfer from social contexts to individual understanding (Driver, Asoko, & Leach, 1994). Students encounter new ideas in the classroom, which is a social situation in the context of which they make sense of the information individually (Chiappetta, 2007). Vygotsky developed his idea of the zone of proximal development (ZPD) to illustrate the knowledge that can be achieved by working in a group as opposed to working alone (Chiappetta, 2007). It becomes a teacher's job both to supply this social context for the ZPD and to provide opportunities for students to make sense of the information individually after social interaction (Chiappetta, 2007).

Learning takes place within specific communities (Driver, Asoko, & Leach, 1994). In the case of AP Physics, the students are in the community of their own classroom and are learning to participate in the scientific community. Through the use of inquiry labs, these students are able to experience and learn from both communities. They work within lab groups to communicate and construct knowledge with their peers about the new content as teachers guide them through the use of the suggested Science Practices to learn more about the scientific community and how scientists interact. They begin to develop scientific communication skills through social interaction and discussion with peers, while individual lab reports and reflections facilitate their personalization of the new knowledge to make it their own.

Bruner and Discovery Learning

During the Cold War period, Bruner advocated that students learn through discovery (Chiappetta, 2007). This new method of “discovery learning” was founded on the notion that people learn by doing rather than by rote memorization of facts (Bruner, 1961). As in the inquiry-based labs of AP Physics, learning thus conceived takes place through problem-solving activities in which students use prior knowledge to create their own answers to a question (Bruner, 1961). Bruner argued that students need to interact with their environment and perform experiments in order to learn (Bruner, 1961). Like Dewey, Bruner viewed teachers as guides who encourage students to figure answers for themselves (Chiappetta, 2007); in his own words, “success in teaching depends upon making it possible for children to have a sense of their interaction” (Bruner 2013, p. 80).

Students accordingly should be encouraged to approach tools, not as fixed objects, but as amplifiers of various capacities (Bruner, 2013). Thus, in an AP Physics inquiry-based lab, students may need to think of supplies in new and different ways; a piece of tape, for example, may be used to hold electrons. Likewise, students are encouraged to find alternatives tools for performing a given task; thus the measurement of the period of an object, which is often based on time and use of a stop watch, could alternatively be carried out by taking length measurements. In keeping with Bruner's (2013) suggestions, students can through discovery and inquiry-based labs come to realize that tools are not fixed and can learn to create different meanings for common objects.

Review of Related Literature

The review of related literature begins with a discussion of the historical context and the evolution of inquiry in conjunction with the formation of national standards. Attention is thus given to studies of distinctions between inquiry labs and those traditionally used in science classrooms. Next, research into learning cycles and their development is reviewed. Finally, changes in the AP Physics course and in AP science more broadly are explained.

Historical Context

The first public high school opened in Boston in 1821, but such schools did not become common until the 1920s or 1930s (Spring, 2014). High school curricula generally emphasized the sciences, with the coursework usually being determined by the assigned textbook (Spring, 2014). Most teachers, however, had a very weak background in science (Chiappetta, 2007). During early 1800s, most the country's elite students attended private high schools in which the prevailing trend was to emphasize preparation for college science and a focus on content and memorization was deemed appropriate for achieving this purpose (Chiappetta, 2007). High school science teachers thus taught diluted college courses with little lab work or attention to technology or investigation (Chiappetta, 2007).

The Cold War period. Founded in 1950, the National Science Foundation (NSF) represented an effort to draw more students to scientific fields. NSF founder Vannevar Bush was of the opinion that educating more science students was key to maintaining national security and U.S. leadership in the world, and this meant improving instruction and stimulating more interest in science (Spring, 2014). Responding to the launch of the Sputnik satellite by the Soviet Union in 1957, President Eisenhower and Congress passed the National Defense Education Act (NDEA) the following year to ensure that the U.S. education system would not fall behind those of other countries (Chiappetta, 2007). The NDEA accordingly advocated incentives for high-ability students to pursue studies in the sciences, sponsored programs to increase the quality of science teachers, and increased funding for the NSF (Spring, 2014).

These developments set the stage for revision of the science curriculum. One of the main reformers was Joseph Schwab (Deboer, 2006), according to whom the United States faced three main challenges in this regard, namely developing more scientists, cultivating political leaders able to make policy based on an understanding of science, and educating the public as to the changing nature of science (Deboer, 2006). Scientific inquiry was the educational model favored by Schwab, who held that students should see science "as a series of conceptual structures that should be continually revised with new information or as evidence is discovered" (Barrow, 2006, p. 266; Deboer, 2006). Anticipating the AP Physics inquiry labs, the thought was that students needed to study science in the manner in which it was performed in the real world, which meant more inquiry-type lab activities (Barrow, 2006). Science was to be seen as malleable and flowing (Chiappetta, 2007). As in the "evaluate" stage of the 7E Model (Eisenkraft, 2003), students were also called on to read scientific reports, analyze data, and discuss conclusions reached by scientists (Barrow, 2006). Anticipating the “elaborate” stage of the 7E Model, Schwab thought it more important for students to carry out their own investigations so as to arrive at their own understanding of the nature of science (Deboer, 2006).

During the 1950s through the 1980s, the era of the Cold War and efforts to surpass Russia saw federal funding of science education skyrocket (Chiappetta, 2007). The textbooks sponsored by the U.S. government, which were better than those that were commercially available, advocated science taught as inquiry, an approach that Schwab’s work had popularized, though in fact many high schools across the country neglected to adopt the method (Chiappetta, 2007). Though well-meaning, many of these new science inquiry-based courses created the impression that scientific inquiry is subject-specific and excludes many students owing to its difficulty (Deboer, 2006). In any case, by the early 1980s, federal funding for science programs, including inquiry, began to decrease and student achievement and interest in science to decline (Chiappetta, 2007).

Formation of national standards. As it had been earlier in the Cold War era, science education was again in the 1970s and 1980s criticized for failure to prepare students for futures in science and technology (Chiappetta, 2007). Concern over national defense was augmented by concern over economic competition as Japan began to emerge as a major force in technology-related industries, such as electronics and automobiles, that were once dominated by the United States (Chiappetta, 2007). Published by the Reagan administration, a 1983 report titled *A Nation at Risk* blamed the public school system for the United States’ economic woes with particular reference to competition from Japan and West Germany (Spring, 2014). The report as intended elicited a call for more rigorous academic standards, improved teacher quality, and curricular reform (Spring, 2014).

Also during this period the National Science Foundation (NSF) sponsored Project Synthesis (Harms & Yager, 1981), an initiative that combined several previous NSF surveys and studies in an effort to refocus science education in the United States (Bybee, 2000). One of the findings of the study was that science educators were using the term "inquiry" in a multitude of ways (Bybee, 2000), and it accordingly defined four goal clusters for improving science education, namely personal needs, societal needs, academic preparation, and career education. Along with the traditional focus on academic content, the goals for students included being able to "(1) use science in their daily lives, (2) deal responsibly with science related societal issues, and (3) demonstrate awareness of science related careers" (Staver & Bay, 1987, p. 630). The notion science as inquiry in turn played a smaller role in science education in favor of a focus on societal issues (Chiappetta, 2007).

In 1985, F. James Rutherford and the American Association for the Advancement of Science (AAAS) began another such initiative, Project 2061, designed to produce a scientifically literate society by the year 2061 (Bybee, 2000). This goal was to be achieved by identifying everything that students should know and be able to do by the time they graduate high school (Chiappetta, 2007). Project 2061 brought inquiry back into the science classroom by setting goals and placing specific benchmarks for teaching the concept, thereby paving the way for inquiry to be included in the National Science Education Standards (NSES) (National Research Council, 1996).

Indeed, these standards made inquiry a high priority (Chiappetta, 2007). The NSES provided guidance regarding what students should know, how they should be assessed, and how teachers should teach inquiry (Barrow, 2006). The concept of inquiry was also defined more clearly, and broadly, as referring to “the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work” (NRC, 1996, p. 23). Inquiry was to be content, understood as that which a student should know and be able to do, as well as a teaching strategy associated with specific activities (Bybee, 2000). In an effort to clarify the NSES, the National Research Council published the Inquiry and the National Science Education Standards (National Research Council, 2000). This document identified five essential features of inquiry, namely scientifically-oriented questions that engage students, student-collected evidence, student-developed and evidence-based explanations, evaluations of these explanations, and communication and justification of them (Barrow, 2006).

In 2013, in an effort to maintain America’s competitiveness in an ever-expanding global market, the National Research Council again furthered the understanding of inquiry with their release of the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013). The NGSS described behaviors in which scientists participate, such as formulating hypotheses, procedure development, collecting and analyzing data, and peer discussion, and set out to define “inquiry” more precisely so as to clarify for students its relevance and that of science generally in their lives (NGSS Lead States, 2013).

Most recently, in 2014, the College Board adopted a newly-revised curriculum for AP Physics that includes inquiry as a standard. In order to clarify the new recommendations, the College Board developed Science Practices (SPs, for which see

Appendix G) that "align to the . . . curriculum framework to capture important aspects of the work that scientists engage in, at the level of competence expected of AP Physics students" (College Board, 2015, p. 28). Inquiry has now become, not just an idea mentioned in passing, but a standard, a requirement, of the AP Physics curriculum with, according to the earlier formulation, as much worth as much of the content knowledge of the course.

Inquiry vs. Traditional Labs

Inquiry labs are designed to increase students' involvement and their development of critical thinking and problem-solving skills (College Board, 2015). Labs can be seen on a continuum ranging from teacher-structured to guided to student-directed, open inquiries (Chang, Chen, Guo, Cheng, Lin, & Jen, 2011). At one end of this spectrum, confirmation inquiry is closest to a traditional lab method, since the teacher provides students with a question and method for answering it (Bianchi & Bell, 2008), so they usually know the answer in advance. A structured inquiry lab, by contrast, asks students to generate an explanation supported by evidence gathered based on a question and procedure developed by the teacher (Bianchi & Bell, 2008). Moving further toward the student-directed end of the spectrum, teachers may only provide students with a question for which they then develop a procedure to answer in guided inquiry (Bianchi & Bell, 2008). Most of the 7E Model labs in the present action research study were rooted in guided inquiry. At the furthest end of the spectrum is open inquiry, in which students develop both the question and procedure (Bianchi & Bell, 2008). Advanced Placement (AP) Physics inquiry labs naturally focus on the part of the continuum between guided inquiries and student-directed, open inquiries (College Board, 2015). In labs anywhere on the continuum, the teacher acts more as a facilitator than as a provider of direct instruction (Chang et al., 2011). Inquiry labs allow students and teachers to work together in an environment resembling a true scientific community. Constructivist principles are evident in inquiry labs because students solve higher-order thinking problems that lead them to create their own knowledge, with the teacher serving as a guide (Chang et al., 2011). As students become more experienced with inquiry labs, they can be expected to develop more refined reasoning methods (College Board, 2015).

According to Chang et al. (2011), to show true proficiency in inquiry, a student should be able to

1. ask questions and/or create a hypothesis based on experience or given evidence;
2. use available resources to develop a method to answer the question or confirm the hypothesis;
3. collect data with correct instruments using the developed plan; and
4. analyze and interpret data to form logical conclusions.

Instructors can easily assess a student's competence during inquiry labs and their ability to complete similar inquiry tasks in the future based on these four criteria (Chang et al., 2011).

Using a posttest-only, control group design involving 20 physical science classes in a large, urban, inner-city comprehensive high school over a period of 36 weeks, Freedman (1997) found that participation in science laboratories improved the attitudes of students—who in that study were of various races and ethnicities—toward science and the acquisition of scientific knowledge. The use of inquiry labs instead of traditional labs has been associated with improvements in three areas, namely statements of experimental procedures, lab write-ups, and data analysis and interpretation (Szott, 2014). In a study of his own eleventh- and twelfth-grade physics students at a high school in Alberta, Canada, Szott (2014) observed that open-ended laboratory activities gave students opportunities to design experiments, make models based on data, and work collaboratively with peers. Likewise, a study of 62 high school chemistry students in a large, urban public high school in Turkey by Acar Sesen and Tarhan (2013) found that students participating in inquiry labs tended to have fewer misconceptions about the topic of study (in this case, electrochemistry) than those who participated in traditional labs. Students' procedures also became more descriptive after participation in several inquiry labs (Szott, 2014). To enhance the students' procedures and ensure the correct usage of unfamiliar science terminology, on the other hand, direct instruction was found to be needed in scientific vocabulary and report-writing skills (Szott, 2014). Blanchard, Southerland, Osborne, Sampson, and Annetta (2010), in a study of 1,700 students in 12 middle schools and 12 high schools designed to assess the effectiveness of guided inquiry during a one-week forensics unit, found that those who participated in this form of learning increased their procedural knowledge more than those who participated in traditional laboratory activities that were solely teacher-directed.

Students participating in an inquiry lab also often collect more data than those participating in a traditional lab. Thus Szott (2014) found that the former, having had more time and freedom to explore during the physics labs, made insightful observations that may have been overlooked in a traditional lab. Again, as with the procedures, guidance from instructors and practice writing reports was found to be necessary for students to become proficient. The purpose of inquiry labs is not for students to obtain correct answers, but to interpret and analyze their results.

Students beginning an inquiry lab may feel overwhelmed by having to develop their own procedures (Szott, 2014). However, as Acar Sesen and Tarhan (2013) found, their attitudes toward a subject and laboratory work in general may improve with the completion of several inquiry labs; traditionally-taught students, by contrast, showed no significant change in attitude over multiple labs. Also, Szott (2014) found that students in his class appeared more engaged in the activities than they had during a traditional lab. Blanchard et al. (2010) likewise found that guided inquiry could benefit students in high-poverty schools by promoting a positive attitude toward science.

Inquiry experiments take no longer to complete than traditional labs (Szott, 2014). A sticking point is often that teachers must be willing to let go of some control in order to conduct them. At the same time, students require support and encouragement throughout the process, for instance by being allowed to rewrite insufficient lab reports (Szott, 2014).

Updating the Scientific Method

Scientific inquiry has mainly been associated with the traditional view of the scientific method, despite the fact that the history of science and experimentation has demonstrated weaknesses with this view (Finely & Pocovi, 2000). Traditionally, the scientific method has been taught as a series of steps, including identifying a problem, forming a hypothesis, conducting an experiment, analyzing the data, and reaching a conclusion. Usually at the end of a lesson a brief statement is to be found stating that there is no real order to the steps (Finely & Pocovi, 2000). Many teachers have used the scientific method as a way to create lab activities. These hands-on activities are referred to as inquiry, but this does not necessarily mean that they are meaningful for a student (Wheeler, 2000). Thus many traditional AP Physics labs simply follow the steps of the scientific method along a predetermined path toward a known answer.

The traditional scientific method differentiates scientific from faith-based understandings of nature, which is why it is considered a revolutionary intellectual achievement (Finely & Pocovi, 2000). However, if science is to be taught as inquiry and to develop the richness discussed by Doll (2013), the traditional scientific method as it is taught in textbooks must be amended (Finely & Pocovi, 2000). According to Doll (2013), for students who use a curriculum to change their understandings, the curriculum must allow for students to make multiple interpretations and construct multiple meanings. Everything in a curriculum cannot be laid out for the student in a perfect order in the manner of the traditional scientific method. Science must move beyond the collection of facts and predetermined steps (Doll, 2013); that which is currently understood as a fact must be shown to be fluid while students are left free to manipulate, create, and work with facts in imaginative ways to develop richness in their own learning. One step on this path, then, is to abandon the traditional view of the scientific method in favor of a new way of communicating the work of scientists.

In pursuit of this latter goal, Finely and Pocovi (2000) recommend first switching to a new form of the scientific method in which it is clear to students that their observations, findings, and experiments are influenced by their own understandings of the world. Students create their own meanings for a given activity. Observations are not always reliable, and opinions can dictate how data are interpreted. As in the 7E Model, teachers must leverage students' prior knowledge by helping them to see how it can affect their understanding of the question at hand (Eisenkraft, 2003).

As students develop a hypothesis, they must learn to rely on observations and the theories of others, knowing and using ways to collect data beyond direct experimentation (Finely & Pocovi, 2000). In the context of the “explore” stage in the 7E Model, students are encouraged to develop reasons for their predictions and ways to collect the information needed to confirm their predictions. The collection of data may involve an actual lab or researching another scientist's work. Students need to understand that all data has limits that can restrict how a question is solved, even as the theory that they use as the basis for their explorations influences how they collect and analyze their data during the “explore” stage (Finely & Pocovi, 2000).

So also students must learn that conclusions are neither certain nor final, again in contrast with traditional approaches (Finely & Pocovi, 2000). No scientific theory is carved in stone or absolute. Thus, even after students have collected data that confirm a finding, they must assess their findings as described in the “explain” stage of the 7E Model. During this self-assessment, students can judge whether an alternative theory or model could better explain their results or analysis.

One of most misunderstood parts of the traditional scientific method is the conclusion (Finely & Pocovi, 2000). Just because a theory proposed by a scientist is supported by data does not mean that the theory will meet with universal approval. Students must learn to present their ideas and to know that this is not the last step. Their findings must be peer-reviewed, replicated, and tested in different areas. In the context of the “extend” portion of the 7E Model, students can apply their findings to other situations in order to demonstrate that science does not stop at the conclusion step of the traditional scientific method.

Through a revision of the traditional scientific method and its connection to the 7E Model, then, students can be exposed to a better inquiry-based lab in AP Physics and gain a better understanding of how science really works. These students may not become professional scientists, but the use of inquiry methods can foster organized thinking habits that will serve them throughout any future educational pursuits and careers. Students will also not be left with the misperception that memorization skills and following the steps are sufficient for good scientific thinking (Alberts, 2000).

Investigative Science Learning Environment

Etkina et al. (2010) conducted an investigation of the effectiveness of inquiry combined with learning cycle activities known as Investigative Science Learning Environment (ISLE). The study of 186 participants was conducted in eight undergraduate introductory, algebra-based physics lab sections at Rutgers University; four of the sections participated in the inquiry labs and four in more traditional labs. Both groups participated in the same lecture sections. Students in the inquiry group had to design their own experiments, which were not entirely student-directed and less informal. Similar to the AP Physics inquiry labs, ISLE students were given guiding questions to focus them on a specific aspect of the curriculum. They also received rubrics to guide them in how to write the lab report. After each lab design, students were assigned readings about research that demonstrated scientific inquiry and reflection questions about the passage. The traditional lab groups also had homework, usually in the form of practice problems from a textbook (Etkina et al., 2010).

ISLE students in the inquiry group initially struggled to begin the lab in the absence of a given procedure. They were not allowed to ask the instructor questions. The inquiry students were required to determine whether their procedure was acceptable, and they used their guiding questions and rubrics as information (Etkina et al., 2010). One of the AP Physics Science Practices requires students to justify their procedures in a manner much like this step in the ISLE study.

When using the ISLE format, the inquiry students' lab reports contained more analysis and interpretation of the results than the traditional student's lab reports (Etkina et al., 2010). The overall scientific communication scores using the lab report rubric were also higher for the inquiry group than the traditional group. The traditional students were able to use the mathematical representations (formulas) correctly, but could not always interpret them clearly. They also failed to evaluate assumptions made in the lab correctly, for example knowing that multiple trials needed to be done but not why. The inquiry student groups communicated "evidence of a more sophisticated approach to the same investigation compared to the report written by the student from the non-design group" (p. 83). It was hoped that the performance of AP students participating in the 7E Model inquiry labs would mirror the results of the inquiry students in ISLE study. In the present action research study, students also experienced traditional lecture class sessions followed by inquiry labs.

The ISLE study used data from numerous sources to support the underlying hypothesis. In addition to student lab reports graded in accordance with a predetermined rubric similar to rubrics developed by the College Board, students in both traditional and inquiry groups completed a lab write-up in response to a question with which neither group was familiar (Etkina et al., 2010). Students were graded on procedural development, communication, and discussion of how they would collect and analyze data. The graded components of the ISLE study were similar to those graded according to the Science Practices in the current action research study.

Learning Cycle Models

According to Konicek-Moran and Keeley (2015), the learning cycle has over the past five decades undergone more variations and revisions than any other comparable model. For them, every learning cycle assumes a student participates in some sort of activity involving some sort of teacher input regarding the content and a heavy emphasis on application of this content in a different context. The first discussion of learning cycles in print was in 1962 by Atkin and Karplus, as is discussed in detail below. Bybee and the Biological Science Curriculum Study (BSCS) developed one of the most famous learning cycles, the 5E Model, in 1989, which was subsequently modified into the 7E Model by Eisenkraft in 2003 (Konicek-Moran & Keeley, 2015). The new AP Physics curriculum was designed to “promote student learning of essential physics content and foster development of deep conceptual understanding through an inquiry-based model of instruction” (College Board, 2015, p. 1). Many of the laboratory activities were designed based on learning cycles, the 5E and 7E Models included, and many of them make use of learning cycle resources as supplementary materials to help teachers.

Soomro, Qaisrani, Rawat, and Mughal (2010) found in a study of secondary physics students working with simple machines that use of a learning cycle in teaching physics increased student achievement compared with traditional teacher-centered instruction. Lectures alone did not provide students with the opportunity to use their knowledge in meaningful ways, but the learning cycle allowed students to construct their own knowledge and to apply it to different situations, thereby making their learning meaningful (Soomro et al., 2010).

Karplus's Learning Cycle

In 1962, J. Myron Atkin and Robert Karplus authored an article for *The Science Teacher* suggesting that students should discover scientific concepts through guided inquiry (Konicek-Moran & Keeley, 2015). Their theory, based on the work of Piaget and embracing Karplus's learning cycle, grew into the Science Curriculum Instructional Strategy (SCIS) (Konicek-Moran & Keeley, 2015). The learning cycle consists of three instructional phases, namely exploration, concept introduction, and concept application, which combine experience with social transmission and encourage students to self-regulate (Karplus, 2003). The numerous versions of Karplus' learning cycle all focus on concept reconstruction and acknowledging students' prior understanding (Konicek-Moran & Keeley, 2015).

The first phase of exploration allows students to gain experience with the environment. By learning through their own discovery and reactions, they explore new concepts with little guidance or expectation of specific accomplishments from the teacher (Karplus, 2003). While participating in the exploration, students are expected to begin to generate questions that they cannot answer with their current knowledge.

Concept introduction, the second phase of the learning cycle, provides social transmission by supplying a definition of a new concept through which students begin to make sense of their questions from the first phase (Karplus, 2003). They thus begin to create a new form of reasoning; thus "concept introduction is especially effective when it involves the formal definition of a concept whose concrete definition is already understood by the students" (Karplus, 2003, p. S56). Generally, there is direct teacher instruction during this phase (Konicek-Moran & Keeley, 2015).

In the third phase, concept application, students apply the new concept to various situations (Karplus, 2003). This process is often particularly beneficial for those who need some time to understand a concept, for they have greater active interaction with it. Teachers can use this phase to conference with students individually so as to identify and resolve misconceptions and help resolve those misconceptions.

Bybee's 5E Model

The 5E model or learning cycle was developed in the early 1990s by Rodger Bybee and colleagues as part of an effort to enhance a new elementary science program, and it has since been adapted for use in numerous classrooms (Bybee, 1997, 2014). This research-based model, which is informed by a constructivist perspective, challenges students' misconceptions through activities that access prior knowledge through its five stages of engaging, exploring, explaining, elaborating, and evaluating (Bybee, 2014). The first stage has the goal of engaging students' attention and interest, and the exploration phase provides them with hands-on experiences to resolve any misconceptions from the previous stage. During the explaining stage, the teacher directs students toward a correct understanding and describes key aspects of the material, while the elaboration stage involves students in experiences that can expand and enrich the content from the previous stages. During the final stage, students are evaluated and receive feedback on their learning.

The 5E model remains popular because it helps teachers to plan their lessons and activities (Konicek-Moran & Keeley, 2015). When using this approach, their students do not simply proceed step-by-step through a lesson; rather, the 5E learning cycle exposes students to the core content as it arises naturally during exploration. Ideas are introduced in the course of the lesson as students have questions and perceive the need to learn the information, and activities are structured so that students can use the five phases to monitor and evaluate their own progress.

Eisenkraft's 7E Model

Based on research into curriculum and lesson plans, Eisenkraft (2003) expanded the 5E model to a 7E model that emphasizes knowledge transfer (Bybee, 2014). The newer model adds an "elicit" stage before "engage" and an "extend" stage after "evaluate" (Eisenkraft, 2003), and it has been endorsed by Bybee (2014). The AP development committee based the new AP Physics inquiry labs on the 7E model (College Board, 2015).

To review, the first stage of the 7E model is "elicit." Eisenkraft (2003) distinguished this stage from "engage" in order to draw attention to the importance of accessing students' prior knowledge, since they use it to construct new knowledge. One simple way in which a teacher may encourage students' participation in this stage is to ask for their thoughts or beliefs about a particular topic. Thus, in AP Physics labs, a teacher may pose a question to the class designed to elicit students' prior knowledge. AP teachers can also assess students' misconceptions about a topic during the elicit stage. The elicit stage is closely followed by the engage stage, the main goal of which, in either the 5E or 7E model, is to capture the students' attention (Eisenkraft, 2003). Teachers ask questions, pose problems, or present conflicting notions to pique a student's interest. Students should be puzzled and thoughtful about the content during this stage, which does not have to involve a full lesson but can be merely a brief demonstration designed to spark students' interest and raise questions in their minds (Bybee, 2014). The "engage" and "elicit" stages are distinguished, again, to make sure that students' prior knowledge is accessed (Eisenkraft, 2003). Ayvaci, Yildiz, and Bakirci (2015) found that activities that strengthen pre-knowledge during the engage phase helped to increase students' comprehension and to diminish their misconceptions in a unit on reflection and mirrors.

The 7E model affords students opportunities to design and plan experiments, record data, and develop hypotheses during the explore phase (Eisenkraft, 2003), as teachers pose a question and provide advice but then take on the role of a guide or coach (Bybee, 2014). Students in this phase test the ideas and questions generated during the previous phase through concrete, hands-on activities that begin to clarify their knowledge and understanding of the subject (Bybee, 2014). In AP Physics, the actual inquiry lab experiment took place during the explore phase.

The explain phase is more teacher-led than the other phases of the 7E Model, in that students are presented with content, scientific laws, or models to explain the phenomena witnessed during the previous phase (Bybee, 2014). A critical part of this phase involves guidance by teachers or sometimes other resources that brings students to a deeper understanding of the topic of study. Eisenkraft (2003) considered it imperative that the explain phase occur after the explore phase so that concepts can be developed before students become weighed down by terminology. In AP Physics, the teacher and the students examined the observations and data collected and used newly-introduced physics concepts to support what they had observed during the lab.

“Elaboration” is the phase during which students apply their understanding to other situations (Bybee, 2014). Eisenkraft (2003) suggested that numerical problems for students to solve be introduced at this point, and thus the AP Physics students were given sample problems and alternative experiments to study during the elaboration phase. In the study cited above, students who participated in the elaboration phase of the 5E Model lab devoted to light reflection and mirrors were better equipped to transfer knowledge that they had constructed to other types of problems than those who had not participated in this phase (Ayvaci, Yildiz, & Bakirci, 2015).

As mentioned, the elaboration phase was added to the 7E model to emphasize the transfer of learning, as students begin both to apply a concept to very similar topics within the same unit of study and to make connections among broader physics concepts and even concepts beyond the physics course (Eisenkraft, 2003). In AP Physics, the extend phase represented a move beyond sample calculations to the transfer of new knowledge to other subjects and real world applications. This stage was very important in AP Physics because the students’ AP exam contained questions requiring them to apply their knowledge to completely new situations.

The last phase in the 7E model, “evaluation,” allows for summative assessments by the teacher while encouraging students’ self-assessment of their understanding and abilities (Bybee, 2014). In AP Physics, this last phase included the formal lab report and the unit test. Within the lab report, students reflected on the process and judged their own understanding of the topic. Through the evaluation stage, the teacher gained insight into the students' grasp of the topic and their ability to communicate this knowledge in a narrative form similar to that found on the AP exam. Based on students' assessments, teachers may need to reevaluate the cycle and repeat certain phases (Bybee, 2014).

Research on the 5E/7E Model in the Context of Physics

Much research has been done on the effectiveness of the 5E Model. Thus, in a study of 42 tenth-grade Turkish physics students, Hirca, Calik, and Seven (2011) found that combining the 5E model with various types of conceptual change activities, such as worksheets, computer simulations, and multiple texts, bolstered the students' achievement in and attitude toward physics in the course of a unit on work, power, and energy. This study also showed an increase in homogeneity within the class and a decrease in students' misconceptions in association with use of the model. In another Turkish study, this time of 45 sixth-graders, Gurbuz, Turgut, and Salar (2013) claimed that use of the 7E Model during a unit that included twelve 40-minute lessons on electricity increased the experimental group's performance on posttests and retention tests over the control group because the model helped students to connect the material with their daily lives (Grubuz, Turgut, & Salar, 2013).

Citing studies of and interviews with teachers from the Toledo Area Partners in Education (TAPESTRIES) and the Active Science Teaching Encourages Reform project (Project ASTER), Duran and Duran (2004) identified numerous positive outcomes of combining the 5E Model with inquiry. Based on interviews with 1,200 teachers who had participated in these initiatives, these researchers found that the 5E Model served as an effective guide when using inquiry in the classroom for teachers. Before introduction of the learning cycle, teachers in the study had been uncomfortable using inquiry, especially in presenting topics in which they were not well versed. The teachers described the 5E Model as flexible, helping them to personalize inquiry for each student. The students in the study for their part grew more comfortable with science explanations and more experienced in problem-solving; they also became better and more confident writers. Even relatively weak students also seemed to excel, since the 5E Model served to incorporate all of the modalities of learning.

Acisli and Turgut (2011) generated physics laboratory materials based on the 5E Model for use in an electricity unit studied by 88 General Physics Laboratory II students at Atatürk University in Turkey. They found that students who had participated in constructivist activities using the 5E model showed stronger scientific operational skills, such as better communication and problem solving, than those who had not. Thus a t-test comparing the pretest and posttest scores similar to the one used in the present action research study demonstrated that the experimental group was more successful on the achievement posttest than the control group. Ayvaci et al. (2015) also showed an increase in student achievement and attitude when using 5E Model labs about light reflection and mirrors with undergraduate students.

As mentioned earlier, most of the research done on the effectiveness of the 7E Model has in fact been conducted in Turkey, where a constructivist approach to science curriculum development and science education was adopted in 2005 (Balta & Sarac, 2016). The present study thus adds to the picture by taking into account 7E Model inquiry labs in the United States. In a meta-analysis of 7E Model research that examined 35 distinct effect sizes from 24 experimental studies and 2,918 students, Balta and Sarac (2016) found the overall effect of the learning cycle to have been positive, with short-term usage of the model showing more positive effects than longer term applications, an outcome that the researchers attributed to a novelty factor in the former case. This finding further encouraged use of the 7E Model with AP Physics inquiry-based labs, most of which lasted only a few class period sessions. Having found the effect of the 7E Model to be considerable, the Turkish researchers encouraged educators to incorporate it into their own teaching.

Kocakaya and Gonen (2010) used the 7E Model to develop computer-assisted physics instruction in an electrostatics unit for 79 student teachers in their second, third, and fourth years of study at a university in Diyarbakir, Turkey. They found, again using a t-test comparison of a pretest and posttest, a decrease in the student teachers' misconceptions regarding the topic and an increase in their knowledge levels and application abilities, though no change in their attitudes towards physics. In a study of 208 high school chemistry students enrolled in three government schools in Ibadan, Nigeria, Adesoji and Idika (2015) similarly found an increase in performance in the subject through use of 7E Model instruction compared with a control group of students who received traditional instruction, as well as, in this case, an increase in positive attitudes toward the subject.

Changing Advanced Placement Science

As discussed above, until the recent changes in the AP Physics curriculum, the material tended to be teacher-centered, and content standards were determined by a set of percentages given by the College Board. The College Board also dictated the curriculum to the teachers, who designed their courses to meet its standards. The students for their part had very little involvement in determining their own interests within the context of course. This situation was in direct contradiction to Freire's (2013) view of a curriculum as an "organized, systematized, and developed 're-presentation' to individuals of the things about which they [students] want to know more" (p. 160). The old system of traditional labs with predetermined methods and predictable answers showed students the content, but it did not allow them to create their own paths to understanding, so that education seemed to be presented like "bits of information to be deposited" (p. 160) in a student.

According to Freire (2013), educational plans that do not reflect the interests of students are destined to fail. Before changes in the AP programs, the College Board, through discussions with universities and colleges, discovered that science professors were finding AP science students ill-prepared for work in upper-level labs that require independent thought. The College Board accordingly called for more inquiry in science courses. It was in this context that, as discussed, the 7E Model was chosen for the physics inquiry program as part of an effort to promote students' participation in the evaluation and elaboration of physics content and thus to prepare them better for higher-level physics courses.

Also before the changes to AP Physics, teachers were not given standards to follow in curriculum development. Instead, the College Board provided a list of topics to be covered along with their weighting on the actual AP exam. Electricity, for example, accounted for some 25% of questions on the exam. The weighting represented the only real indication of what material to cover, despite the fact that, at least according to Popham (2013), rational planning requires that an educator be well informed regarding what is to be accomplished during a course.

In order to clarify the new inquiry recommendations, the College Board developed Science Practices (SPs). SPs “align to the . . . curriculum framework to capture important aspects of the work that scientists engage in, at the level of competence expected of AP Physics students” (College Board, 2015, p. 28). Popham (2013) described SPs as performance objectives that make clear “the type of learner behavior which is to be produced by the instructional treatment” (p. 96). In order to be effective, SPs need to be very specific as to what students should be able to do, to be written clearly, and to be set out in terms that allow the desired behavior to be measured (Popham, 2013). For example, SP 4.2 states “The student can design a plan for collecting data to answer a particular scientific question” (College Board, 2014a, p. 127). SPs keep teachers and students informed regarding what is expected of them by the end of the course. The new revisions to AP science courses combine the main content of the subject with processes (Herrington & Yezierski, 2015) in ways that foster conceptual understanding in science.

Franklin Bobbitt favored a move away from the learning of content alone, arguing that “Education is now to develop a type of wisdom that can grow only out of participation in the living experiences of men, and never out of mere memorization of verbal statements of facts” (p. 11). From this perspective, the goal is for students to see science as something more than abstract concepts and instead to be able to apply the knowledge that they learn to practical situations. Through such participation in simulated real-world activities, they become prepared for future experiences outside of the classroom.

In the past, then, learning and assessment in AP Physics emphasized numerical calculations and rote usage of given formulas. The lab that was done was very traditional, involving little investigation. Often, students who were adept at math were able to pass the AP exam without truly grasping the main concepts of physics. In these respects, high school science education seemed not to have changed much since the 1800s.

The various stages of the 7E Model, by contrast, were designed to help students recall prior knowledge, generate enthusiasm for a topic, examine a topic further, and to use newly-acquired knowledge in various situations. These are the steps for students to be successful in the inquiry lab process and to gain a deeper understanding of science topics. Bobbitt (2013) suggested that 7E Model inquiry labs promote a move away from memorization toward participation so that students are not only recalling information but also applying it in relevant situations. In physics, the focus is no longer on pure mathematical skill, in part because there may be more than one correct answer to a given inquiry lab question. Through use of the model, students can see their own discoveries used in applications to today's technology.

Benefits for Traditionally Underrepresented Groups

Discussion during the AP Physics course is meant to include Isaac Newton's Laws of Motion, Daniel Bernoulli's principles of fluids, the contributions of Albert Einstein and Max Planck to modern physics, and Gustav Kirchoff's Laws of Circuits (College Board, 2014a). Most of the materials and resources suggested for the class involve demonstrations and computer simulations; video biographies of Newton and Ben Franklin are also listed. Through these materials, pacing guides, and course overviews, the topics covered in any AP Physics 1 or 2 course are clear to see.

MinutePhysics' video "Open Letter to the President: Physics Education" sums up the underlying message that is taught in a physics classroom. The video points out that most standards for physics classes across the country involve discoveries made before 1865, with even most ”modern physics” topics covered having taken shape by 1905. According to the video, the current standards leave out all the “cool stuff,” giving students the impression that the important contributions to physics occurred long ago. Physics is thus rendered as the lifeless product of a series of dead white males.

Worse, students are covertly taught that, if they are not white and male, they are not welcome in the field; for no one else has ever made any contribution to physics. Before 1905, women and minorities had limited roles in education, especially in science. Because underrepresented students are not exposed to current work in physics, they are unable to see scientists who share their backgrounds and cultures. Thus white boys and men may feel comfortable and understand the culture and interests of scientific fields while girls and women and minorities find themselves having to adjust to a perceived white male norm (Spivack, 2014).

The demography of the students in the teacher-researcher’s classes has remained largely consistent. In a given class of 20 or so students, most (12 to 16) are usually Caucasian males from upper- and middle-class families; the rest will include one or two minority females, but rarely any minority males. A study commissioned by the Educational Testing Service (ETS) (2008) found that this trend is typical across most of the nation; thus in 2004 “only 0.5% of African American students and less than one percent of low income students took an AP exam” in the nation’s high schools (p. 4).

The ETS study suggests that, typically, more female than male students participate in AP programs (2008), but it is important to recall that it took into account all AP courses, not specifically science courses. Another study, by the American Institute of

Physics (2009), did indicate that the number of girls and women in physics is growing, though much more slowly in advanced than in lower-level courses. According to the report, fewer than four in ten students took AP Physics B and that only a little more than a quarter of students taking AP Physics C were female. These findings are more consistent with the trend in the teacher-researcher's classes.

The course description for AP Physics encourages "the elimination of barriers that restrict access for AP courses to students from . . . groups that have been traditionally underrepresented in the AP Program. Schools should make every effort to ensure that their AP classes reflect the diversity of their student population" (College Board, 2014a, p. 2). These advanced physics classes are open to all students who meet the prerequisites, but only a certain segment of the school's population registers for them.

The history taught in the current physics curriculum and most science courses, then, is dominated by white men, usually from privileged backgrounds, to the exclusion of the contributions of minorities and women. Students whose backgrounds are traditionally underrepresented in science thus lack role models and may feel that they do not belong in the field. Such stereotypes as "only white guys do science" and "only boys are good a math" must be overcome. Through 7E model inquiry labs, the teacher-researcher sought to show that, even though physics historically has been dominated by white men, people of every race, gender, and background can make significant contributions to the field.

Moje (2007) described inquiry as a socially just pedagogy in that it affords all students "opportunities to question, challenge, and reconstruct knowledge" (p. 4). Inquiry allows students to become apprentices in science and to generate their own questions and ideas (Thadani, Cook, Griffis, Wise, & Blakely, 2010). This perspective inverts the traditional roles of teachers and students so that the latter take responsibility for their work and their ideas. Their ideas become the center of the discussion, giving each student, specifically those from underrepresented groups, more power in the classroom. Marshall and Alston (2014) demonstrated statistically significant gains for all students, males and females, Caucasians, Hispanics, and African Americans, through the use of inquiry-based practices. Their study also showed a narrowing of the achievement gap between minority and white students when inquiry was used.

Through real-world experiences, student-to-student collaboration, and interactions that place value on each student's point of view, inquiry labs and other student-centered curricula have also been shown to decrease the achievement gap between boys and girls in science. This was argued by Baker (2013), who also pointed out that the right materials must be available for girls to remain involved in an activity rather than taking a passive role. Inquiry has been shown in numerous studies to improve attitudes toward science for females and minorities. Thus, in a study of 123 middle school girls participating in a one-week, inquiry-based science and technology enrichment program, Kim (2016) showed that guided and open inquiry activities can disabuse female students of the notion that all scientists were "lab-coat-wearing males or that women are not capable of doing science and having a career as scientists or engineers" (p. 183). The study's findings also demonstrated that participation in inquiry helped girls to maintain their interest in science.

Cunningham and Helms (1998) argued that inquiry can help to change students' impressions of science as a perfect discipline and a fixed subject, and that it can improve female students’ confidence in their own findings and thus to see themselves as future scientists. An inquiry lab requires a different kind of student, one that goes against the norm of many traditional physics classes, for students in inquiry are not just memorizing facts but are assisted in figuring out how something works. This much was argued by Carlone (2004), with the allowance that inquiry-type learning can be frustrating for some girls, especially those who have adopted a “good student identity” (p. 409) and focus on the right answer when more than one approach is possible.

By incorporating 7E inquiry-based labs in the AP Physics curriculum, students who are traditionally underrepresented in the classroom can enjoy more chances to participate, create their own ideas, and develop leadership roles. Through a focus on inclusivity, the teacher-researcher’s classroom can become a place for all students to succeed, a place where science is not just a patriarchal system.

Conclusions

This summary of relevant literature has related the theoretical framework of the present study to learning cycles and inquiry labs and demonstrated how inquiry as a practice developed through the work of Dewey, Vygotsky, and Piaget. The benefits and drawbacks of combining inquiry with learning cycles were examined through a review of numerous studies, many of them conducted in Turkey and at the undergraduate level, while a gap was revealed in research on the effectiveness of the 7E Model inquiry labs in high school AP-level classrooms. The present study was accordingly designed to explore how AP students communicate their procedural development, conceptual understanding, and skills in data analysis on lab-based exam questions after participation in 7E Model inquiry labs.

CHAPTER 3: METHODOLOGY OF THE STUDY

This chapter lays out the details of this action research study, which involved the teacher-researcher's classroom in a small, private high school in upstate South Carolina at which students have traditionally scored well on AP science exams. The College Board recently introduced an inquiry-based model of science laboratory learning based on a new form of the AP exam that challenged the perceptions of communities, teachers, and students regarding what it means to "do well" in high-level AP science courses. The teacher-researcher's students, for example, owing to a lack of experience with inquiry labs, generally had trouble answering the AP inquiry lab-based questions. The procedural development of an inquiry lab itself is a challenge; and when answering an inquiry lab-based question, students must communicate clear procedural descriptions, analyses, and conclusions. In most other science classes, students are only asked to write in order to demonstrate the knowledge that they have acquired in the context of short answer and essay assessment questions (Yore, Bisanz, & Hand, 2003). With the new AP mandate, students must not only become proficient in problem-solving for lab procedure development but also develop better written scientific communication skills so as to write up, explain, and justify their procedures and conclusions.

In this chapter, the problem of practice (PoP), the research question, the purpose of the study, and its setting and sample population are discussed in detail and the action research method outlined. Ethical considerations during the research are also reviewed and the role of the researcher throughout the study described. The research plan, including data collection methods, data analysis, and a plan for reflection, is then presented.

Reintroduction of the Problem of Practice

The identified problem of practice for the present action research study involved AP Physics students in the teacher-researcher's classroom, who, have typically performed well on the traditional AP exams. With the introduction of new inquiry-based lab questions, however, students began finding it difficult to maintain previous levels of achievement. The College Board had recently introduced a new form of the exam, one portion of which requires students to design and evaluate inquiry-based physics labs. The 7E Model has been the basis for these labs. In order to prepare students for the new exam section, the teacher-researcher introduced structured inquiry labs in the fall of 2017. This study, then, investigated the impact of the inquiry labs on the exam performance of these AP Physics students will be the focus of the study.

Reintroduction of Research Question

This action research study was designed to describe the learning situation in a private high school in upstate South Carolina and thereby to add to the body of knowledge regarding students' expectations in inquiry-based laboratories and high-level science advanced placement course work in an era of high-stakes state accountability. The research question was accordingly formulated as follows:

RQ: What are the effects of 7E Model inquiry labs in Advanced Placement (AP) Physics student achievement on AP exam inquiry lab questions?

Purpose Statement

The primary purpose of the study was to determine the effect of 7E Model inquiry labs on students' performance on AP physics inquiry lab questions. The secondary purpose was to devise an action plan for improving the effectiveness of AP science teachers in the unique context of the teacher-researcher's school.

Action Research Method

Setting

The teacher-researcher conducted this study at her current place of employment, Monarch High School (a pseudonym), a small, private high school in the downtown area of a large city in upstate South Carolina. The school is a part of a kindergarten-through-twelfth-grade college preparatory education program run through the Episcopal Church. Monarch prides itself on its 100% college acceptance for seniors and on its AP program, with students traditionally scoring above the state average for passage rate on AP exams. Twenty-two AP courses are offered by the school. According to the school's website, 167 Monarch students took a total of 366 AP exams in 2017, and the passing rate (meaning the portion of students who scored a 3 or better) on the exam for the school was 79.6%, compared with the state average of 58.5%. AP courses offered by the school at the time of the study included Physics 1 and 2, Biology, Chemistry, Environmental Science, Calculus AB and BC, Statistics, English Literature, Chinese Language and Culture, and Latin.

The high school's population of approximately 400 was culturally but not racially diverse, as can be seen in Table 3.1. The cultural diversity was a function of the fact that quite a few of the students were born in Germany.

Table 3.1 Enrollment Statistics for Monarch K-12

Category	Total School Population	High School Population
Total Enrollment (male/female)	1,100 (575/525)	408 (210/198)
International	165	61
African-American	44	16
Latino	16	6
Native American	2	2
Asian American	31	16
Multiracial	27	6
Caucasian	897	342
Middle Eastern	1	0
Other/Unreported	83	19
Receiving Financial Aid (does not include faculty tuition remission)	152	55

The demographics of AP Physics have not generally reflected the gender or racial demographics of the school as a whole, being dominated by male students and lacking any African American students, though the sections that featured in the study did include more girls than had been the case in previous years. The study took place in the teacher-researcher's classroom and adjoining laboratory space. The laboratory and classroom were equipped with the instrumentation and supplies necessary to conduct each of the inquiry-based labs. All data were collected in the classroom and lab by the teacher-researcher. AP Physics 1 normally meets for the entire school year, approximately 180 days, with one 52-minute period a day. Labs were completed during the class, being synchronized with the progression of the course. Once students had acquired sufficient experience, the 7E Model labs were begun during class times. There was no set time during the unit when the labs were performed.

Sample

Because the teacher-researcher was unable to modify students' schedules to accommodate random assignment to groups, purposive sampling was used. The participants in the study consisted of students registered for AP Physics 1 in the fall of 2017. The demographic composition of the class has varied from year to year and was not tabulated until the fall semester. AP Physics 1 students have usually been juniors and senior, generally ranging in age from 16 to 18, most previously identified as gifted and talented. All of the students had completed Chemistry I, Biology I, and Honors Algebra II, and most had completed Honors Pre-Calculus, while around half were taking AP Calculus and Physics concurrently and/or had previously taken an additional AP science course. Again, most AP Physics students have been white upper and middle class males, though there were more females in the sections studied than in previous years. Table 3.2 provides a demographic an overview of the participants in the two different class sections.

Table 3.2 Demographic information for class sections

	Class Section 4	**Class Section X**
Total Participants	17	20
Males/Females	6/11	14/6
White/Asian/Other	14/2/1	18/1/1
ESOL	2	2
First AP Science Course	11	10

At the beginning of the school year, students in the course and their parents were asked to sign a form of consent to participate in the study. Table 3.3 provides a detailed description of all participants gathered from student surveys administered at the beginning of the study.

Table 3.3 Student Participant Information

Student ID #	**Class Period**	**Sex**	**Race**	**Grade**	**ESOL Yes or No**
77	4	F	W	12	No
58	4	F	W	12	No
99	4	F	A	11	Yes
70	4	F	W	12	No
82	4	F	W	11	No
87	4	F	W	11	No
95	4	F	W	11	No
61	4	F	O	11	No
68	4	F	W	12	No
91	4	M	W	12	No
83	4	M	W	12	No
57	4	M	W	12	No
54	4	F	W	12	No
64	4	F	A	11	Yes
92	4	M	W	11	No
50	4	M	W	12	No
80	4	M	W	11	No
19	X	F	W	12	No
42	X	M	W	12	No
14	X	M	W	11	No
49	X	F	W	11	No
44	X	F	W	11	No
18	X	F	W	11	No
32	X	M	O	11	No
34	X	F	W	11	Yes
10	X	F	W	12	No
30	X	M	W	11	Yes
36	X	M	W	12	Yes
40	X	M	W	12	No
46	X	M	W	12	No
26	X	M	W	12	No
20	X	M	A	12	No
38	X	M	W	12	No
15	X	M	W	11	No
24	X	M	W	12	No
35	X	M	W	11	No
25	X	M	W	11	No

Ethical Considerations

A teacher-researcher must consider the ethical implications of any action research project, giving equal attention to each participant in this respect. They must be fully informed of the research and its purpose. Consent from the administration to report the results of the research to an outside source was also obtained.

Ethical action research should follow the principles of beneficence and honesty (Mertler, 2014). In terms of the former, the research stood to benefit current and future AP Physics students, the purpose being to assess the impact of inquiry labs on student achievement. The aim of the research was to help students better their skills; an improved understanding of scientific communication and problem-solving techniques offered clear benefits for the teacher-researcher and the students. The principle of honesty was observed by using informed consent forms, telling participants about the research plan throughout the process, and maintaining accurate data collection practices.

Standardized questions relating to lab experiences often assume that students have had access to a particular type of equipment or instrument or have had a particular life experience. Owing to cultural differences within the school or at home, the student participants had various levels of the background knowledge necessary to understand a question or proposed lab development. It was the teacher-researcher's responsibility to provide for them, as far as possible, a level playing field. Thus, for example, when simulations could not be performed in the classroom, comparable ones were identified for students online. The teacher-researcher also made an effort to select assessments that would be fair to all participants.

The personal nature of action research also meant that the relationships between the teacher-researcher and the participants, and her own bias, had to be taken into consideration in designing the research plan. A rich background description of the classroom setting and relationships within it has accordingly been included to make clear the circumstances of the study. The teacher-researcher was careful to review each piece of data objectively, without regard for her personal inclinations. Participants also brought their own biases into the study. In particular, students, especially at the AP level, tend to focus on obtaining the right answer and pleasing the teacher. By making data collection part of the regular classroom activities, students were able to record their responses accurately, without feeling pressured to answer in a certain way. After the data were collected and analyzed, participants were informed of the findings.

Role of the Researcher

The researcher in this action research study was the teacher of the AP Physics classes. She both implemented the 7E Model and gathered and analyzed the data. As is the case with action research methods, the teacher-researcher thus became a participant in the study by implementing the method and examining her own classroom practices and methods in an effort to facilitate the introduction of improvements in her educational practice (Mertler, 2014). Through the reflection component in action research, the teacher-researcher improved her skills as an educator by exploring the effect of the 7E Model on student performance on inquiry lab-based exam questions.

Research Methods

The current study, then, was conducted as action research, which generally includes four main stages, namely identification of the research problem and question, data collection, data analysis, and reflection (Mertler, 2014).

Identification of the Research Problem

The teacher-researcher was faced with changes to the AP Physics curriculum after the College Board implemented new learning objectives that included the addition of Science Practices (SPs) to the course. As a consequence, students were required to learn how to participate in inquiry labs and to answer an inquiry lab-based question on the AP exam. The teacher-researcher's students had always done well on the AP exam, but they struggled with the scientific communication skills needed to answer the new inquiry-based questions. Since the College Board had based the new lab manual for AP Physics around the 7E Model (College Board, 2014a), the teacher-researcher wondered whether implementation of the inquiry labs associated with the model would affect student achievement on the inquiry lab-based exam question. She first conducted the literature review described in Chapter 2 to gather more information on inquiry labs, the 7E Model, scientific communication, and ways to conduct research on the problem.

Research Plan

The teacher-researcher implemented the structured inquiry labs called for in the 7E Model in the fall of 2017 in her sections of AP Physics 1. The action research study investigated the impact of these labs on students' exam performance, following a one-group, pretest-posttest design in which the independent variable was the implementation of 7E Model inquiry labs and the dependent variable was the effect on student performance on inquiry lab-based exam questions. According to Mertler (2014), the one-group, pretest-posttest design allows teacher-researchers to detect change. In this case, a pretest was administered at the beginning of the study, the model was implemented, and a posttest was administered at the end (Table 3.4). The student participants' scores on the pretest and posttest were then compared, keeping in mind that any given change may or may not have been due to the method implemented. More specifically, the experimental group, which consisted of both class sections, was given a pretest in the form of an old AP exam inquiry lab question at the beginning of the study and then exposed to the treatment, i.e., 7E Model inquiry labs, after which an inquiry lab-based question measuring the same skills as the pretest was administered as a posttest.

Table 3.4. One-group, pretest-posttest design (Mertler, 2014)

Group	**Time →**		
Experimental	Pretest	7E Model inquiry labs	Posttest

Table 3.5 illustrates how the 7E Model was used during the study; the experimental group completed four inquiry labs.

Table 3.5. 7E Model used in the study

Stage	Average Velocity Constant	Investigating Motion 1D (AP Manual)	Investigating Motion 2D - Horizontal Launch	Investigating Motion 2D - Angled Launch
Elicit	What do you know/remember about speed and velocity?	How can we represent motion? What is the most accurate way? Why?	How does 1D motion differ from 2D?	What additional information will you need to calculate velocity if a particle is launched at an angle?
Engage	How can you get a toy car to have an average velocity of _____ repeatedly? Students will discuss. Then write a procedure for homework.	Plot a qualitative graph of the following: Constant velocity, Speeding up, Slowing down, Constant acceleration, Changing directions. Compare with partner.	Can you predict where a car will land as it is launched horizontally off the table using on the given materials? Students will discuss. Then write a procedure for homework.	Can you determine a procedure that will allow you to find the initial launch velocity of a toy dart gun if it is launched at an angle? Students discuss and then write a procedure with a partner
Explore	Students carry out their procedures in groups. Modifying and adjusting as needed.	Students develop procedure to construct graphs of constant velocity and constant acceleration using motion carts.	Students carry out their procedures and compete to see how close they can get to a given target.	Students carry out the developed procedure using the equipment than deemed necessary.
Explain	Students will write up their procedure and findings in the lab notebook. Class discussion of what worked best. How did they make it reproducible? Peer Post-it Review of procedures and methods. Students rewrite based on suggested revisions.	Students will write up their procedure in the lab notebook. Attach graphs representing given situations in notebook to support. Class comparison of graphs and procedures to get them.	Students will write up their final procedures in the lab notebook. Students will discuss how error was introduced to their calculations and how the error affected the outcome. Students will also discuss improvements that could be made and assumptions they made in the lab.	Students will write up their final procedures in the lab notebook. Students will discuss the accuracy of their method.

Elaborate	Students answer teacher given questions in lab notebook to apply knowledge about average velocity.	Students are given a variety of graphs to make with the carts using their knowledge.	Further 2D problems will be assigned.	Students will develop an alternate procedure (but not gather data) to determine the initial velocity of the toy dart gun. Students must then justify which procedure is the most accurate.
Evaluate	Teacher will use rubric to evaluate final lab write up.	Teacher will use rubric to evaluate final lab write up and answers to graph matching.	Teacher will use rubric to evaluate final lab write up.	Teacher will use rubric to evaluate final lab write up
Extend	Students will use knowledge gained on future lab based questions and on the next lab.	Students will complete an inquiry lab based question on their unit test.	Students will complete an inquiry lab based question on their unit test.	Students will complete an inquiry lab based question on their unit test.

Data collection

Again according to Mertler (2014), formative and summative assessments are reliable sources of data because they are already administered during the "teaching-learning process" (p. 148), a more feasible approach than creating instruments that would not be normally used in the classroom. Thus, each form of data to be collected during the study was already built into the class structure. During class, students normally took quizzes, wrote lab reports, and received assessment through unit tests. The types of data collected in this study from the experimental group were the pretest, lab reports, and the unit test that served as the posttest. The teacher-researcher administered and graded the pretest and unit tests and was present while the students participated in the labs, the reports for which she also graded using the specified rubric for each based on its SPs.

Pretest. One way to account for the lack of random assignment to groups is to conduct pretests (Mertler, 2014). At the beginning of the school year, before students had participated in any type of inquiry lab, each was given a pretest, which, again, the teacher selected from a bank of old AP inquiry lab exam questions released to teachers through the College Board (Appendix B). The pretest was treated as a homework grade for actual class evaluation purposes; it was graded according to the College Board rubric developed when the question was originally tested (Appendix B).

The pretest was also used to guide students toward proper procedure writing. Thus, after the pretest, the student participants and teacher-researcher reflected together on the question. The teacher-researcher reviewed the rubric, and students worked in groups to improve answers, providing peer feedback on writing procedures clearly.

Lab reports. The experimental group completed four 7E Model inquiry labs over the course of the study. For each, students were required to complete a formal lab report, which was graded according to the lab manual rubric after the 7E Model had been implemented. Students received a copy of the rubric from the teacher-researcher before they began the lab, which provided guidelines for assessing the extent to which individual students met the SPs addressed during the lab (Appendix C). Students were scored as proficient, nearly proficient, on the path to proficiency, or an attempt for each SP. Thus, for example, the labs completed in the first unit involved one- and two-dimensional motion and so, in accordance with the lab manual (College Board, 2015), addressed SPs 1.5, 2.1, 2.2, 4.2, 4.3, and 5.1 (Appendix G). Students were rated on how well they met the SP through the written communication of the lab report.

Posttest. For the unit test, all students were given an inquiry-based lab question to which they applied the learning acquired during the experiments for the given current unit (Appendix D). In addition to knowledge from the current unit, students were at times required to access knowledge from earlier units in order to answer a question. Application of knowledge both acquired in the unit and previously in this way corresponded to the “extend” step in the 7E Model, the transfer of knowledge to new contexts. The unit test lab question was, again, graded by the teacher-researcher in accordance with the College Board’s rubrics (Appendix D) and, again, selected by the teacher-researcher from a bank of previous AP questions.

Because the pretest and its rubric were discussed with the student participants so as to enhance their abilities in procedure writing, it was deemed necessary to use a different question on the posttest, though the inquiry lab-based question assessed the same SPs and content.

Data Analysis

While constructivism generally involves the analysis of qualitative data, the data collected were both qualitative and quantitative. The qualitative data gathered through lab report analysis informed the teacher-researcher about the progress being made throughout the study. Quantitative data gathered in the form of pretest and posttest scores were analyzed to demonstrate the significance of the treatment, the 7E Model inquiry labs, during the study. Mackenzie and Knipe (2006) claim that while the constructivist research is most likely to rely on qualitative data, quantitative data can be utilized in constructivist research to deepen the description and analysis of the study.

Descriptive statistics were used to analyze the data gathered from the study. A major advantage of descriptive statistics is that they allow researchers to describe the data gathered using just a few indices (Fraenkel, Wallen, & Huyn, 2014). The data collected for this study were quantitative in nature, being in the form of raw scores on the pretest, lab reports, and posttest. The mean of the percentage correct from the pretest and posttest was found and compared using a t-test performed in Excel.

According to Mertler (2014), the use of an experimental group with a pretest and posttest allows the teacher-researcher to make a number of evaluations about the effectiveness of the treatment, in this case, the 7E Model inquiry labs. First, the teacher-researcher compared the experimental group's pretest and posttest mean scores to determine whether the 7E Model inquiry labs influenced the students' performers on inquiry lab-based exam questions, and the scores from each lab report were then compared. Through the lab reports, the teacher-research was able to monitor student growth in scientific communication over the course of the study. The reports also provided information on ways to adjust the 7E Model labs as the study progressed.

Reflection

After the data were collected and analyzed, participants were informed of the findings. The study involved their own learning, so the outcomes had the potential to influence their approaches to inquiry and science communication. After participating in a lab or assessment, participants reflected on their growth, or lack thereof, both during and after the study, and revisions to instruction, the research plan, or future studies were made. By reflecting on the research data in this way, participants' opinions were used to refine the inquiry lab methods to be used in upcoming classes. The students informed the researcher regarding the steps that worked best for them and those that were unclear. This information helped to guide to further research (Mertler, 2014). With this input from the student subjects, the data gathered and the reflections of the teacher-researcher and students were used to develop an action plan to improve current lab practices so as to enhance student learning.

Conclusions

The purpose of this action research study was to answer the research question regarding the effect of 7E Model inquiry labs on the performance of AP Physics students on AP exam inquiry lab questions. After the research question was determined and a literature review conducted, the teacher-researcher used a one-group, pretest-posttest design to answer the question. Data were collected from an experimental group in the form of a pretest, lab reports, and an inquiry lab-based exam question on a unit test that served as the posttest. Data were analyzed to determine the impact of the 7E Model on student achievement through a comparison of the pretest and posttest scores. Finally, the teacher-researcher reflected on the data together with the student participants in order to develop an action plan for future implementation or study.

CHAPTER 4: FINDINGS FROM THE DATA ANALYSIS

This study examined the effect of 7E Model inquiry-based labs on student performance on AP Physics inquiry lab-based questions. The identified Problem of Practice (PoP) involved AP Physics at the teacher-researcher's high school, where students had tended to score well on the traditional AP exams but were finding the new questions challenging. The teacher-researcher conducted the study during regular class time. Through a t-test and other descriptive statistics gathered from pretests, lab reports, and a final unit test, a substantial description of the students' achievement was obtained, which is presented in this chapter.

To fill in the details of the study, students were given a pretest on August 25, 2017 to complete as a take-home assignment that then served as a baseline for the research. For the next six weeks, until September 6, 2017, student-participants completed four 7E Model labs as part of a unit on one- and two-dimensional motion. After each lab, they wrote up a lab report describing their procedure, the data gathered and analyzed, any calculations, and error analysis. The students then answered an inquiry lab-based question on their unit test to determine any effect of the 7E Model inquiry-based labs.

Reintroduction of the Research Question

This action research study sought to measure the effect of newly-developed 7E Model inquiry labs on student performance on lab-based AP exam questions. The research question was accordingly formulated as follows:

RQ: What are the effects of 7E Model inquiry labs in Advanced Placement (AP) Physics on student performance on AP exam inquiry-based lab questions as measured by unit assessments?

Reintroduction of the Purpose of the Study

The primary purpose of the present study was to determine the effect of 7E Model inquiry labs on AP Physics students' performance on AP exam inquiry-based lab questions for two sections of AP Physics 1 using the 7E Model in the teacher-researcher's classroom. The secondary purpose was to devise an action plan to increase the effectiveness of AP teachers serving the particular population of high-level science students at the teacher-researcher's school.

Findings of the Study

Overall Results of the Pretest

Students were given a pretest (Appendix B) on the first day of school, at which point they had of course received no instruction. They were told to use only their prior knowledge to answer the question to the best of their ability. The pretest counted as a completion homework grade, meaning that those students who attempted the question and turned it in received credit. The pretest was assigned on a Friday and returned on the following Monday.

The average score on the pretest was 2.7 out of a possible 12 points (22.8% correct). Students had the greatest difficulty with the data analysis portion of the question, which is unsurprising given that most had not had physics in three or four years. Most also confused acceleration and velocity when trying to explain the data analysis. No student mentioned the possibility of graphing the data, and many simply left this section blank. The breakdown of scores by points is presented in Table 4.1.

Table 4.1 Summary of Pretest Scores by Point Criteria

	Point Criteria	Points Possible	Group X	Group 4	Overall
Procedure Development	For taking distance measurements for 8 to 11 distinct fixed positions per run	1	0.65	0.35	0.50
	For measuring time for the same 8 to 11 distinct positions, consistent with the description of the experimental setup	1	0.35	0.29	0.32
	For an experimental technique consistent with being able to determine the requested quantities	2	0.75	0.41	0.58
	For a diagram of the experimental setup with clear labels and consistent with the technique described (awarded even if the technique is wrong)	1	0.30	0.18	0.24
	For a technique that allows data for all positions to be taken in a single run	1	0.65	0.47	0.56
Data Analysis	For a clear and detailed explanation of the data analysis process	2	0.15	0.06	0.10
	For equations or clear prose and use of data to identify the two distinct regions of motion (constant acceleration and constant velocity)	1	0.25	0.35	0.30
	For clearly and correctly identifying time (t)	1	0.05	0.06	0.054
	For clearly and correctly identifying acceleration (a)	1	0.10	0	0.05
	For having the final answers correct and no incorrect statements or calculations among the correct ones	1	0.05	0	0.025
	Total Points	12	3.3	2.2	2.7
	Percent Correct	N/A	27.5	18.1	22.8

The students' procedure writing was weak, indicating the need to continue the study. In particular, it tended to lack detail; thus some students mentioned equipment but not how to use it. Students also had a tendency to make up equipment or use it incorrectly. Their greatest weakness was in describing the timing of experiments, with many students merely saying that they would time the runner in the scenario but not specifying how or when measurements would be taken. Only a few students mentioned the possibility of repeating the experiment.

The pretest was given as a take-home assignment because the teacher-researcher did not want to devote a full class period to it. This design worked for most of the students, but two students' scores were noticeably higher than expected, and it was suspected and later confirmed that those students had looked up the answer on the Internet—though they still did not answer the question well and had weak procedures. Despite having seen the grading rubric, then, students did not have sufficient knowledge about procedure writing to answer the question fully. Table 4.2 presents observations about the students' answers, which illustrate a lack of knowledge of how to use equipment, incorrect expressions of timing, and a misunderstanding of velocity.

Overall Findings from Lab 1

Students were given the following "problem" for homework on a Tuesday night:

> Using your knowledge of the average velocity definition and formula, devise an experiment that imparts an average velocity of **0.200 m/s** to a cart. Students will work in groups of 2 or 3 to achieve this goal. Develop a procedure to set the cart in motion such that its average velocity between two predetermined points is constant and as close to 0.200 m/s as possible.

Table 4.2 Total Points Earned by Individual Students with Comments on Answers

Student Code (X)	Comment about student answer	Points
24	Drawing and materials only in part a. In using b to score for a, student makes incorrect assumptions about when certain things would occur.	6
32	No clear procedure. Lots of thoughts written all over the page. Nothing coherent.	1
35	Writes a lot about the "set up." Not needed. Is recording data for "all 11 runners" does not address the world class runner. Uses video camera for stopwatch and distance.	10
49	No procedure in part a. Only equipment and measurements listed. Procedure in part b. Has a way to measure time, but not distance.	1
44	Uses unrealistic equipment. Accounts for multiple trials. Only times the whole run.	3
18	Mentions tape (did they look up old rubric?).	7
26	Timing procedure is awkwardly written. Sounds off.	3
30	No procedure, just a graph. Confuses acceleration and velocity (part b).	1
10	Does not take enough data according to procedure. Right idea, but needs more data. Writes procedure in b. Timing procedure is vague.	4
19	Described procedure in part a, does not agree with what is described for part b. Has multiple students, but no description of how timing will take place or how it will gather data.	1
46	Students stop the watches, but never start them.	3
34	Answered part a in part b. Only gives a list of materials in part a. Graded as a whole. Allows for multiple trials. very unclear about when timing begins and ends.	0
25	Unclear timing procedure.	3
40	Recording time with lasers.	2
36	No part b, answered in part a. Only lists stopwatches as equipment, but has distances measured. Never starts the stopwatches. Analysis with procedure.	6
42	Uses a radar gun to collect speed. Multiple trials. Accounts for error by using a timer with a sensor (professional track timer). Probably overly wordy. Does not follow point values from rubric, but would almost work.	2
38	No diagram. Procedure mentions no equipment. Part b is not answered at all.	0
15	Very clear procedure.	6
20	Uses odd wording "categories: instead of sections? Never discusses how time is obtained. "observe the acceleration."	2
14	Has each student run the race. No mention of runner. Does some analysis/calculations in procedure. Says they will record time, but not how.	5

Student Code (4)	Comment about student answer	Points
58	Uses equipment that doesn't exist. Confuses procedure with data analysis. Has multiple trials, but of each student, not the runner.	3
95	“determine what you would like to determine.” “collect standard data.” wants to measure speeds, but lists no way of doing so. Uses formulas that are not real.	1
83	“clock the runner multiple times” no equipment, no measurements, no details.	1
77	Allows for multiple trials. Has data analysis in procedure section.	5
91	Unclear procedure, especially regarding stopping and starting the timers. Confuses data analysis and procedure.	5
68	Only uses two timed spots at 50 and 100m. “find the rate of running” but does not say how.	0
57	Part of the procedure was illegible. Does mention timing it. Was doing as class began the day it was due.	2
54	Measure speeds but using a speedometer, not sure that is possible. Also begins to analyze data within the procedure. Allows for multiple trials.	3
64	Student only times once. Not detailed and tries to uses kinematic formulas that cannot be applied to this situation.	1
99	Uses the phrase “second chronogra” Maybe a timer?	4
61	Uses “etc. . .” to describe how many data measurements to take after listing them off 3 possible ones. Not specific enough. Also not clear when timers begin and end. “take recorded data for each student” which data? begins analysis within the procedure.	3
92	“which line are the numbers the same as the one before it” no idea what numbers student is referring to. Says he is using a stopwatch, but doesn’t say for what.	3
50	Uses “speed monitoring” equipment to measure the speed. No way to determine acceleration, just measuring speed at different points. Very short	1
80	Needs to define “checkpoint” and “evenly spaced”. confusing step 3. Has some analysis in with procedure. Does allow for multiple trials	3
82	Never uses anything to measure length. Discusses breaking into sections but does not explain how. Students run multiple times, but no mention of the runner	0
87	No procedure, tries to use mathematical formulas. Lists stopwatch as materials.	0
70	May have possibly copied a previously released rubric. Uses “the tape” and no tape was listed in the question. Students never start timers, just stop them. Unclear, but still seems copied from the rubric.	2

After you have developed your method, you must perform **five** consecutive trials and take the mean of the average velocity obtained for those 5 trials. Report your results in your report.

When students arrived in class on Wednesday, they were given time to compare their procedures with their partners and to decide which might give the best results. All students modified their original procedures, especially once they began the actual lab. They collected data the remainder of the period and were told to bring a written procedure for what they had done to class the next day.

The class as a whole then discussed the aspects of a good lab report and how to be specific in scientific writing, such as mentioning all of the equipment used, making diagrams to support verbal argumentation, and avoiding assumptions about the reader's understanding. Students were also given guidance regarding good peer feedback with peer feedback cards. They spent the remainder of the class reading each other's procedures and providing written feedback on post-it notes. Most read two other lab procedures beyond those from their original lab group. Students were then given two days to re-write their lab procedures and finish their data analysis (which involved finding the average velocity) and were also asked to examine their overall work for errors.

Students' lab reports and feedback showed some common trends in both classroom sections. Thus many found it quite difficult to describe what they would use to time the car in the scenario and when they would stop and start the timing. Students also tended to include calculations as part of the actual procedure instead of placing them in a separate section. Further, many students failed to use the feedback that they received when rewriting their procedures, in part because the student feedback notes often assumed too much of other students' procedures. Because students had done the lab, they often inferred what other students meant in there procedures, so the feedback given was not always helpful. They also failed to detect inaccuracies in describing the timing. Comments about their performance on the science practices appear in Table 4.3.

Table 4.3 Student Performance on Science Practices (SPs) in Lab 1

SP 4: The student can plan and implement data-collection strategies in relation to a particular scientific question.	
4.1 - The student can justify the selection of the kind of data needed to answer a particular scientific question	Students generally gathered the correct data; however, through reading procedures very few students discussed why they were gathering that data. Many said they would measure the length of the track, but did not say that is would be used as the displacement in the velocity formula.
4.2 - The student can design a plan for collecting data to answer a particular scientific question.	Students designed a plan to collect the displacement and the time in order to calculate velocity as demonstrated in their data tables; however, they did not all verbalized this plan in the procedure.
4.3 - The student can collect data to answer a particular scientific question.	Students did well collecting the data and placing it in a reliable data table. Students do need to pay more attention to significant figures and units. A few students collected data they did not need (different lengths or heights), but it did not affect their final answer. They did not use the extraneous data in their calculations.
4.4 - The student can evaluate sources of data to answer a particular scientific question.	Most all students successfully found the average velocity of their car. The ones who did not find the correct average velocity generally made mathematical errors. Many students correctly identified that timing was their main source of error, but could not articulate why timing caused the error.

Overall Findings from Lab 2

After two days of instruction on the definitions and mathematical formulas of displacement/position, velocity, and acceleration, students were given a handout with basic instructions and analysis questions to answer (Appendix E). Although this pre-instruction seems counterintuitive to the 7E Model, students were not instructed on motion graphs or how to describe motion through graphs. Lab 2 did not concern the instruction given, but the instruction given was needed prior knowledge for the lab. To begin the lab, students were asked to predict the appearance of eight different motion graphs for a set of situations; they then consulted with their lab partners and compared their graphs, discussing and justifying their choices. Through the discussion, the partners came to an agreement regarding the graph that they considered correct.

Students then used Pasco SmartCarts connected to SparkVue graphing software on their laptops. Based on situations used for their graphing predictions, they developed brief procedures for the carts in the scenarios, the motions of which were graphed by the software. Students were then asked to answer four analysis questions in their lab notebooks to determine whether they could connect the relationship of the slope of the graphs with the motion of the cart. As an extension activity, students were given eight graphs (Appendix F) and asked to use the carts to describe the motion depicted in the graph. Their lab notebooks were then graded by the teacher-researcher using a rubric.

Overall, the two classes had an average grade of 88 out of 100. Some students were quite disappointed with their grades—those who had disregarded the instructions on the handout and failed to include some of the sections in their notebooks. In particular, students failed to answer the analysis questions. Nevertheless, they enjoyed the lab, making good connections among the graphs that they had drawn, the graphs produced by the software, and the motions of the cart. Students did have trouble describing fully the motion depicted in the graphs on the extension activity, often merely indicating that it increased or remained constant. To describe the graphs fully, they needed to address the position, velocity, and acceleration of the cart, including both magnitude and direction.

Students had the most trouble with the acceleration graphs of the cart. Table 4.4 presents comments about students' performance on the listed science practices addressed in the lab.

Table 4.4 Student Performance on Science Practices (SPs) in Lab 2

SP 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems.	
1.5 - The student can re-express key elements of natural phenomena across multiple representations in the domain.	Students needed to express the motion of the cart through graphs and their written descriptions. Students did well showing the different graphs, but had trouble expressing themselves in words. The comments made in their labs often were lacking description of position, velocity, and acceleration. This often included no discussion of how the graph reflects the direction of the quantities.
SP 4: The student can plan and implement data-collection strategies in relation to a particular scientific question.	
4.2 - The student can design a plan for collecting data to answer a particular scientific question.	Student procedures for achieving the different motion situations were brief, but precise. During the lab, students did seem to have some confusion as to how best to describe what they had done; however, the procedures in the lab notebooks were good.
SP 5: The student can perform data analysis and evaluation of evidence.	
5.1 - The student can analyze data to identify patterns or relationships.	Students had trouble answering the analysis questions. Many could tell that the slope on a position vs. time graph was velocity, but very few could tell that the slope on the velocity vs. time graph was acceleration. Many also incorrectly assumed a line with no slope on a velocity vs. time graph represented an object at rest, just like that of a position vs. time graph. Most students did understand the relationship of direction representation on the graph.
5.2 - The student can refine observations and measurements based on data analysis.	Through discussion with their partners, students refined their original predictions of the motion graphs. These predictions were then further refined through the use of the SparkVue software graphs. By the

	end of the lab, most students could verbally identify the motion of the cart by looking at a graph; however, their written descriptions did not indicate complete understanding.

Overall Findings from Lab 3

After two class periods of instruction on kinematic equations and one day of instruction on horizontally-launched projectiles, students were tasked with finding the initial velocity of a toy car launched horizontally off of a table using only a meter stick (rather than a stopwatch). The aim was for them to employ the kinematic equations to predict the landing position of the car and to use this information to determine the launch velocity, again with the kinematic equations. In addition to availing themselves of the proper mathematical relationships and formulas, the students had to develop a replicable procedure to obtain the needed data. After the lab was completed, they were asked to identify any assumptions that they had made when doing their work and how these assumptions could have affected their calculations. Students were also asked why they were not allowed to use a stopwatch, ways in which the lab could be improved, and to account for the differences between their calculated and actual values.

Students were initially quite frustrated at being unable to use a stopwatch. They also took considerable time deciding how their measurements could be used to find the information requested. They knew to find the horizontal distance traveled and vertical distance of launch but were unsure how to transfer these data to their calculations.

The students' procedures were better, though many still described their calculations within the procedure rather than separately and provided insufficient information in their labeling diagrams—the procedures and/or the diagrams needed to be more detailed so a reader could understand the experimental setup. The procedural information regarding the measurements also needed greater clarity in the write-up or on the diagram label.

Furthermore, students left their method analysis incomplete, without discussion of assumptions or improvements. Many attributed their inaccuracies to "human error," though class discussion had covered what constituted error in the lab. Some students did offer very good suggestions for improvements in the lab, including having the car land in sand to mark the exact landing spot. The word "assumptions" also tended to confuse students. The teacher-researcher wanted them to list, for example, that they had ignored friction and air resistance or assumed a perfectly horizontal launch; however, the students offered comments such as "we assumed the calculations were right" or "we assumed the calculated time could be used in both the x and y" or "we assumed gravity was on earth." They also contradicted themselves in discussing the stopwatch, failing to recognize that their calculations were actually more accurate using distance measurements so that this instrument could not improve the accuracy of their calculations.

Many students were disappointed with their grades on this lab assignment as well. The majority of low grades were a result of failure to addressing the questions asked or leaving sections out of the lab report. The average lab grade for both classes combined was 87.1 out of 100 possible points. Table 4.5 illustrates the science practices in the lab and the students' performance carrying them out.

Table 4.5 Student Performance on Science Practices (SPs) in Lab 3

SP 1: The student can use representation and model to communicate scientific phenomena and solve scientific problems.	
1.5 - The student can re-express key elements of natural phenomena across multiple representations in the domain.	Students had to use data from different parts of the investigation and relate it to mathematical formulas learned in class. Many students had great difficulty in knowing where and how to use the data in the formulas. Some student groups had to be guided several times as to how to manipulate their data.
SP 2: The student can use mathematics appropriately.	
2.1 - The student can justify the selection of a mathematical routine to solve problems.	Students had difficulty selecting the correct equations to use when solving for the requested information.
2.2 - The student can apply mathematical routines to quantities that describe natural phenomena.	Students had difficulty using the correct equation with the correct data. Many times they used data from the y direction in an x direction equation and vice versa. Some student groups did not know that the distance the ball landed would be their displacement in the x and other similar confusion.
SP 4: The student can plan and implement data-collection strategies in relation to a particular scientific question.	
4.3 - The student can collect data to answer a particular scientific question.	Student collected displacement measurements in both the x and y direction. Students did have trouble knowing what constituted the displacement in the x vs. displacement in the y. A few students tried to measure the hypotenuse of the flight of the cart.
4.4 - The student can evaluate sources of data to answer a particular scientific question.	Students had trouble analyzing their data for errors. Some student groups were able to identify that using the more accurate measurement of distance rather than time helped to eliminate a source of possible error. Some student groups were able to understand that they had assumed no air resistance. Very few groups were able to identify friction as an assumption.

Overall Findings from Lab 4

After two days of classroom instruction on angled-launch projectiles, students were tasked with finding the initial velocity of a dart fired from a toy gun. Students were not limited with regard to measurement tools in this lab. They were given two days in class to work on their procedure, collect data, and complete the lab write-up.

On the first day, the students quickly developed procedures and began to collect data to support them. They did not, however, spend enough time thinking through their procedures, an outcome that can probably be attributed to the excitement of shooting the dart guns. Most student groups claimed to have finished data collection on the first day. On the second day, students tried to complete the calculations involved in the lab. Many students had difficulty with the required manipulation of the mathematical equations, with well over half of the groups measuring only the initial launch angle and displacement (information insufficient to answer the question posed in the lab). Students then had to revise their procedures to include gathering extra data, and most decided to time the dart.

Their questions lead the teacher-research to conclude that the students did not fully understand how to perform the correct calculations or what they were looking for in the data analysis. They often confused initial velocity in the horizontal and vertical dimensions. Some student groups also mistakenly tried to measure the velocity at the highest point in the launch.

Further trouble was encountered in creating an alternate procedure for the extension activity. Some students merely modified the launch angle or made minor improvements in their original procedures. The aim, however, was to develop a completely different procedure for determining the initial velocity of the dart. Students who did create a modification, such as filming the launch for better timing, experienced improvements in accuracy, while those who came up with alternatives generally moved to a horizontal launch procedure in order to remove the angle as a possible source of error. No student developed a method to remove timing as a means to reduce error.

There was improvement in students' procedure writing and diagram construction in terms of greater detail and increased clarity. Students also began to provide more detail to describe the timing of the launch, something that had been lacking in previous write-ups. The overall average of the two classes improved to 89.7 out of 100 possible points. Most lost points resulted from errors in calculation rather than in constructing procedures. Table 4.6 provides a breakdown of SPs addressed in the lab and students' achievement therein.

Table 4.6 Student Performance on Science Practices (SPs) in Lab 4

SP 1: The student can use representation and modeling to communicate scientific phenomena and solve scientific problems.	
1.5 - The student can re-express key elements of natural phenomena across multiple representations in the domain.	Students had to use data from different parts of the investigation and relate it to mathematical formulas learned in class. Many students had great difficulty in knowing where and how to use the data in the formulas. Some student groups had to be guided several times as to how to manipulate their data.
SP 2: The student can use mathematics appropriately.	
2.1 - The student can justify the selection of a mathematical routine to solve problems.	Students did not understand the difference between initial velocity and the velocity separated into its component vectors. Students had trouble working from the component vector in the x or y direction to find the resultant initial velocity.

2.2 - The student can apply mathematical routines to quantities that describe natural phenomena.	Students had trouble using sine and cosine to find the resultant initial velocity. Some students found the correct answer but did not understand why it was correct. They continued to do other mathematical routines, such as the Pythagorean theorem, which were not needed and did not provide the correct answer.
SP 4: The student can plan and implement data-collection strategies in relation to a particular scientific question.	
4.3 - The student can collect data to answer a particular scientific question.	Students originally did not collect enough data to answer the posed question. However, once students realized they needed to collect more data (time in flight), they were able to do so successfully. All students were able to determine the data to collect by the end of the second day.
4.4 - The student can evaluate sources of data to answer a particular scientific question.	Students had difficulty determining which of their two procedures had the least amount of error. Students still thought that timing is the most accurate method, even though it has been discussed that it introduces error. Students often equate an easy procedure with less error.

Overall Results from the Unit Test

At the end of the six-week unit that contained the four 7E Model inquiry-based labs, students completed a unit test consisting of ten multiple choice questions and two multi-part free response questions. One of the free response questions was an inquiry lab-based question (Appendix D), which asked students to develop a procedure to determine acceleration from gravity experimentally. In part A, students had to identify which materials to use and how. Part B asked students to describe a procedure using the equipment and materials listed for Part A to determine acceleration from gravity. Mathematical reasoning was tested in Part C, as students were asked to show how they could use their data in an equation to predict acceleration from gravity. Finally, in Part D, students were asked to list two assumptions or sources of error that could have caused the lab results to differ from the actual acceleration from gravity.

Generally, students ascertained that they would need a way to measure height, for which they usually chose a meter stick, and a way to measure time, for which they usually chose a stopwatch. Students lost points in Part A by failing to state how the equipment would be used in the experiment. Most students were able to come up with a clear and concise procedure for Part B, though several lost the third possible point because they did not state that the procedure should be repeated multiple times. The final part of the question was usually answered successfully, even by students who had missed other parts. Those who missed a point in Part D usually did so because they listed only one assumption.

Part C gave students the most trouble, as many tried to use the average velocity formula (change in distance divided by change in time) or the average acceleration formula (change in velocity divided by change in time) to answer the question. The problem was that, when they chose to use the average velocity formula, they were neglecting the acceleration of the dropping object, and when they tried to use the average acceleration formula, they did not have a way to calculate the final velocity required in the formula. Even students that chose the correct formula to use in the data analysis often failed to state that the initial velocity was zero and therefore failed to earn one of the two available points. Table 4.7 presents the point breakdown for individual students on the question, and Table 4.8 the average scores for both sections and the final average for the question.

Table 4.7 Student Performance on Posttest by Points Awarded

	Part A		Part B			Part C		Part D	
Student Code (4)	Listed Viable Materials (1 point)	Listed material use (1 point)	Clear, concise procedure (1 point)	Listed measure-ments and instrument (1 point)	Mentions repeating the procedure (1 point)	Listed a correct formula (1 point)	Stated initial v is zero (1 point)	Stated 2 sources of error or assump-tions (2 points)	Total Points Earned (9 points)
95	1	1	1	1	0	1	1	2	8
83	1	1	1	1	0	0	0	0	4
77	1	1	1	1	1	1	1	2	9
91	1	1	1	1	1	1	1	1	8
68	1	1	1	1	1	1	0	1	7
57	1	1	1	1	0	1	1	1	7
54	1	1	1	1	1	1	1	2	9
64	1	1	1	1	0	1	1	2	8
99	1	1	1	1	1	1	0	1	7
61	1	1	0	0	0	0	0	2	4
92	1	1	1	1	1	1	1	2	9
50	1	1	1	1	1	0	0	1	6
80	1	1	1	1	0	1	1	2	8
82	1	1	1	1	1	1	1	2	9
87	1	0	1	1	1	1	1	1	7
70	1	0	1	1	1	0	0	1	5

	Part A		Part B			Part C		Part D	
Student Code (X)	Listed Viable Materials (1 point)	Listed material use (1 point)	Clear, concise procedure (1 point)	Listed measure-ments and instrument (1 point)	Mentioned repeating the procedure (1 point)	Listed a correct formula (1 point)	Stated initial v is zero (1 point)	Stated 2 sources of error or assump-tions (2 points)	Total Points Earned (9 points)
58	1	1	1	1	1	1	1	2	9
95	1	1	1	1	0	1	1	2	8
83	1	1	1	1	0	0	0	0	4
77	1	1	1	1	1	1	1	2	9
91	1	1	1	1	1	1	1	1	8
68	1	1	1	1	1	1	0	1	7
57	1	1	1	1	0	1	1	1	7
54	1	1	1	1	1	1	1	2	9
64	1	1	1	1	0	1	1	2	8
99	1	1	1	1	1	1	0	1	7
61	1	1	0	0	0	0	0	2	4
92	1	1	1	1	1	1	1	2	9
50	1	1	1	1	1	0	0	1	6
80	1	1	1	1	0	1	1	2	8
82	1	1	1	1	1	1	1	2	9
87	1	0	1	1	1	1	1	1	7
70	1	0	1	1	1	0	0	1	5

Table 4.8 Average Student Performance on Posttest Question by Points Awarded

	Group X Point Average	Group 4 Point Average	Average of Both Groups
Listed Viable Materials (1 point)	1	1	1
Listed material use (1 point)	0.75	0.88	0.816
Clear, concise procedure (1 point)	0.95	0.94	0.945
Listed measurements and instrument (1 point)	0.8	0.94	0.87
Mentioned repeating the procedure (1 point)	0.6	0.64	0.62
Lists a correct formula (1 point)	0.45	0.76	0.61
States initial v is zero (1 point)	0.2	0.65	0.42
States 2 sources of error or assumptions (2 points)	1.45	1.47	1.46
Total earned (out of 9)	6.2	7.3	6.75
Percent Correct (%)	68.9	81.0	74.9

Interpretation of the Study

As students progressed through the study, they began to write better, more detailed procedures and to become more comfortable coming up with them on their own. The overall lab grades remained largely unchanged, as shown in Table 4.9.

Table 4.10 presents a student-by-student breakdown of the lab scores. In the first two labs, students lost the majority of points owing unclear procedures, poor diagrams, and general failure to follow the directions for the write-up. In the last two labs, students began to write much better procedures, but began having more difficulty setting up the mathematical formulas to analyze their data, resulting in a loss of points from mathematical errors instead of improper procedure writing. Many students continued losing points on their lab write-ups because they did not follow the directions regarding the contents of the report. As the goal of the study was to determine the effective of the 7E Model inquiry-based labs on student's responses lab-based AP questions, the teacher-researcher was not concerned by the lack of improvement in overall lab grades, which were based on much more than the writing of the procedures.

Table 4.9 Class Averages for Each of the Four Labs

	Lab 1	Lab 2	Lab 3	Lab 4
Class Average (4)	88.56	87.61	89.41	88.06
Class Average (X)	88.63	88.95	84.9	91.3
Overall Average	88.60	88.28	87.16	89.68

Table 4.10 Student Grades for Each of the Four Labs

Student Code (4)	Grade Lab 1	Grade Lab 2	Grade Lab 3	Grade Lab 4
58	93	100	92	100
95	86	80	90	89
83	86	89	70	79
77	100	98	95	89
91	86	94	94	88
68	95	90	99	100
57	84	92	86	88
54	93	92	99	98

64	87	100	88	80
99	86	100	88	85
61	87	81	88	89
92	90	84	98	---
50	83	56	66	66
80	87	87	90	84
82	93	91	89	88
87	90	91	89	88
70	93	90	99	98
Class Average(4)	88.56	87.61	89.41	88.06
Student Code (X)	Grade Lab 1	Grade Lab 2	Grade Lab 3	Grade Lab 4
24	93	83	89	94
32	88	81	67	91
35	87	84	67	93
49	90	95	90	100
44	87	94	90	90
18	89	100	88	95
26	92	88	84	92
30	90	90	75	73
10	86	97	97	98
19	--	85	84	96
46	88	97	88	96
34	84	94	90	100
25	83	83	78	95
40	91	89	91	94
36	92	82	99	88
42	91	88	99	100
38	94	82	87	100

15	91	88	84	85
20	90	96	76	73
14	78	81	73	73
Class Average (X)	88.63	88.95	84.9	91.3

Student scores on the posttest lab-based question do show overall improvement from the pretest lab-based question. On the pretest, students answered 22.8% of the question correctly. Very few were able to create a suitable procedure that was sufficiently clear to receive full credit, and almost none could tell how data would be analyzed. However, on the posttest, students answered 75.0% of the question correctly, and almost all were able to generate a proper procedure to answer the question posed. The results of a t-test with a p value of less than 0.0001 demonstrate that the data from the pretest and posttest differ significantly, with the latter being significantly higher than the former.

The overall unit test scores averaged 81.03 out of a possible 100 points, though seven students scored below 60, an F on the school's grading scale. While students generally did better on developing and writing a procedure for the lab-based question, many struggled with the other areas of the test, such as concept application and mathematical routines. The teacher-researcher concluded that the balance between practicing conceptual and mathematical routine questions and the four 7E Model labs was not optimal; in particular, since these labs took more class time than traditional labs, there was less time to devote to in-class practice of other types of questions. Students also spent much of their time outside of class writing up the labs instead of practicing the concepts and formulas individually.

Conclusions

The students improved in their abilities to develop and write up effective procedures over the course of the six-week study, as indicated by the increase in scores from the pretest to the posttest. By completing four different 7E Model inquiry labs, students began to develop better procedures that allowed them to answer a given physics question and to include more detail in their writing and labeled diagrams to help convey the meaning of their words. As reflected in their lab report grades, though, while they began to write better procedures, the students had considerable trouble with the mathematical routines required in the labs. In any case, the improved performance on the inquiry lab-based questions demonstrates that use of 7E Model inquiry-based labs does indeed improve student achievement on AP-type inquiry-based lab questions.

CHAPTER 5: SUMMARY AND DISCUSSION

This chapter begins with a summary of the study, including a description of the problem of practice and the research question. There follows a discussion of the data collection instruments, the findings, and major points to be drawn from the study. Next, the action plan developed by the teacher-researcher in conjunction with the student participants is detailed. The chapter concludes with suggestions for future research.

Focus of the Study

The identified problem of practice (PoP) concerns AP Physics at the teacher-researcher's high school, at which students have tended to score well on the traditional AP exams. With the introduction of new inquiry-based lab questions, however, students found it difficult to maintain their levels of performance. The primary purpose of the present study was to determine the effect of 7E Model inquiry labs on the performance of two sections of AP Physics I students on AP exam inquiry-based lab questions. The secondary purpose was to devise an action plan for increasing the effectiveness of AP teachers in the particular context of high-level science students at the teacher-researcher's school. The research question was accordingly as follows:

RQ: What are the effects of 7E Model inquiry labs on the performance of Advanced Placement (AP) Physics students on AP exam inquiry-based lab questions as measured by unit assessments?

Overview of the Study

At the beginning of the school year in August 2017, the teacher-researcher began this action research study in an effort to determine the effectiveness of 7E Model inquiry-based labs in improving students' performance on AP exam inquiry lab questions. The study was conducted in the teacher-researcher's classroom at a small independent school in upstate South Carolina. The 37 student-participants were enrolled in AP Physics 1 for the 2017-18 school year. After gathering consent forms from prospective student-participants and their parents, they were given a pretest that consisted of an old AP exam question on the first day of the study. The teacher-researcher graded this pretest according to the AP rubric developed by the College Board. The student-participants received a completion grade for classroom purposes. Their actual performance on the assignment was only assessed for this study.

Throughout the six-week study, the student-participants completed four 7E Model inquiry labs focused on their current unit of study, kinematics. After each lab, they submitted a lab report describing their procedures and analyzing their findings. The teacher-researcher graded these reports based on a combination of her own rubrics and ones developed using the College Board's Science Practices (SPs). The reports counted toward the student-participants' course average. The teacher-researcher also made comments about the SPs covered in the labs.

At the end of the unit, students took a unit test consisting of a mixture of old AP exam questions and questions in the style of the new AP exam, 10 multiple-choice in format and 3 free-response. One of the free-response questions was an inquiry lab-based question. Students completed the test in a single 52-minute class period, and the teacher-researcher graded the multiple-choice questions according to the AP answer key and the free-response questions according to those of the College Board. A t-test was then used to compare the pretest with the inquiry-based lab question from the unit test.

Summary of the Study

Over the course of the study, the students began to write more detailed procedures and to become more comfortable developing them, though the overall lab grades remained relatively unchanged. In the first two labs, the majority of points were lost owing to unclear procedures, poorly-executed diagrams, and general failure to follow the directions for the lab and the write-up. In the last two labs, students showed considerable improvement, but had greater difficulty setting up the mathematical formulas to analyze their data and therefore lost points owing to mathematical errors, and many continued to lose points for failing to follow the directions regarding what the reports should include. As the goal of the study was to determine the effectiveness of the 7E Model inquiry-based labs, the teacher-researcher was not concerned by the lack of improvement in overall lab grades, which took many other factors into account beyond the development and writing of the procedure.

In their scores on the posttest lab-based question, 75.0% of students did show overall improvement compared with the pretest, on which only 22.8% answered the question correctly. At the time of the pretest, few could create a procedure that deserved full credit, and almost none could determine how the data should be analyzed. By the time of the posttest, all students were able to generate a proper procedure to answer the question posed to them. The results of a t-test with a p value of less than 0.0001demonstrated that the results from the pretest and posttest differed at a level of statistical significance; specifically, the posttest results were considerably higher than those of the pretest.

Discussion of Major Points of the Study

Based on examination of the data gathered from the pretest and posttest, lab grades, and general observations, the teacher-researcher concluded that the 7E Model labs did help students to develop the skills needed to answer the inquiry lab-based question on the AP exam. Like the students in the ISLE study (Etkina et al., 2010), the students in the present study began to show better scientific communication skills. The model afforded them opportunities to practice developing a procedure and communicating about it, even as they accessed and extended their prior knowledge and became better prepared to answer the unknown question that they would face on the AP exam.

The teacher-researcher found the 7E Model to be a good structure for developing and implementing the inquiry labs. As Duran and Duran (2004) found when they combined the 5E Model with inquiry, the teacher-researcher found that the 7E Model served as a guide to constructing inquiry lab activities. These activities did require more classroom time than traditional activities, but they provided a framework that facilitated accessing the students' prior knowledge and maintaining their attention. By following the 7E Model, student-participants were well-equipped to explore and analyze their findings, with the teacher-researcher's assistance when necessary. Transfer of knowledge to similar and different situations was also ensured through the last two steps of the cycle associated with the model. Conducting an inquiry lab in isolation, by contrast, may not have created the conditions for accessing prior knowledge or transferring knowledge to new situations. In traditional science classes, labs are often completed without ever being connected to a larger or alternative purpose or to other learning. The 7E Model helped student-participants to see how their new knowledge could be used in various situations.

Also as with the ISLE study (Etkina et al., 2010), students initially had difficulty beginning to develop their procedures but, once the initial discomfort caused by having to do so had passed, many found themselves enjoying the inquiry labs. The teacher-researcher was uncertain, however, how long this interest in creating their own procedures could be sustained, that is, whether the labs were appealing simply for their novelty or rather because they actually did assist students in expressing their creativity and applying their knowledge in different ways. She was also uncertain whether students who were still having trouble with procedure development at the end of the unit would have enjoyed greater success after a longer period of exposure to the 7E Model labs.

The data gathered for this study were insufficient to determine whether the 7E Model labs alone were responsible for the improvement from the pretest to the posttest. The mere act of writing and receiving further exposure to physics content certainly may have played a role. The teacher-researcher concluded, though, that the 7E Model labs did provide an effective structure for students to begin to think critically about developing procedures, communicating them clearly, and interpreting lab results, while merely performing the labs would not have provided the right steps and process for success on the actual inquiry lab-based question. Students were able to apply knowledge gained through the 7E Model labs to a new question on the posttest. By constructing their own knowledge through the labs, they were able to transfer it to a new situation.

Limitations

Time was the major limiting factor of the study; as mentioned, 7E Model inquiry labs take more time than traditional lab activities. The activities consume more in-class time, and students must spend more time outside of class writing procedures and interpreting data. It was in part because the teacher-researcher was aware of this fact that the decision was made to administer the pretest as a take-home assignment. Also as mentioned, a limitation was revealed in the fact that two students apparently found answers to the pretest question online, where the AP grading rubrics are readily available. However, owing to their inexperience with this type of question, these students still did not answer it correctly, though their unauthorized consultation of the Internet distorted their representations of their abilities. A further limitation of the use of a take-home assignment as a pretest was that students may not have treated it as seriously as they would have an in-class pretest.

Further, in their efforts to incorporate all of the steps of the 7E Model, some students may have rushed their labs in ways that they would not have had they been given direct instructions. Students also may have been left with less time to devote to learning physics concepts as they worked to complete the inquiry-based labs. This last limitation may have been responsible for the low overall unit test scores, which again averaged 81.03 out of a possible 100 points and included seven failing scores below 60. While students generally did better developing and writing up a procedure for the lab-based question, many still struggled with the other areas of the test, in particular concept application and mathematical routines. The teacher-researcher concluded that additional time would have allowed for a better balance between practicing conceptual and mathematical routine questions and participating in the four 7E Model labs.

Because the teacher-researcher graded the pretest, lab reports, and posttest, there could be inherent bias within the grading. This is true even in the case of the assignments and free responses, which were assessed according to a rubric developed by the College Board. To be specific, the teacher-researcher obviously began the study with hopes that the 7E Model inquiry labs would help her students to succeed on the inquiry lab-based questions on the AP exam and therefore may unintentionally have scored the pretest lower and the posttest higher.

A further limitation concerns sample size: there were simply not enough student-participants in the study to generalize findings to a larger population, despite the fact that enrollment in the teacher-researcher's AP Physics 1 classes at the time of the study was higher than had been the norm. The student-participants were placed in one of two sections based on their class schedules. All students participated in the experimental group, so there was no control group with which to compare it, in part owing to the relatively small total number of students and the need to keep the two sections synchronized.

Action Plan: Implications of the Findings

The teacher-researcher found the 7E Model inquiry-based labs to be effective in helping students develop skills to answer the lab-based question on the AP exam correctly. These skills support the SPs suggested by the College Board for all AP science courses. These are not, however, the only skills needed to be successful in AP Physics 1. Students also need time to practice other types of questions that they will encounter on the AP exam, in particular those dealing with quantitative translation and mathematical reasoning, but the 7E Model inquiry-based labs did not leave enough time to develop the skills necessary to prepare for such questions.

In reflection with the student participants, the teacher-researcher discovered that many of them had felt overwhelmed by the amount of work required for the 7E Model inquiry labs completed during the unit of study. Thus, while describing the labs as helpful and enjoyable, some students nevertheless stated their preference to have devoted more time to practicing the concepts.

Going forward, the teacher-research made plans to continue conducting 7E Model inquiry labs, but to complete only one during each unit. Cutting back the inquiry labs in this way, students would develop the lab procedures, carry them out, and interpret the results in a way that fosters the construction of meaning while still having sufficient time to practice the concepts, in particular the mathematical reasoning that the course demands. As the lab grades showed, students began to struggle with this skill and had insufficient time to practice it. By incorporating 7E Model inquiry-based labs within a preexisting AP Physics 1 curriculum, students can benefit from the concepts learned during the inquiry-based labs and through a curriculum that also gives attention to other pertinent topics within the AP Physics 1 framework.

If more than one inquiry lab were needed or desired during a particular unit, another option would be for the teacher-research to only focus on one SP during the lab. Perhaps procedure becomes the focus for the first lab, mathematical calculations the second, and error analysis during the third lab. This would be a way to save time and the teacher-research could give more specific feedback about a particular SP, instead of giving broad feedback on many SPs.

In addition to reducing the number of 7E Model inquiry-based labs, the teacher-researcher planned to continue to monitor their effectiveness in terms of student achievement over a longer period of time. Toward this end, a similar longitudinal study comparing original pretest scores and final scores with the inquiry lab-based question on the AP exam in the spring semester would be informative. With more time, the teacher-research and student-participants would also have the opportunity to become more comfortable with the 7E Model inquiry-lab format, resulting in more productive lab interactions—or possibly in tedium and reduced effectiveness. Indeed, Sarac (2016) determined the 7E Model to be more effective over the short than the long term.

Kocakaya and Gonen (2010) found that the 7E Model had no effect on students' attitudes toward physics, while Ayvaci et al. (2015) found that it improved them. In order to shed light on these conflicting results, it would be useful to monitor students' attitudes, not only toward physics in general, but also specifically toward physics labs and the acquisition of knowledge in the subject. Proceeding under the impression that positive attitudes on the part of students contribute to success in physics, the teacher-researcher planned to begin monitoring them through classroom observation and measuring them through surveys administered at the beginning and end of each semester.

Since they form part of an action plan, the teacher-researcher planned to share the results, first with the science department at her school, since the 7E Model inquiry labs demonstrated their potential to assist AP science students in other subjects in developing the skills called for in the College Board's SPs, which are not subject-specific. Thus previous experience with inquiry labs would naturally make students more comfortable with the format as they enter higher-level courses so that they could focus on the content rather than being forced to learn both the lab procedure and the course material at the same time.

The teacher-researcher also planned to share the results of this study more broadly during the AP Physics exam grading that takes place yearly in Kansas City, Missouri. At this meeting, AP Physics teachers from across the country and other parts of the world gather to grade exams and participate in professional development opportunities. One night of the meeting is devoted to sharing work and research done by fellow teachers, and it is in this context that the results of the current study could be presented in the form of a poster. Attendees are always interested in improving their classroom practices and thereby their students' scores, especially with respect to the new inquiry lab question on AP exams. The poster thus could spark discussion and sharing of ideas for improving the effectiveness of 7E Model inquiry labs.

Suggestions for Future Research

There is a need for research into the use of 7E Model inquiry labs among diverse populations including, but not limited to, those defined in terms of socioeconomic status, race, and gender. The current study was done with a very limited—mainly white and male—group of students, the relatively insignificant differences among whom were not taken into account. It therefore remains to be seen whether the effectiveness of 7E Model inquiry labs would vary among various groups of students. Also useful would be consideration of levels of the subject beyond AP Physics. Such issues could not be explored in the context of the teacher-researcher’s relatively small and homogeneous school.

Avenues for future study also include the questions used in the pretests and posttests and the SPs. In this relatively brief (six-week) study, the pretest and posttest questions necessarily differed, but over the course of a longer study, perhaps covering an entire school year, it would be possible to explore changes in responses to the same question. So also, it would be informative to study whether, for example, 7E Model inquiry labs are more effective for some SPs than others. The student-participants’ development in respect to individual SPs was difficult to track during this relatively brief study because each lab focused on a specific subset of SPs; that is, the SPs, as course-long goals, do not all appear in every unit or lab. By following individual SPs over the course of an entire school year, teachers could optimize the balance of 7E Model inquiry labs and other methods that may be better suited to certain SPs.

Ayvaci et al. (2015) found an increase in the achievement of undergraduate college students with the use of 5E Model labs in units of study focused on light reflection and mirrors. Measuring such achievement or content knowledge was beyond the scope of the present study, but doing so would be informative, and not just regarding the inquiry lab-based question. For while student participants began to write better procedures over the course of the study, many continued to struggle with the general physics knowledge that they had covered. This difficulty with physics concepts may have been due to students’ lack of familiarity with the class at the point in the school year when the study was conducted, but in any case a longer-term study of physics achievement could further support the use of the 7E Model labs within the course.

Knowledge of the subject together with the ability to develop procedures and communicate effectively are all essential aspects of a good physics student.

Conclusions

The learning theory known as constructivism was developed during a period of educational reform in the United States through the research of Piaget, Bruner, and Vygotsky. According to this theory, learners create and construct meaning from experience (Ertmer & Newby, 1993; Colburn, 2000; Keser & Akdeniz, 2010; Harasim, 2012). Building on this work, J. Myron Atkin and Robert Karplus suggested that students should discover scientific concepts through guided inquiry (Konicek-Moran & Keeley, 2015), and learning cycles were developed to guide the inquiry process. Applying constructivist principles and further developing the learning cycles, Eisenkraft (2003) designed the 7E Model learning cycle as a means to ensure that prior knowledge is accessed and that new knowledge is transferred to a variety of situations.

In 2014, the College Board announced multiple revisions to its AP Physics curriculum. One major change was the introduction of an inquiry lab-based question among the five free-response questions on the AP Physics 1 exam. The Board encouraged use of a learning cycle model for instruction during the inquiry labs, and the 7E Model inquiry labs are suited to the task, since they promote movement away from memorization in favor of participation and applying information to a range of relevant situations. The focus of AP Physics is thus no longer on pure mathematical skill, for students must investigate to determine whether there may be more than one correct answer to the lab. The knowledge acquired in 7E Model inquiry labs can be applied in answering the inquiry lab-based question on the AP exam.

To sum up, then, the teacher-researcher sought to determine whether the 7E Model inquiry labs would improve students' performance on the inquiry-based lab question. She accordingly conducted an action research study of two sections of AP Physics 1. Comparison of a pretest and posttest of inquiry lab-based questions using a t-test demonstrated a statistically significant difference between the two sets of scores. These results indicate that participation in the 7E Model inquiry labs did indeed improve students' performance on the inquiry lab-based question. While other factors could have contributed to the increase, the 7E Model inquiry labs seem to have played a significant role by providing a structure that emphasized prior knowledge and facilitated students' construction of their own knowledge and transfer of it to similar and dissimilar situations.

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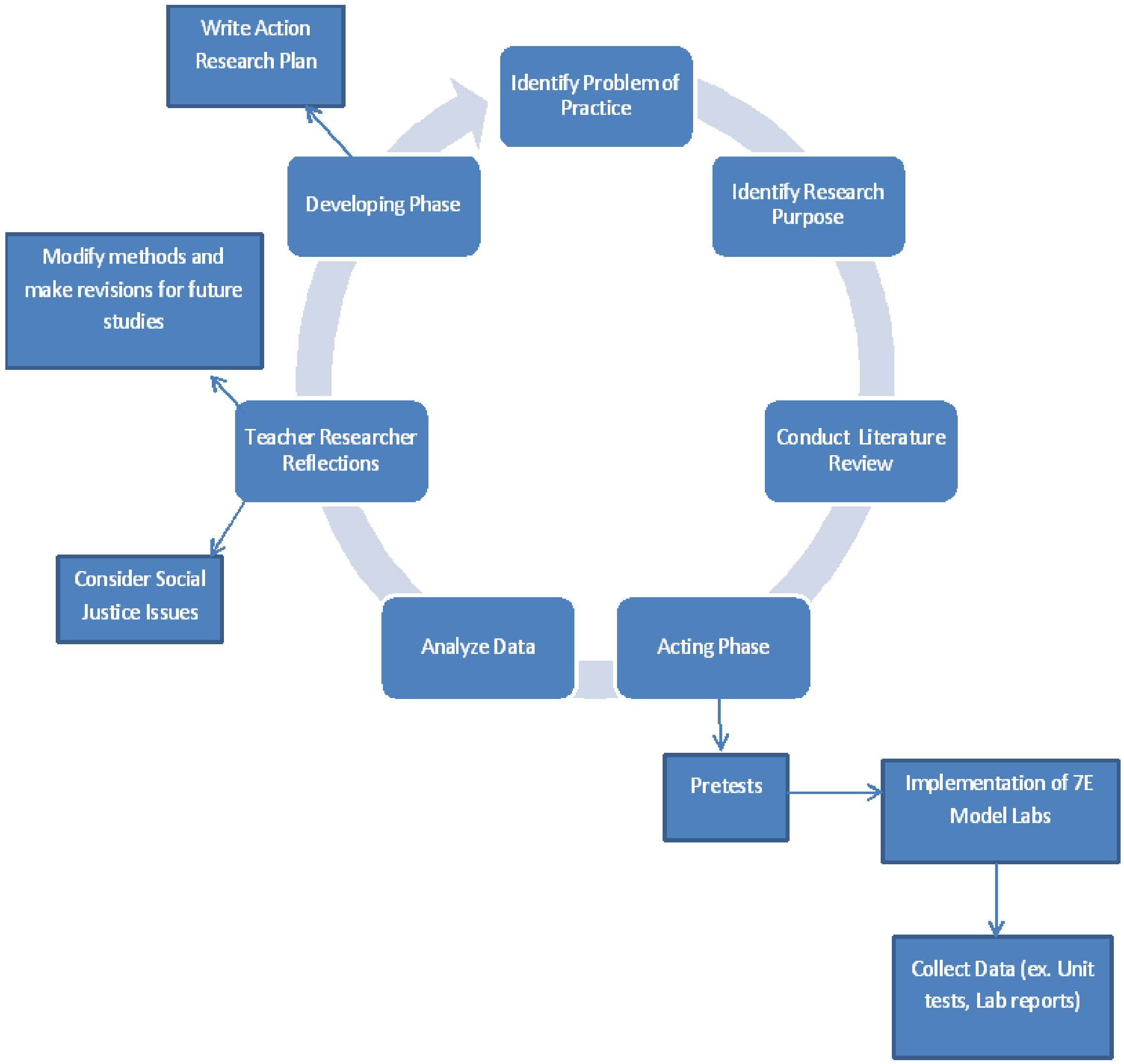
APPENDIX A: CONCEPTUAL FRAMEWORK



APPENDIX B: PRETEST WITH RUBRIC

The following is an inquiry lab based question used as the pretest for the study (College Board, 2006a, p. 6).

A world-class runner can complete a 100 m dash in about 10 s. Past studies have shown that runners in such a race accelerate uniformly for a time t_u and then run at constant speed for the remainder of the race. A world-class runner is visiting your physics class. You are to develop a procedure that will allow you to determine the uniform acceleration a_u and an approximate value of t_u for the runner in a 100 m dash. By necessity your experiment will be done on a straight track and include your whole class of eleven students.

a. By checking the line next to each appropriate item in the list below, select the equipment, other than the runner and the track that your class will need to do the experiment.

_____ Stopwatches _____Tape measures _____Rulers _____Tape

_____Metersticks _____Starter's pistol _____String _____Chalk

b. Outline the procedure that you would use to determine a_u and t_u, including a labeled diagram of the experimental setup. Use symbols to identify carefully what measurements you would make and include in your procedure how you would use each piece of the equipment you checked in part (a).

c. Outline the process of data analysis, including how you will identify the portion of the race that has uniform acceleration, and how you would calculate the uniform acceleration.

The following is the rubric for grading the pretest (College Board, 2006b, p. 5). The total point value for the question was 15. The rubric shows how students could earn the points and provides examples of good responses.

Two general approaches were used by most of the students.

Approach A: Spread the students out every 10 meters or so. The students each start their stopwatches as the runner starts and measure the time for the runner to reach their positions.

Analysis variant 1: Make a position vs. time graph. Fit the parabolic and linear parts of the graph and establish the position and time at which the parabola makes the transition to the straight line.

Analysis variant 2: Use the position and time measurements to determine a series of average velocities ($\upsilon_{avg} = \Delta x / \Delta t$) for the intervals. Graph these velocities vs. time to obtain a horizontal line and a line with positive slope. Establish the position and time at which the sloped and horizontal lines intersect.

Analysis variant 3: Use the position and time measurements to determine a series of average accelerations $\left(\Delta x = \upsilon_0 t - at^2/2\right)$. Graph these accelerations vs. time to obtain two horizontal lines, one with a nonzero value and one at zero acceleration. Establish the position and time at which the acceleration drops to zero.

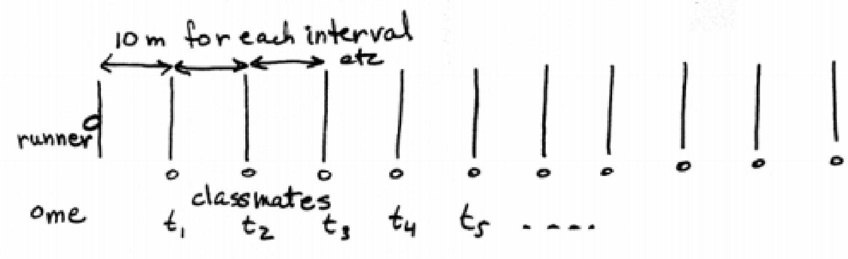
Approach B: Concentrate the students at intervals at the end of the run, in order to get a very precise value of the constant speed υ_f, or at the beginning in order to get a precise value for a_u. The total distance *D* is given by $D = \left(a_u t_u^2/2\right) + \upsilon_f \left(T - t_u\right)$, where *T* is the total measured run time. In addition, $\upsilon_f = a_u t_u$. These equations can be solved for a_u and t_u (if υ_f is measured directly) or υ_f and t_u (if a_u is measured directly). Students may have also defined and used distances, speeds, and times for the accelerated and constant-speed portions of the run in deriving these relationships.

(a) 2 points

For checking off a distance-measuring device and describing its use in part (b)	1 point
For checking off a stopwatch and describing its use in part (b)	1 point

(b) 6 points

Sample response



Use the tape measure and chalk to mark off the 100 meters in 10 meter lengths. Set a classmate with a stopwatch at marks as shown. Use the starter's pistol to signal the runner to run and the classmates to start their stopwatches. Each person turns off the stopwatch when the runner reaches his or her mark. You then have measurements of the time to reach each increment of 10 meters.

For taking distance measurements for 8 to 11 distinct fixed positions per run	1 point
For measuring time for the same 8 to 11 distinct fixed positions, consistent with the description of the experimental setup	1 point
For an experimental technique consistent with being able to determine the requested quantities	2 points
For a diagram of the experimental setup with clear labels and consistent with the technique described (awarded even if the technique is wrong)	1 point
For a technique that allows data for all positions to be taken in a single run	1 point

(c) 7 points

Approach A

For a clear and detailed explanation of the data analysis process	3 points
Note: This part of the solution was graded holistically and students could earn between 0 and 3 points depending on the clarity and completeness of their explanation.	
For equations or clear prose and use of the data to identify the two distinct regions of motion (constant acceleration and constant velocity)	1 point
For clearly and correctly identifying t_u	1 point
For clearly and correctly identifying a_u	1 point
For having the final answers correct and no incorrect statements or calculations among the correct ones	1 point

APPENDIX C: LAB REPORT RUBRIC

The following is an example of a lab rubric developed from the Science Practices. The rubric is for a 1D and 2D motion lab from the College Board lab manual (2015, p. 58).

Science Practice 4.2 – The student can design a plan for collecting data to answer a particular scientific question	
Proficient	Follows directions and adds a thorough description of a design plan (with clearly labeled diagrams), including predictions and assumptions.
Nearly Proficient	Follows directions and adds design plan that is mostly complete (with diagrams), and including assumptions.
On the Path to Proficiency	Follows directions but does not clearly indicate a plan for experimental design and procedure.
An Attempt	Misinterprets directions or does not indicate a viable plan for experimental design and procedure.
Science Practice 4.3 – The student can collect data to answer a particular scientific question.	
Proficient	Collects accurate data in a methodical way and presents data in an organized fashion.
Nearly Proficient	Collects mostly but not entirely accurate and complete data or the presentation of the data is somewhat disorganized.
On the Path to Proficiency	Collects somewhat inaccurate or incomplete data and the presentation of the data lacks organization.
An Attempt	Collects inaccurate or incomplete data and doesn’t provide any organization for this data.
Science Practice 5.1 – The student can analyze data to identify patterns or relationships.	
Proficient	Appropriately uses a velocity-time graph to determine the acceleration of the ball and position-time graphs to determine the speed of the ball on the track. Accurately graphs horizontal displacement vs. speed and interprets the results.
Nearly Proficient	Makes conclusions and calculations from data (perhaps graphs) but indicates no clear correlations.
On the Path to Proficiency	Requires significant assistance in analyzing velocity-time graphs or relating horizontal distance traveled for a projectile launched horizontally to the initial speed of the projectile.
An Attempt	Attempts to use incorrect features of a velocity-time graph to determine the acceleration of an object.

APPENDIX D: POSTTEST WITH RUBRIC

The following is the posttest question given to student participants as one of the free response questions on the unit test.

One day in lab, students were given a ping pong ball and asked to determine experimentally the value of acceleration due to gravity; they had access to standard laboratory equipment.

a. List all equipment needed to conduct the experiment. Tell how each piece of equipment will be used.
b. Using the equipment described in part a, write a clear, concise procedure detailing the steps that should be taken to gather the data necessary to determine an accurate answer to the lab question.
c. Using the data gathered in part b, describe the mathematical procedures that the students should take to determine the acceleration due to gravity.
d. List two improvements that could be made to improve and improve accuracy from the procedure in part b

The following is the rubric used to grade the posttest responses.

Part A – 2 points

1 pt – Student lists easily-found laboratory materials that could be used to conduct a viable experiment

1 pt – Student lists how the materials would be used in the experiment.

Example: *Materials: meterstick - will measure distance of falling ball, stopwatch – will measure the time it takes for the ball to hit the ground.*

Part B – 3 points

1 pt – Student developed a clear, concise procedure that is easily understood and could be reproduced.

1 pt – Within the procedure, student uses the materials and measurements that were described in part A. No additional materials are used besides those listed in part A.

1 pt – Student makes a point to reduce error, such as repeating the experiment several times and averaging the results.

Example – *Using the meterstick, one student will measure two meters upward. The student will then drop the ball from the 2 m height distance and start the stopwatch at the same time. The stopwatch will be stopped immediately when the ball hits the floor. The student should repeat the experiment several times and average the results.*

Part C – 2 points

1 pt – Correctly identifying any formulas needed to find the acceleration from gravity.

1 pt – For stating that the initial velocity was zero.

Example - $\Delta x = v_0 t + \frac{1}{2} a\, t^2$, where $v_0 = 0$

Part D – 2 points

2 pts – Student list at least two ways the experiment could be improved.

Example – *A video recorder could be used to spot exactly what time the ball landed to improve timing measurements. Students could drop the ball at varying distances multiple times to increase the number of trials and reduce error.*

APPENDIX E: LAB 2 STUDENT HANDOUT

Depicting Motion

PreLab:

Before you begin, sketch the following qualitative graphs in your lab notebook.

- Position vs. time for an object at rest
- Position vs. time for an object moving in the positive direction with a constant speed
- Position vs. time for an object moving in the negative direction with a constant speed
- Position vs. time for an object accelerating in the positive direction starting at rest

- Velocity vs. time for an object at rest
- Velocity vs. time for an object moving in the positive direction with a constant speed
- Velocity vs. time for an object moving in the negative direction with a constant speed
- Velocity vs. time for an object accelerating in the positive direction starting at rest

Compare your graphs with a partner. Do not change your initial graph, but comment if your graphs were different from your partners.

Lab:

Now hook up your cart to Sparkview. You should see both a position vs. time graph AND a velocity vs. time graph. Develop a reproducible procedure for the cart to do each of the following situations.

- Cart at rest
- Cart moving in the positive direction with a constant speed
- Cart moving in the negative direction with a constant speed
- Cart accelerating in the positive direction starting at rest

One “run” of the cart may encompass more than one of the above situations. If you do this, make sure you know where on the graph each example is demonstrated.

Print your graphs. Label them with the appropriate title. Attach them in your lab notebook.

Analysis Questions:

1. Explain the significance of the slope of a position vs. time graph. Include a discussion of positive and negative slope.
2. What type of motion is occurring when the slope of a position vs. time graph is zero? Is constant? Is changing?
3. What type of motion is occurring when the slope of a position vs. time graph is constant?

4. What type of motion is occurring when the slope of a velocity vs. time graph is zero? Is not zero?

Extension

Using the Graph Matching sheet provided, use your cart to create the graphs given. Answer the questions on the provided sheet and attach in your lab notebook.

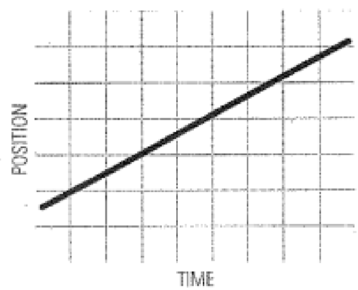
Lab Notebook Format:

- PreLab (with partner discussion comments)
- Procedure
- Attached printed graphs
- Answers to Analysis questions
- Extension sheet attached.

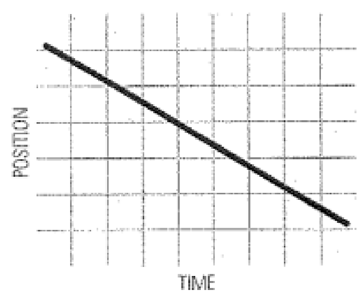
APPENDIX F: LAB TWO EXTENSION ACTIVITY

Describe the motion you used to match the position vs time graphs, using words like:
distance / increases / decreases / constant / speed / speeding up / slowing down

(A)



(B)



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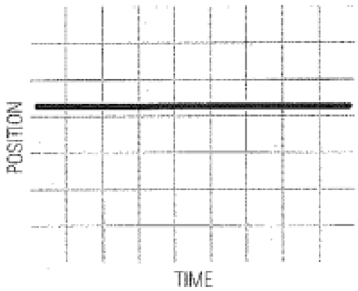
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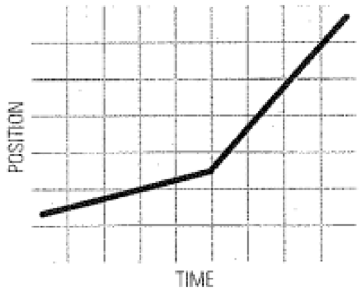
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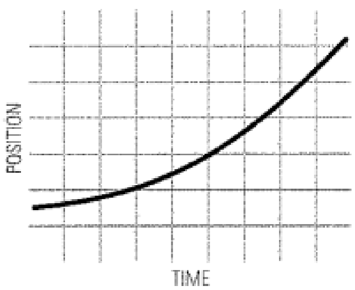
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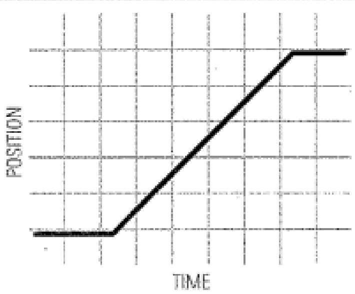
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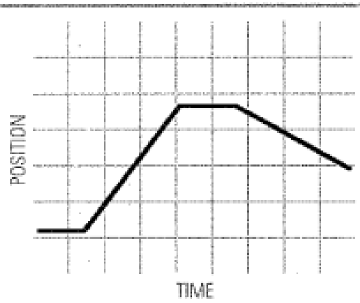
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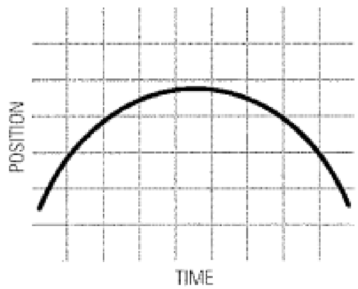

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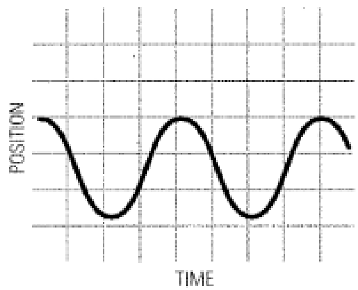

APPENDIX G: COMPLETE LIST OF ALL AP PHYSICS SCIENCE PRACTICES

(SPs)

SP 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems.	
1.1	The student can create representations and models of natural or man-made phenomena and systems in the domain.
1.2	The student can describe representations and models of natural or man-made phenomena and systems in the domain.
1.3	The student can refine representations and models of natural or man-made phenomena and systems in the domain.
1.4	The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
1.5	The student can re-express key elements of natural phenomena across multiple representations in the domain.
SP 2: The student can use mathematics appropriately.	
2.1	The student can justify the selection of a mathematical routine to solve problems.
2.2	The student can apply mathematical routines to quantities that describe natural phenomena.
2.3	The student can estimate numerically quantities that describe natural phenomena.
SP 3: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course.	
3.1	The student can pose scientific questions.
3.2	The student can refine scientific questions.
3.3	The student can evaluate scientific questions.
SP 4: The student can plan and implement data collection strategies in relation to a particular scientific question.	
4.1	The student can justify the selection of the kind of data needed to answer a particular scientific question.
4.2	The student can design a plan for collecting data to answer a particular scientific question
4.3	The student can collect data to answer a particular scientific question.
4.4	The student can evaluate sources of data to answer a particular scientific question.
SP 5: The student can perform data analysis and evaluation of evidence.	
5.1	The student can analyze data to identify patterns or relationships.
5.2	The student can refine observation and measurements based on data analysis.
5.3	The student can evaluate the evidence provided by data sets in relation to a particular scientific question.

SP 6: The student can work with scientific explanation and theories.	
6.1	The student can justify claims with evidence.
6.2	The student can construct explanations of phenomena based on evidence produced through scientific practices.
6.3	The student can articulate the reasons that scientific explanations and theories are refined or replaced.
6.4	The student can make claims and predication about natural phenomena based on scientific theories and models.
6.5	The student can evaluate alternative scientific explanations.
SP 7: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.	
7.1	The student can connect phenomena and models across spatial and temporal scales.
7.2	The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

(College Board, 2014a)