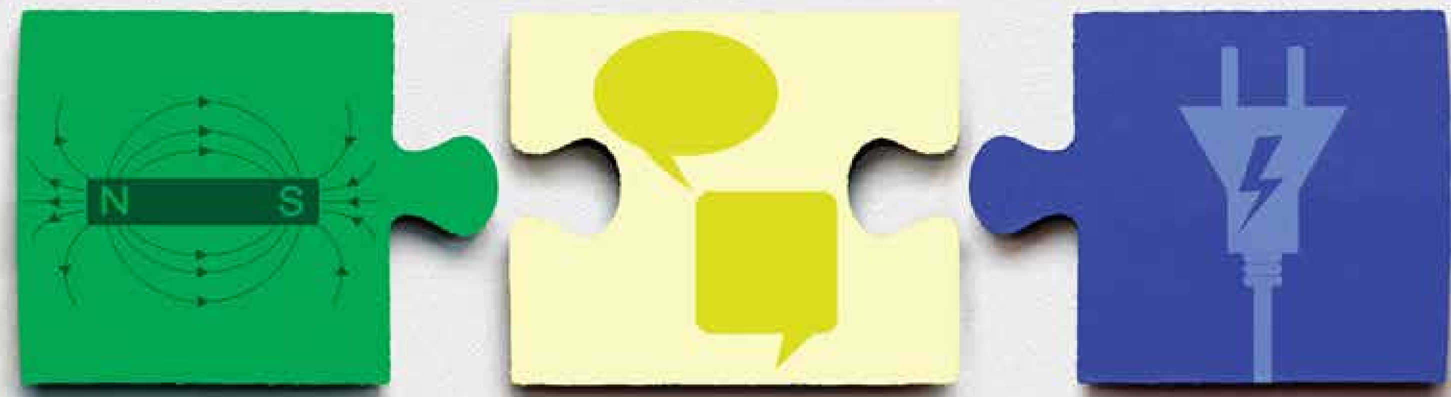
Argument-Driven Inquiry in PHYSICS

VOLUME 2



ELECTRICITY AND MAGNETISM LAB INVESTIGATIONS for GRADES 9–12

Todd L. Hutner, Victor Sampson, Adam LaMee, Daniel FitzPatrick, Austin Batson, and Jesus Aguilar-Landaverde

nsta Press
National Science Teaching Association

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PREFACE

A Framework for K–12 Science Education (NRC 2012; henceforth referred to as the *Framework*) and the *Next Generation Science Standards* (NGSS Lead States 2013; henceforth referred to as the *NGSS*) call for a different way of thinking about why we teach science and what we expect students to know by the time they graduate high school. As to why we teach science, these documents emphasize that schools need to

> ensure by the end of 12th grade, *all* students have some appreciation of the beauty and wonder of science; possess sufficient knowledge of science and engineering to engage in public discussions on related issues; are careful consumers of scientific and technological information related to their everyday lives; are able to continue to learn about science outside school; and have the skills to enter careers of their choice, including (but not limited to) careers in science, engineering, and technology. (NRC 2012, p. 1)

The *Framework* and the *NGSS* are based on the idea that students need to learn science because it helps them understand how the natural world works, because citizens are required to use scientific ideas to inform both individual choices and collective choices as members of a modern democratic society, and because economic opportunity is increasingly tied to the ability to use scientific ideas, processes, and habits of mind. From this perspective, it is important to learn science because it enables people to figure things out or to solve problems.

These two documents also call for a reappraisal of what students need to know and be able to do by the time they graduate from high school. Instead of teaching with the goal of helping students remember facts, concepts, and terms, the *Framework* and *NGSS* now prioritize helping students to become *proficient* in science. To be considered proficient in science, the *Framework* suggests that students need to understand four disciplinary core ideas (DCIs) in the physical sciences,[1] be able to use seven crosscutting concepts (CCs) that span the various disciplines of science, and learn how to participate in eight fundamental scientific and engineering practices (SEPs; called science and engineering practices in the *NGSS*). The DCIs are key organizing principles that have broad explanatory power within a discipline. Scientists use these ideas to explain the natural world. The CCs are ideas that are used across disciplines. These concepts provide a framework or a lens that people can use to explore natural phenomena. As a result, these concepts often influence what people focus on or pay attention to when they attempt to understand how something works or why something happens. The SEPs are the different activities that scientists and engineers engage in as they attempt to generate new concepts, models, theories, or laws that are both valid and reliable. All three of these dimensions of science are

1 Throughout this book, we use the term *physical sciences* when referring to the disciplinary core ideas of the *Framework* (in this context the term refers to a broad collection of scientific fields), but we use the term *physics* when referring to courses at the high school level (as in the title of the book).

important. Students not only need to know about the DCIs, CCs, and SEPs but also must be able to use all three dimensions at the same time to figure things out or to solve problems. These important DCIs, CCs, and SEPs are summarized in Figure 1.

FIGURE 1

The three dimensions of science in *A Framework for K–12 Science Education* and the *Next Generation Science Standards*

Science and engineering practices	Crosscutting concepts
1. Asking Questions and Defining Problems 2. Developing and Using Models 3. Planning and Carrying Out Investigations 4. Analyzing and Interpreting Data 5. Using Mathematics and Computational Thinking 6. Constructing Explanations and Designing Solutions 7. Engaging in Argument From Evidence 8. Obtaining, Evaluating, and Communicating Information	1. Patterns 2. Cause and Effect: Mechanism and Explanation 3. Scale, Proportion, and Quantity 4. Systems and System Models 5. Energy and Matter: Flows, Cycles, and Conservation 6. Structure and Function 7. Stability and Change
Disciplinary core ideas for the physical sciences* • PS1: Matter and Its Interactions • PS2: Motion and Stability: Forces and Interactions • PS3: Energy • PS4: Waves and Their Applications in Technologies for Information Transfer	

* These disciplinary core ideas represent one of the four subject areas in the *Framework* and the *NGSS;* the other subject areas are life sciences, earth and space sciences, and engineering, technology, and applications of science.

Source: Adapted from NRC 2012 and NGSS Lead States 2013.

To help students become proficient in science in ways described by the National Research Council in the *Framework*, teachers will need to use new instructional approaches that give students an opportunity to use the three dimensions of science to explain natural phenomena or develop novel solutions to problems. This is important because traditional instructional approaches, which were designed to help students "learn about" the concepts, theories, and laws of science rather than help them learn how to "figure out" how or why things work, were not created to foster the development of science proficiency inside the classroom. To help teachers make this instructional shift, this book provides 17 laboratory investigations designed using an innovative approach to lab instruction called argument-driven inquiry (ADI). This approach is designed to promote and support three-dimensional instruction inside classrooms by giving students an opportunity to use DCIs, CCs, and SEPs to construct and critique claims about how things work or why things happen. The lab activities described in this book will also enable students to develop the disciplinary-based literacy skills outlined in the *Common Core State Standards* for English language arts (NGAC and CCSSO 2010) because ADI gives students an opportunity to give presentations to their peers, respond to audience questions and critiques, and then write, evaluate, and revise reports as part of each lab. In addition, these investigations will help students learn many of the mathematical ideas and practices outlined in the *Common Core State Standards* for mathematics (NGAC and CCSSO 2010). Use of these labs, as a result, can help teachers align their teaching with current recommendations for improving classroom instruction in science and for making physics more meaningful for students.

The labs included in this book all focus on the topics of electricity and magnetism. Thus, these labs primarily focus on two of the four physical sciences DCIs from the *NGSS* that are outlined in Figure 1 (although some labs do align with other DCIs as well). These two DCIs are Motion and Stability: Forces and Interactions (PS2) and Energy (PS3). The other two DCIs for physical sciences from the *NGSS* are the focus of other books in the ADI series. All the labs, however, are well aligned with at least two of the seven CCs and seven of the eight SEPs. In addition, the labs in this book are well aligned with the big ideas and science practices for Advanced Placement (AP) Physics 1, 2, and C: Electricity and Magnetism (see Figure 2, p. xii). These labs, as a result, can be used in a wide range of physics courses, including, but not limited to, a conceptual physics course for 9th or 10th graders that is aligned with the *NGSS,* an introductory physics course for juniors or seniors, or even an AP Physics 1, 2, or C: Electricity and Magnetism course.

Finally, this book is the second volume in the ADI Physics series. The first volume has 23 labs focused on mechanics. The structure of the lab handouts is the same in both volumes, making the classroom use of both lab manuals seamless from a structural point of view.

FIGURE 2

Selected big ideas and science practices for AP Physics 1 and 2 and the content areas and science practices for AP Physics C: Electricity and Magnetism

AP Physics 1 and 2 big ideas	AP Physics 1 and 2 science practices
1. Systems: Objects and systems have properties such as mass and charge. Systems may have internal structure. 2. Fields: Fields existing in space can be used to explain interactions. 3. Force Interactions: The interactions of an object with other objects can be described by forces. 4. Change: Interactions between systems can result in changes in those systems. 5. Conservation: Changes that occur as a result of interactions are constrained by conservation laws.	1. Modeling: Use representations and models to communicate scientific phenomena and solve scientific problems. 2. Mathematical Routines: Use mathematics appropriately. 3. Scientific Questioning: Engage in scientific questioning to extend thinking or to guide investigations. 4. Experimental Methods: Plan and implement data collection strategies in relation to a particular scientific question. 5. Data Analysis: Perform data analysis and evaluation of evidence. 6. Argumentation: Work with scientific explanations and theories. 7. Making Connections: Connect and relate knowledge across various scales, concepts, and representations in and across domains.

AP Physics C: Electricity and Magnetism content areas

- Electrostatics
- Conductors, capacitors, dielectrics
- Electric circuits
- Magnetic fields
- Electromagnetism

AP Physics C: Electricity and Magnetism laboratory objectives

1. Visual representations
2. Question and method
3. Representing data and phenomena
4. Data analysis
5. Theoretical relationships
6. Mathematical routines
7. Argumentation

Source: Adapted from *https://apcentral.collegeboard.org/pdf/ap-physics-1-course-and-exam-description.pdf?course=ap-physics-1-algebra-based* (for AP Physics 1); *https://apcentral.collegeboard.org/pdf/ap-physics-2-course-and-exam-description.pdf?course=ap-physics-2-algebra-based* (for AP Physics 2); *https://apcentral.collegeboard.org/pdf/ap-physics-c-electricity-and-magnetism-course-and-exam-description.pdf?course=ap-physics-c-electricity-and-magnetism* (for AP Physics C: Electricity and Magnetism).

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INTRODUCTION

The Importance of Helping Students Become Proficient in Science

The current aim of science education in the United States is for *all* students to become proficient in science by the time they finish high school. *Science proficiency*, as defined by Duschl, Schweingruber, and Shouse (2007), consists of four interrelated aspects. First, it requires an individual to know important scientific explanations about the natural world, to be able to use these explanations to solve problems, and to be able to understand new explanations when they are introduced to the individual. Second, it requires an individual to be able to generate and evaluate scientific explanations and scientific arguments. Third, it requires an individual to understand the nature of scientific knowledge and how scientific knowledge develops over time. Finally, and perhaps most important, an individual who is proficient in science should be able to participate in scientific practices (such as planning and carrying out investigations, analyzing and interpreting data, and arguing from evidence) and communicate in a manner that is consistent with the norms of the scientific community. These four aspects of science proficiency include the knowledge and skills that all people need to have in order to be able to purse a degree in science, be prepared for a science-related career, and participate in a democracy as an informed citizen.

This view of science proficiency serves as the foundation for the *Framework* (NRC 2012) and the *NGSS* (NGSS Lead States 2013). Unfortunately, our educational system was not designed to help students become proficient in science. As noted in the *Framework*,

> K–12 science education in the United States fails to [promote the development of science proficiency], in part because it is not organized systematically across multiple years of school, emphasizes discrete facts with a focus on breadth over depth, and does not provide students with engaging opportunities to experience how science is actually done. (p. 1)

Our current science education system, in other words, was not designed to give students an opportunity to learn how to use scientific explanations to solve problems, generate or evaluate scientific explanations and arguments, or participate in the practices of science. Our current system was designed to help students learn facts, vocabulary, and basic process skills because many people think that students need a strong foundation in the basics to be successful later in school or in a future career. This vision of science education defines *rigor* as covering more topics and *learning* as the simple acquisition of new ideas or skills.

Our views about what counts as rigor, therefore, must change to promote and support the development of science proficiency. Instead of using the number of different topics covered in a course as a way to measure rigor in our schools, we must start to measure rigor in terms of the number of opportunities students have to use the ideas of science as a way to make sense of the world around them. Students, in other words, should be expected to learn how to use the core ideas of science as conceptual tools to plan and carry out investigations, develop and evaluate explanations, and question how we know what we know. A rigorous course, would thus be one where students are expected to do science, not just learn about science.

Our views about what learning is and how it happens must also change to promote and support the development of science proficiency. Rather than viewing learning as a simple process where people accumulate more information over time, learning needs to be viewed as a personal and social process that involves "people entering into a different way of thinking about and explaining the natural world; becoming socialized to a greater or lesser extent into the practices of the scientific community with its particular purposes, ways of seeing, and ways of supporting its knowledge claims" (Driver et al. 1994, p. 8). Learning, from this perspective, requires a person to be exposed to the language, the concepts, and the practices of science that makes science different from other ways of knowing. This process requires input and guidance about "what counts" from people who are familiar with the goals of science, the norms of science, and the ways things are done in science. Thus, learning is dependent on supportive and informative interactions with others.

Over time, people will begin to appropriate and use the language, the concepts, and the practices of science as their own when they see how valuable they are as a way to accomplish their own goals. Learning therefore involves seeing new ideas and ways of doing things, trying out these new ideas and practices, and then adopting them when they are useful. This entire process, however, can only happen if teachers provide students with multiple opportunities to use scientific ideas to solve problems, to generate or evaluate scientific explanations and arguments, and to participate in the practices of science inside the classroom. This is important because students must have a supportive and educative environment to try out new ideas and practices, make mistakes, and refine what they know and what they do before they are able to adopt the language, the concepts, and the practices of science as their own.

A New Approach to Teaching Science

We need to use different instructional approaches to create a supportive and educative environment that will enable students to learn the knowledge and skills they need to become proficient in science. These new instructional approaches will need to give students an opportunity to learn how to "figure out" how things work or why things happen. Rather than simply encouraging students to learn about the facts, concepts, theories, and laws of science, we need to give students more opportunities to develop explanations for natural phenomena and design solutions to problems. This emphasis on "figuring things out" instead of "learning about things" represents a big change in the way we will need to teach science at all grade levels. To figure out how things work or why things happen in a way that is consistent with how science is actually done, students must do more than hands-on activities. Students must learn how to use disciplinary core ideas (DCIs), crosscutting concepts (CCs), and science and engineering practices (SEPs) to develop explanations and solve problems (NGSS Lead States 2013; NRC 2012).

A DCI is a scientific idea that is central to understanding a variety of natural phenomena. An example of a DCI in physics is Conservation of Energy and Energy Transfer. This DCI not only explains the relationship between the power dissipated by resistors in series and in parallel, but also explains why a magnet moving through a coil of wire feels a force resisting the motion.

CCs are those concepts that are important across the disciplines of science; there are similarities and differences in the treatment of the CC in each discipline. The CCs can be used as a lens to help people think about what to focus on or pay attention to during an investigation. For example, one of the CCs from the *Framework* is Energy and Matter: Flows, Cycles, and Conservation. This CC is important in many different fields of study. Physicists use this CC to study mechanics, thermodynamics, electricity, and magnetism. Biologists use this CC to study cells, growth and development, and ecosystems. It is important to highlight the centrality of this idea, and other CCs, for students as we teach the subject-specific DCIs.

SEPs describe what scientists do to investigate the natural world. The practices outlined in the *Framework* and the *NGSS* explain and extend what is meant by *inquiry* in science and the wide range of activities that scientists engage in as they attempt to generate and validate new ideas. Students engage in practices to build, deepen, and apply their knowledge of DCIs and CCs. The SEPs include familiar aspects of inquiry, such as Asking Questions and Defining Problems, Planning and Carrying Out Investigations, and Analyzing and Interpreting Data. More important, however, the SEPs include other activities that are at the core of doing science: Developing and Using Models, Constructing Explanations and Designing Solutions, Engaging in Argument From Evidence, and Obtaining, Evaluating, and Communicating Information. All of these SEPs are important to learn, because there is no single scientific method that all scientists must follow; scientists engage in different practices, at different times, and in different orders depending on what they are studying and what they are trying to accomplish at that point in time.

This focus on students using DCIs, CCs, and SEPs during a lesson is called *three-dimensional instruction* because students have an opportunity to use all three dimensions of science to understand how something works, to explain why something happens, or to develop a novel solution to a problem. When teachers use three-dimensional instruction inside their classrooms, they encourage students to develop or use conceptual models, design investigations, develop explanations, share and critique ideas, and argue from evidence, all of which allow students to develop the knowledge and skills they need to be proficient in science (NRC 2012). Current research suggests that all students benefit from three-dimensional instruction because it gives all students more voice and choice during a lesson and it makes the learning process inside the classroom more active and inclusive (NRC 2012).

We think the school science laboratory is the perfect place to integrate three-dimensional instruction into the science curriculum. Well-designed lab activities can provide opportunities for students to participate in an extended investigation where they can not only use one or more DCIs to understand how something works, to explain why something happens, or to develop a novel solution to a problem but also use several different CCs and SEPs during the same lesson. A teacher, for example, can give his or her students an opportunity to investigate the factors influencing the strength of an electromagnet. The teacher can then encourage them to use what they know about Types of Interactions (a DCI) and Ampère's law (an important idea in electricity and magnetism) and their understanding of Cause and Effect and of Scale, Proportion, and Quantity (two different CCs) to plan and carry out an investigation to figure out how the electromagnet works. During this investigation they must ask questions, analyze and interpret data, use mathematics, develop a model, argue from evidence, and obtain, evaluate, and communicate information (six different SEPs). Using multiple DCIs, CCs, and SEPs at the same time is important because it creates a classroom experience that parallels how science is done. This, in turn, gives all students who participate in a school science lab activity an opportunity to deepen their understanding of what it means to do science and to develop science-related identities. In the following section, we will describe how to promote and support the development of science proficiency during school science labs through three-dimensional instruction.

How School Science Labs Can Help Foster the Development of Science Proficiency Through Three-Dimensional Instruction

Science instruction in the 1980s and 1990s followed a similar sequence in most U.S. classrooms (Hofstein and Lunetta 2004; NRC 2005). This sequence began with the teacher introducing students to an important concept or principle through direct instruction, usually by giving a lecture about it or by assigning a chapter from a textbook to read. Next, the students were given a hands-on laboratory experience. As defined by the NRC (2005, p. 3), "[l]aboratory experiences provide opportunities for students to interact directly with the material world … using the tools, data collection techniques, models, and theories of science." The purpose of these laboratory experiences or "labs" was to help students understand the concept or principle that was introduced to them earlier by giving them a concrete experience with it. To ensure that students "got the right result" during the lab and that the lab actually illustrated, confirmed, or verified the target concept or principle, the teacher usually provided students with a step-by-step procedure to follow and a data table to fill out. Students were then asked to answer a set of analysis questions to ensure that everyone "reached the right conclusion" based on the data they collected during the lab. The lab experience would then end with the teacher going over what the students should have done during the hands-on activity, what they should have observed, and what answers they should have given in response to the analysis questions. This final review step was done to ensure that the students "learned what they were supposed to have learned" from the hands-on activity and was usually done, once again, through whole-class direct instruction.

Classroom-based research, however, suggests that this type of laboratory experience does little to help students learn key concepts. The National Research Council (2005, p. 5), for example, conducted a synthesis of several different studies that examined what students learn from this type of lab and found that "research focused on the goal of student mastery of subject matter indicates that typical laboratory experiences are no more or less effective than other forms of science instruction (such as reading, lectures, or discussion)." This finding was troubling when this report was released because, as noted earlier, the main goal of this type of lab was to help students understand an important concept or principle by giving them a hands-on and concrete experience with it. In addition, this type of lab does little to help students learn how to plan and carry out investigations or analyze and interpret data because students have no voice or choice during the activity. Students are expected to simply follow a set of directions rather than think about what data they will collect, how they will collect it, and what they will need to do to analyze it once they have it. This type of traditional or "cookbook" lab also can lead to misunderstanding about the nature of scientific knowledge and how this knowledge is developed over time due to the emphasis on following procedure and getting the right results.

Many science teachers started using more inquiry-based labs in the late 1990s and early 2000s to help address the shortcomings of more traditional cookbook lab activities. Inquiry-based lab experiences that are consistent with the definition of *inquiry* found in *National Science Education Standards* (NRC 1996) and *Inquiry and the National Science Education Standards* (NRC 2000) share five key features:

1. Students need to answer a scientifically oriented question.

2. Students must collect data or use data collected by someone else.
3. Students formulate an answer to the question based on their analysis of the data.
4. Students connect their answer to some theory, model, or law.
5. Students communicate their answer to the question to someone else.

Many teachers also changed the traditional sequence of science instruction when they started using more inquiry-based labs. Rather than introducing students to an important concept or principle through direct instruction and then having students do a cookbook lab to demonstrate or confirm it, they used an inquiry-based lab as a way to introduce students to a new concept or principle and then gave them a formal definition of it (NRC 2012). This type of sequence is often described as an "activity before concept" approach to instruction because the activity provides a concrete and shared experience for students that a teacher can use to help explain a concept.

Although inquiry-based labs give students much more voice and choice, especially when compared with more traditional cookbook approaches, they do not do as much as they could do to promote the development of science proficiency. Teachers tend to use inquiry-based labs as a way to help students learn about a new idea rather than as a way to help students learn how to figure out how things work or why they happen. Students, as a result, rarely have an opportunity to learn how to use DCIs, CCs, and SEPs to develop explanations or solve problems. In addition, inquiry-based labs in the early 2000s rarely gave students an opportunity to participate in the full range of scientific practices. These inquiry-based labs were often designed so students had many opportunities to learn how to ask questions, plan and carry out investigations, and analyze and interpret data but few opportunities to learn how to participate in the practices that focus on how new ideas are developed, shared, refined, and eventually validated within the scientific community. These important practices include developing and using models, constructing explanations, arguing from evidence, and obtaining, evaluating, and communicating information (Duschl, Schweingruber, and Shouse 2007; NRC 2005). Most inquiry-based labs that were used in the 1990s and 2000s also did not give students an opportunity to improve their science-specific literacy skills. Students were rarely expected to read, write, and speak in a scientific manner because the focus of these labs was learning about content and how to collect and analyze data in science, not how to propose, critique, and revise ideas.

Changing the focus and nature of inquiry-based labs so they are more consistent with three-dimensional instruction can help address these issues. To implement such a change, teachers will not only have to focus on using DCIs, CCs, and SEPs during a lab but will also need to emphasize "how we know" in physics (i.e., how new knowledge is generated and validated) equally with "what we know" about electricity, magnetism, and conservation (i.e., the theories, laws, and unifying concepts). We have found that one way to make this shift in focus is to make the practice of arguing from evidence or scientific argumentation the central feature of all lab activities so this practice drives decision making during an investigation. We define *scientific argumentation* as the process of proposing, supporting, evaluating, and refining claims based on evidence (Sampson, Grooms, and Walker 2011). The *Framework* (NRC 2012) provides a good description of the role argumentation plays in science:

> Scientists and engineers use evidence-based argumentation to make the case for their ideas, whether involving new theories or designs, novel ways of collecting data, or interpretations of evidence. They and their peers then attempt to identify weaknesses and limitations in the argument, with the ultimate goal of refining and improving the explanation or design. (p. 46)

When teachers make the practice of arguing from evidence the central focus of lab activities, students have more opportunities to learn how to construct and support scientific knowledge claims through argument (NRC 2012). Students, as a result, have more opportunities to learn how scientific ideas are generated, shared, and refined over time. For example, when students know that they have to support a new idea through argument, they begin to think more about the goal of an investigation (e.g., identify a pattern, test a potential causal relationship, confirm a relationship) and the criteria that other people will use to determine if the new idea is valid or acceptable when they are ready to share it. Students are then able to make better decisions about what to do during an investigation (e.g., what data to collect, how to collect it, and how to analyze it given the goal of the investigation) based on what they are trying to do and their understanding of what will be convincing to others. They also have more opportunities to learn how to evaluate the ideas and arguments made by others. Students, as a result, learn how to read, write, and speak in scientific manner because they need to be able to propose and support their claims when they share them and evaluate, challenge, and refine the claims made by others.

We developed the argument-driven inquiry (ADI) instructional model (Sampson and Gleim 2009; Sampson, Grooms, and Walker 2009, 2011) as a way to change the focus and nature of labs so they are consistent with three-dimensional instruction. ADI gives students an opportunity to learn how to use DCIs, CCs, and SEPs to figure out how things work or why things happen. This instructional approach also places scientific argumentation at the cener of all lab activities. ADI lab investigations, as a result, make lab activities more authentic and educative for students and thus help teachers promote and support the development of science proficiency. This instructional model reflects current theories about how people learn science (NRC 1999, 2005, 2008, 2012) and is also based on what is known about how to engage students in argumentation and other important scientific practices (Erduran and

Jimenez-Aleixandre 2008; McNeill and Krajcik 2008; Osborne, Erduran, and Simon 2004; Sampson and Clark 2008; Sampson, Enderle, and Grooms 2013). We explain the stages of ADI and how each stage works in Chapter 1.

How to Use This Book

The intended audience of the book is primarily practicing high school physics teachers. We recognize that physics teachers teach many different types of physics courses. Some courses are conceptual in nature, some are algebra based, and some are calculus based. We understand how teaching these different types of physics courses results in different challenges and needs. We have therefore designed the laboratory investigations included in this book to meet the needs of teachers who teach a wide range of courses. Some labs, for example, require students to determine a general relationship or trend and do not require a lot of mathematics. These labs can be used in a physics course that is more conceptual in nature. Other labs, in contrast, require students to develop a mathematical model that they can use to explain and predict changes in the energy of electromagnetic systems. These labs are intended for students in Advanced Placement (AP) Physics C: Electricity and Magnetism who are concurrently enrolled in or have successfully completed an introductory calculus course. The majority of the labs, however, were written for an algebra-based physics course. These labs require some algebra, such as determining a mathematical relationship between two variables (which is often, but not always, a linear relationship). All of the labs were designed to give students an opportunity to learn how to use DCIs, CCS, and SEPs to figure things out.

As we wrote the labs for this book, we kept in mind the fact that physics is often a two-year program of study in many school districts. Students usually take Physics I in 11th grade along with Algebra II and then in 12th grade take AP Physics 1, AP Physics 2, or AP Physics C (mechanics is a first-semester topic, and electricity and magnetism is a second-semester topic) along with either AP Statistics or AP Calculus. We have therefore aligned all the labs in this book with the *NGSS* performance expectations and the AP Physics 1 and 2 and AP Physics C: Electricity and Magnetism learning objectives so teachers can use these labs in either an introductory physics course or an AP physics course. We believe it is important to focus on three-dimensional instruction in both contexts because students need to learn how to use DCIs, CCs, and SEPs to figure out how things work or why things happen. Lab instruction is also a major component of the AP physics curriculum. In AP Physics 1 and 2 and AP Physics C: Electricity and Magnetism, the College Board recommends that at least 25% of instructional time be devoted to laboratory experiences. These experiences should therefore do more than demonstrate, illustrate, or verify a target concept; they should also promote and support the development of science proficiency.

One of the recent advances in physics education has been the development of physics-specific equipment that students can use during investigations, such as probeware and video cameras for collecting data, and data analysis software, including video analysis software, which enables students to explore the data they collect during an investigation. We recognize that while some physics teachers work in settings where this equipment is readily available and funds are easily accessed to purchase additional equipment, many others do not work in such settings. Many of the labs included in this book can be conducted in lower-tech ways, by using batteries and wires that can be purchased at a local hardware store. Sometimes, however, a lab may not be worth doing if students do not have access to specific equipment. When equipment and/or materials are optional, the materials list table in the Teacher Notes indicates this, and we note in the Lab Handout that students "may also consider using" optional equipment. If the equipment and/or materials are not available to you, when introducing the lab just let students know they do not have the option to use them. We also recognize that the initial cost to purchase some equipment may be high, especially when compared with the equipment needed for a chemistry or biology course. However, the replacement costs for these labs are minimal because the equipment should last several years, particularly when compared with biology or chemistry courses, which require annual replacement of chemicals or specimens.

Finally, we want to make clear that we do not expect teachers to use every lab in this book over the course of an academic year. We wrote this book to support the teaching of electricity and magnetism, which is a topic found in the second-semester curriculum of an introductory physics course. Concepts included under the topic of electricity and magnetism include electrostatics; electric currents, capacitors, resistors and circuits; and magnetic fields and electromagnetism. We suggest that teachers who use this book choose two or three labs for each topic.

There are two types of labs included in the book. The first type of lab is called an introduction lab, and the second type of lab is called an application lab. Introduction labs should be used at the beginning of a unit. These labs often require little formal knowledge of the target concept before students begin the investigation. For example, the lab on Coulomb's law (Lab 1) is an introduction lab and does not require students to know the relationship between the charge on two objects and the forces between them, but students are still expected to use a DCI (Types of Interactions) and two CCs (Patterns and Structure and Function) to figure out the relationship between the amount of charge on an electroscope and the separation distance between the two pieces of foil. After students complete the lab, teachers can use other means of instructional to formalize the laws and formulas related to Coulomb's law. Application labs, on the other hand, are designed to come at the end of a unit. The intent of these labs is to give students an opportunity to apply their knowledge of a specific concept they learned about earlier in the course along with their knowledge of DCIs and CCs to a novel situation. For example, Lab 16 requires students to use their knowledge about Faraday's law, Lenz's law, and the Biot-Savart law to explain why a magnet dropped through a conducting tube will fall with a rate less than the acceleration due to gravity.

Organization of This Book

This book is divided into five sections. Section 1 includes two chapters: the first chapter describes the ADI instructional model, and the second chapter describes the development of the ADI lab investigations and provides an overview of what is included with each investigation. Sections 2–4 contain the 17 lab investigations. Each investigation includes three components:

- Teacher Notes, which provides information about the purpose of the lab and what teachers need to do to guide students through it.
- Lab Handout, which can be photocopied and given to students at the beginning of the lab. It provides the students with a phenomenon to investigate, a guiding question to answer, and an overview of the DCIs and CCs that students can use during the investigation.
- Checkout Questions, which can be photocopied and given to students at the conclusion of the lab activity as an optional assessment. The Checkout Questions consist of items that target students' understanding of the DCIs, the CCs, and the nature of scientific knowledge (NOSK) and the nature of scientific inquiry (NOSI) concepts addressed during the lab.

Section 5 consists of five appendixes:

- Appendix 1 contains several standards alignment matrixes that can be used to assist with curriculum or lesson planning.
- Appendix 2 provides an overview of the CCs and the NOSK and NOSI concepts that are a focus of the lab investigations. This information about the CCs and the NOSK and NOSI concepts is included as a reference for teachers.
- Appendix 3 provides several options (in tabular format) for implementing an ADI investigation over multiple 50-minute class periods.
- Appendix 4 provides options for investigation proposals, which students can use as graphic organizers to plan an investigation. The proposals can be photocopied and given to students during the lab.

- Appendix 5 provides two versions of a peer-review guide and teacher scoring rubric (one for high school and one for AP), which can also be photocopied and given to students.

Changes From ADI Physics Volume 1

We worked to make this volume in the ADI Physics series consistent in structure and tone with Volume 1, which covers mechanics. There are, however, some minor changes we want to point out. The first is the modified structure of the hints in the "Getting Started" section of the Lab Handout for students. Specifically, we have written our hints to emphasize the CCs related to the lab investigation. This should aid teachers in implementing the three-dimensional approach advocated by the NGSS.

Second, since the publication of Volume 1, the College Board has redesigned the AP Physics courses, including AP Physics 1 and 2 and AP Physics C: Electricity and Magnetism. This redesign and revision resulted in new standards, which we include in the standards alignment section of the Teacher Notes for each lab. As part of the revision, the College Board has also updated the scientific practices included in the courses. In the standards matrix in Appendix 1 (p. 403), we have aligned these labs with the new science practices for AP Physics 1 and 2 and AP Physics C: Electricity and Magnetism. As such, the science practices listed for the AP Physics courses are different from those listed in Volume 1.

Third, we have made some changes in how we address NOSK and NOSI. Researchers in science and science education who study the nature of science and nature of scientific inquiry have made updated recommendations for important NOSI concepts. In light of that, in this volume, we no longer include the NOSI concept of "the role of imagination and creativity in science." We also added the following NOSI concepts: (1) how scientists investigate questions about the natural or material world and (2) the assumptions made by scientists about order and consistency in nature.

Safety Practices in the Science Laboratory

It is important for all of us to do what we can to make school science laboratory experiences safer for everyone in the classroom. We recommend four important guidelines to follow. First, we need to have proper safety equipment such as, but not limited to, fume hoods, fire extinguishers, eye wash, and showers in the classroom or laboratory. Second, we need to ensure that students use appropriate personal protective equipment (PPE; e.g., sanitized indirectly vented chemical-splash goggles, chemical-resistant aprons and nonlatex gloves) during all components of lab activities (i.e., setup, hands-on investigation, and takedown). At a minimum, the PPE we provide for students to use must meet the ANSI/ISEA Z87.1D3 standard. Third, we must review and comply with all safety policies and procedures, including but not limited to appropriate chemical management, that have been established by our place of employment. Finally, and perhaps most important, we all need to adopt safety standards and better professional safety practices and enforce them inside the classroom or laboratory.

We provide safety precautions for each investigation and recommend that all teachers follow them to provide a safer learning experience inside the classroom. The safety precautions associated with each lab investigation are based, in part, on the use of the recommended materials and instructions, legal safety standards, and better professional safety practices. Selection of alternative materials or procedures for these activities may jeopardize the level of safety and therefore is at the user's own risk.

We also recommend that you encourage students to read the National Science Teaching Association's *High School Safety Acknowledgment Form* before allowing them to work in the laboratory for the first time. This document is available online at *http://static.nsta.org/pdfs/SafetyAcknowledgmentForm-HighSchool.pdf*. Your students and their parent(s) or guardian(s) should then sign the document to acknowledge that they understand the safety procedures that must be followed during a school science laboratory experience.

Remember that a lab includes three parts: (1) setup, which includes setting up the lab and preparing the materials; (2) the actual investigation; and (3) the cleanup, also called the *takedown*. The safety procedures and PPE we recommend for each investigation apply to all three parts.

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Teacher Notes

Lab 17. Electromagnetism: Why Does the Battery-and-Magnet "Car" Roll When It Is Placed on a Sheet of Aluminum Foil?

Purpose

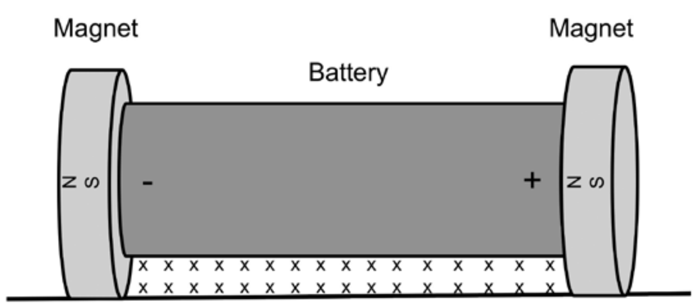
The purpose of this lab is for students to *apply* what they know about the disciplinary core idea (DCI) of Types of Interactions (PS2.B) from the *NGSS* and about electromagnetism by having them develop a model to explain the movement of the battery-and-magnet "car." In addition, this lab can be used to help students understand two big ideas from AP Physics: (a) fields existing in space can be used to explain interactions and (b) the interactions of an object with other objects can be described by forces. This lab also gives students an opportunity to learn about the crosscutting concepts (CCs) of (a) Systems and System Models and (b) Stability and Change from the *NGSS*. As part of the explicit and reflective discussion, students will also learn about (a) how scientific knowledge changes over time and (b) how scientists use different methods to answer different types of questions.

Underlying Physics Concepts

To understand the physics underlying this lab, we start by recognizing that the magnets and the aluminum foil are electric conductors. Thus, when the battery-and-magnet car (henceforth referred to as just "the car") is placed on the aluminum foil, a closed circuit is formed. This leads to a current moving through the magnets and the foil. According to the Biot-Savart Law, the flow of current will create a magnetic field around the current. The Biot-Savart law also states that for a conducting loop carrying current, a magnetic field will be established inside the loop. Figure 17.1 shows the creation of the magnetic field created by the electric current flowing through the loop composed of the battery, magnets, and aluminum foil.

FIGURE 17.1

The magnetic field created by an electric current from the closed circuit formed when the battery-and-magnet car is placed on the aluminum foil



To determine the direction of the magnetic field, we can use a right-hand rule for the magnetic field created by a current-carrying wire to determine that the magnetic field created by the current will be pointing into the page. Notice that the magnetic field will only be established inside the loop of current. This is important for understanding the motion of the car.

Before placing the car on the aluminum foil, a magnetic field also existed around the car due to the presence of the two magnets on either end of the car. Figure 17.2 shows the magnetic field running from right to left, because the north pole of both magnets is pointing toward the left. We use dashed lines for the magnetic field due to the two permanent magnets in Figures 17.2 and 17.3 to avoid confusion with other lines in the figure. Because both magnets point in the same direction, a relatively uniform magnetic field is established around the battery.

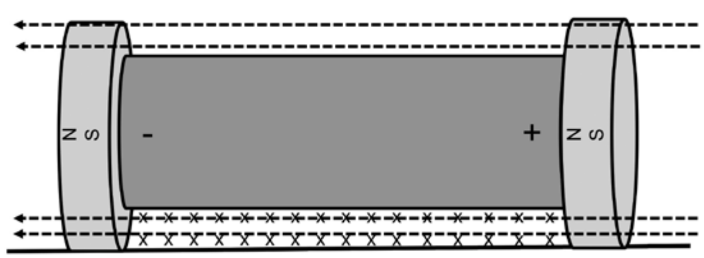
FIGURE 17.2

The magnetic field around the battery due to the magnets on the ends of the battery. The north pole of both magnets faces to the left.

Thus, when we place the car down on the aluminum foil, we have two magnetic fields—one established by the magnets themselves (Figure 17.2) and one from the magnetic field created by the flow of the current (Figure 17.1). Figure 17.3 shows the combination of magnetic fields surrounding the battery when we place the car on the aluminum foil.

FIGURE 17.3

The magnetic fields when the car is placed on the aluminum foil



Notice how there is an additional magnetic field below the battery due to the flow of current but not above the battery. This field will interact with the field established by magnets themselves and create an unbalanced force. This is the force that causes the car to move.

It is important to note that the force exerted on the car exists only below the battery, not above the battery. This force then creates a torque on the magnets, as the force is exerted some radial distance away from their center. It is the torque on the lower half of the magnets that causes the car to move rotationally. It is also important to note that the direction the magnets face is the same. In Figure 17.3, the north pole of both magnets is to the left. This is important because it creates a uniform magnetic field from the magnets. If the magnets face in opposite directions, the magnetic field underneath the battery due to the magnets will not be uniform. This will result in different torques on each wheel. When students conduct the lab, it is OK to let them place the magnets in opposite directions, because this will lead to the car not moving and then they will need to establish why the car does not move under these circumstances.

Once the car starts moving, the physics becomes increasingly complex because the current will also be moving down the aluminum foil as the car moves and the wheels of the car will be rotating. Both magnetic fields will be moving, so students will need to account for additional factors. To mathematically represent this situation, complex sets of differential equations are necessary—mathematics that are beyond the scope of an introductory high school physics course and the AP physics courses. For this reason, we have chosen to present only a conceptual description of the underlying physics for this lab.

Students may establish quantitative relationships between the rotational acceleration of the car and the voltage of the battery and strength of the magnet. As the voltage of the battery increases, the angular acceleration of the car will also increase. This is because a higher voltage will create a larger current, leading to a greater magnetic field inside the loop. Similarly, strong magnets will create a larger magnetic field surrounding the battery. An increase in either magnetic field will lead to an increase in the torque acting on the wheels.

Timeline

The instructional time needed to complete this lab investigation is 170–230 minutes. Appendix 3 (p. 421) provides options for implementing this lab investigation over several class periods. Option C (230 minutes) should be used if students are unfamiliar with scientific writing, because this option provides extra instructional time for scaffolding the writing process. You can scaffold the writing process by modeling, providing examples, and providing hints as students write each section of the report. Option C should also be used if you are introducing students to digital sensors, the data analysis software, and/or the video analysis software. Option D (170 minutes) should be used if students are familiar with scientific writing and have developed the skills needed to write an investigation report on their own. In option D, students complete stage 6 (writing the investigation report) and stage 8 (revising the investigation report) as homework.

Materials and Preparation

The materials needed to implement this investigation are listed in Table 17.1. The equipment can be purchased from a science supply company such as Flinn Scientific, PASCO, Vernier, or Ward's Science. We also suggest companies that specialize in magnets, such as K&J Magnetics, as a source for the magnets for this lab. Video analysis software can be purchased from Vernier (Logger *Pro*) or PASCO (SPARKvue or Capstone). These companies also have apps that can be used on Apple- or Android-based tablets and cell phones. We recommend consulting with your school's information technology coordinator to determine the best option for your students.

TABLE 17.1

Materials list for Lab 17

Item	Quantity
Consumables	
AA batteries	2 per group
C batteries	2 per group
D batteries	2 per group
Duct tape	As needed
Aluminum foil	As needed
Wax paper	As needed
Butcher paper	As needed
Equipment and other materials	
Safety glasses with side shields or safety goggles	1 per student
Disc-shaped neodymium magnets	2 per group
Disc-shaped ceramic magnets (ideally, the same size as the neodymium magnets)	2 per group
Voltmeter	1 per group
Ammeter	1 per group
Multimeter	1 per group
Meterstick	1 per group

Continued

Table 17.1 (*continued*)

Item	Quantity
Stopwatch	1 per group
Electronic or triple beam balance	1 per group
Electronic pole identifier	1 per group
Investigation Proposal A (optional)	1 per group
Whiteboard, 2'× 3'*	1 per group
Lab Handout	1 per student
Peer-review guide and teacher scoring rubric	1 per student
Checkout Questions	1 per student
Equipment for digital interface measurements and video analysis (optional)	
Digital interface with USB or wireless connections	1 per group
Magnetic field sensor	1 per group
Current measurement sensor	1 per group
Voltage measurement sensor	1 per group
Video camera	1 per group
Computer or tablet with appropriate data analysis and video analysis software installed	1 per group

* As an alternative, students can use computer and presentation software such as Microsoft PowerPoint or Apple Keynote to create their arguments.

Use of video analysis software is optional, but using this software will allow students to more precisely measure the movement of the car.

You should conduct a demonstration with two magnets connected to a battery and then placed on a sheet of aluminum foil before students begin their investigation. Learn how to conduct the demonstration before the lab begins; the demonstration provides the context for this lab investigation, so you want to make sure it works correctly.

Be sure to use a set routine for distributing and collecting the materials during the lab investigation. One option is to set up the materials for each group at each group's lab station before class begins. This option works well when there is a dedicated section of the classroom for lab work and the materials are large and difficult to move. A second option is to have all the materials on a table or cart at a central location. You can then assign a member of each group to be the "materials manager." This individual is responsible for collecting all the materials his or her group needs from the table or cart during class and for returning all the materials at the end of the class. This option works well when the materials are small and easy to move (such as magnets, wire, and bulbs). It also makes it easy to inventory the materials at the end of the class before students leave for the day.

Safety Precautions and Laboratory Waste Disposal

Remind students to follow all normal lab safety rules. In addition, tell students to take the following safety precautions:

1. Wear sanitized safety glasses with side shields or safety goggles during lab setup, hands-on activity, and takedown.
2. Never put consumables in their mouth.
3. Wire and other metals with electric current flowing through them may get hot. Use caution when handling components of a closed circuit.
4. Us caution in working with sharp objects (e.g., wires) because they can cut or puncture skin.
5. Neodymium magnets should be at least 30 cm away from sensitive electronic and storage devices. These strong magnets could affect the functioning of pacemakers and implanted heart defibrillators.
6. Big magnets have a very strong attractive force. Unsafe handling could cause jamming of fingers or skin in between magnets. This may lead to contusions and bruises.
7. Neodymium magnets are brittle. Colliding magnets could crack, and sharp splinters could be catapulted away for several meters and injure eyes.
8. Wash their hands with soap and water when they are done collecting the data.

Batteries may be stored for future use. When batteries need replacing, dispose of old batteries according to manufacturer's recommendations.

Topics for the Explicit and Reflective Discussion

Reflecting on the Use of Core Ideas and Crosscutting Concepts During the Investigation

Teachers should begin the explicit and reflective discussion by asking students to discuss what they know about the core ideas they used during the investigation. The following are some important concepts related to the core ideas of types of interactions and electromagnetism that students need to use to explain the motion of the car:

- A field associates a value of some physical quantity with every point in space. Fields are a model that physicists use to describe interactions that occur over a distance. Fields permeate space, and objects experience forces due to their interaction with a field.

- Objects can interact with multiple fields at once, and the vector sum of the fields will determine the motion of the object.
- A current flowing through a conducting material will create a magnetic field around the material. If the current is flowing through a loop, a magnetic field is established inside the loop. The magnitude of the field is proportional to the magnitude of the current in the conducting material/loop. The direction of the magnetic field can be established using a right-hand rule.
- Torque is a measure of force applied perpendicular to a lever arm multiplied by the distance from the point of rotation. Torque is directly proportional to angular acceleration.

To help students reflect on what they know about electromagnetism, fields, and forces, we recommend showing them two or three images using presentation software that help illustrate these important ideas. You can then ask the students the following questions to encourage them to share how they are thinking about these important concepts:

1. What do we see going on in this image?
2. Does anyone have anything else to add?
3. What might be going on that we can't see?
4. What are some things that we are not sure about here?

You can then encourage students to think about how CCs played a role in their investigation. There are at least two CCs that students need to use to determine why the car moves: (a) Systems and System Models and (b) Stability and Change (see Appendix 2 [p. 417] for a brief description of these CCs). To help students reflect on what they know about these CCs, we recommend asking them the following questions:

1. In this investigation, you had to define your system under study. What assumptions did you have to make about the system in order to conduct your investigation?
2. You made models of your system in order to explain how it works. What types of models did you use during this investigation?
3. Your models allowed you to identify factors that affect the rates of change in your system. Why is it important to identify the factors that affect rates of change in systems?
4. What rates of change did you model during this investigation? What additional information would you have needed to model your system using a function?

You can then encourage the students to think about how they used all these different concepts to help answer the guiding question and why it is important to use these ideas to help justify their evidence for their final arguments. Be sure to remind your students to explain why they included the evidence in their arguments and make the assumptions underlying their analysis and interpretation of the data explicit in order to provide an adequate justification of their evidence.

Reflecting on Ways to Design Better Investigations

It is important for students to reflect on the strengths and weaknesses of the investigation they designed during the explicit and reflective discussion. Students should therefore be encouraged to discuss ways to eliminate potential flaws, measurement errors, or sources of uncertainty in their investigations. To help students be more reflective about the design of their investigation and what they can do to make their investigations more rigorous in the future, you can ask them the following questions:

1. What were some of the strengths of the way you planned and carried out your investigation? In other words, what made it scientific?
2. What were some of the weaknesses of the way you planned and carried out your investigation? In other words, what made it less scientific?
3. What rules can we make, as a class, to ensure that our next investigation is more scientific?

Reflecting on the Nature of Scientific Knowledge and Scientific Inquiry

This investigation can be used to illustrate two important concepts related to the nature of scientific knowledge and the nature of scientific inquiry: (a) how scientific knowledge changes over time and (b) how scientists use different methods to answer different types of questions (see Appendix 2 [p. 417] for a brief description of these concepts). Be sure to review these concepts during and at the end of the explicit and reflective discussion. To help students think about these concepts in relation to what they did during the lab, you can ask them the following questions:

1. Scientific knowledge can and does change over time. Can you tell me why it changes?
2. Can you work with your group to come up with some examples of how scientific knowledge related to electricity and magnetism has changed over time? Be ready to share in a few minutes.
3. There is no universal step-by-step scientific method that all scientists follow. Why do you think there is no universal scientific method?
4. Think about what you did during this investigation. How would you describe the method you used to understand why the battery-and-magnet car starts rolling? Why would you call it that?

You can also use presentation software or other techniques to encourage your students to think about these concepts. You can show examples of how our thinking about electricity and magnetism has changed over time (and continues to change as scientists search for a grand unified theory) and ask students to discuss what they think led to those changes. You can show one or more images of a "universal scientific method" that misrepresent the nature of scientific inquiry (see, e.g., *https://commons.wikimedia.org/wiki/File:The_Scientific_Method_as_an_Ongoing_Process.svg*) and ask students why each image is *not* a good representation of what scientists do to develop scientific knowledge. You can also ask students to suggest revisions to the image that would make it more consistent with the way scientists develop scientific knowledge. Be sure to remind your students that it is important for them to understand what counts as scientific knowledge and how that knowledge develops over time in order to be proficient in science.

Hints for Implementing the Lab

- Allowing students to design their own procedures for collecting data gives students an opportunity to try, to fail, and to learn from their mistakes. However, you can scaffold students as they develop their own procedure by having them fill out an investigation proposal. The proposals provide a way for you to offer students hints and suggestions without telling them how to do it. You can also check the proposals quickly during a class period. For this lab we suggest using Investigation Proposal A.
- Learn how to set up the battery-and-magnet car and how to use the equipment before the lab begins. If you set up the magnets improperly, the car will not move. It is also important for you to know how to use the equipment so you can help students when technical issues arise.
- When setting up the demonstration to introduce the lab, make sure that the north poles of the magnets face in the same direction. This establishes a uniform magnetic field around the battery and will result in the car moving. If the magnets' north poles face in opposite directions, the car will not move.
- Allow the students to become familiar with the equipment as part of the tool talk before they begin to design their investigation. Give them 5–10 minutes to examine the equipment and materials before they begin designing their investigations. This gives students a chance to see what they can and cannot do with the equipment.
- The resistance in the circuit comprised of the battery, magnets, and aluminum foil is minimal, so the battery will deplete rather quickly. We suggest providing fresh batteries to each group as they begin to collect data. Because of this, we also suggest using the investigation proposal guide before providing groups with batteries as a way to minimize students' undirected use of the batteries.

- The performance of the magnet car will be improved by using flat aluminum foil. If the foil is wrinkled, this will cause the current to flow in random directions and not directly underneath the battery.
- If you do not have an electronic pole identifier for each group, you can identify the north pole on the magnets prior to class and then place a small sticker on the north pole of each magnet.
- In the lab materials, we have included butcher paper and wax paper, because students must show that the car is not just interacting with Earth's magnetic field to produce the motion. We anticipate that most groups will not initially think of this possibility. This is a good opportunity to discuss initial assumptions and how we often need to run experiments to rule out other possible explanations.
- If students want to test the relationship between the voltage of the battery and the angular acceleration, you can either give them batteries with higher voltage (e.g., 3V batteries, which are sold by Duracell and Energizer) or have them tape two 1.5V batteries together in series.
- Be sure to allow students to go back and re-collect data at the end of the argumentation session. Students often realize that they made numerous mistakes when they were collecting data as a result of their discussions during the argumentation session. The students, as a result, will want a chance to re-collect data, and the re-collection of data should be encouraged when time allows. This also offers an opportunity to discuss what scientists do when they realize a mistake is made inside the lab.

If students use digital interface measurement equipment and video analysis

- We suggest allowing students to familiarize themselves with the sensors, data analysis software, and video analysis software before they finalize the procedure for the investigation, especially if they have not used such software previously. This gives students an opportunity to learn how to work with the software and to improve the quality of the data they collect and the video they take.
- Remind students to follow the user's guide to correctly connect any sensors to avoid damage to lab equipment.
- Remind students to hold the video camera as still as possible. Any movement of the camera will introduce error into their analysis. If using actual camcorders, we recommend using a tripod to hold the camera steady. If students are using a camera on a cell phone or tablet, we recommend using a table to help steady the camera.
- Remind students to place a meterstick in the same field of view as the motion they are capturing with the video camera. Also, the meterstick should be approximately the same distance from the camera as the motion. Most video analysis software requires the user to define a scale in the video (this allows the software to establish distances and, subsequently, other variables dependent on distance and displacement).

Connections to Standards

Table 17.2 highlights how the investigation can be used to address specific performance expectations from the *NGSS;* learning objectives from AP Physics 1 and 2; learning objectives from AP Physics C: Electricity and Magnetism; *Common Core State Standards for English Language Arts* (*CCSS ELA*); and *Common Core State Standards for Mathematics* (*CCSS Mathematics*).

TABLE 17.2

Lab 17 alignment with standards

***NGSS* performance expectation**	• HS-PS2-5: Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.
AP Physics 1 and AP Physics 2 learning objectives	• 1.A.5.2: Construct representations of how the properties of a system are determined by the interactions of its constituent substructures. • 2.D.1.1: Apply mathematical routines to express the force exerted on a moving charged object by a magnetic field. • 3.C.3.2: Plan a data collection strategy appropriate to an investigation of the direction of the force on a moving electrically charged object caused by a current in a wire in the context of a specific set of equipment and instruments, and analyze the resulting data to arrive at a conclusion. • 4.E.1.1: Use representations and models to qualitatively describe the magnetic properties of some materials that can be affected by magnetic properties of other objects in the system.
AP Physics C: Electricity and Magnetism learning objectives	• CNV-8.B.a: Derive the expression for the magnitude of magnetic field on the axis of a circular loop of current or a segment of a circular loop. • CNV-8.C.a: Explain Ampère's Law and justify the use of the appropriate Amperian loop for current-carrying conductors of different shapes such as straight wires, closed circular loops, conductive slabs, or solenoids. • ACT-4.A.a: Determine if a net force or net torque exists on a conductive loop in a region of changing magnetic field.
Literacy connections (*CCSS ELA*)	• *Reading*: Key ideas and details, craft and structure, integration of knowledge and ideas • *Writing*: Text types and purposes, production and distribution of writing, research to build and present knowledge, range of writing • *Speaking and listening:* Comprehension and collaboration, presentation of knowledge and ideas

Continued

Table 17.2 (*continued*)

Mathematics connections (*CCSS Mathematics*)	• *Mathematical practices*: Make sense of problems and persevere in solving them, reason abstractly and quantitatively, construct viable arguments and critique the reasoning of others, model with mathematics, use appropriate tools strategically, attend to precision • *Number and quantity*: Reason quantitatively and use units to solve problems, represent and model with vector quantities, perform operations on vectors • *Algebra*: Interpret the structure of expressions, understand solving equations as a process of reasoning and explain the reasoning, solve equations and inequalities in one variable, represent and solve equations and inequalities graphically • *Functions*: Understand the concept of a function and use function notation; interpret functions that arise in applications in terms of the context; analyze functions using different representations; construct and compare linear, quadratic, and exponential models and solve problems; interpret expressions for functions in terms of the situation they model • *Statistics and probability*: Summarize, represent, and interpret data on two categorical and quantitative variables; interpret linear models; make inferences and justify conclusions from sample surveys, experiments, and observational studies

Lab Handout

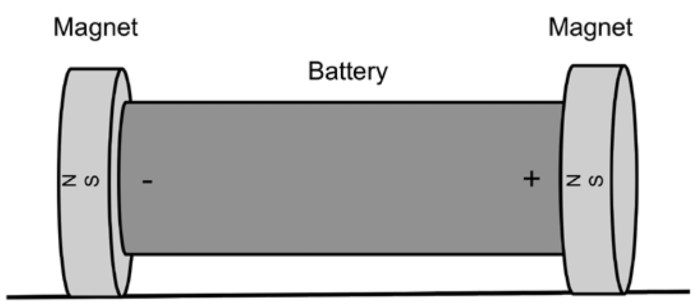
Lab 17. Electromagnetism: Why Does the Battery-and-Magnet "Car" Roll When It Is Placed on a Sheet of Aluminum Foil?

Introduction

Children of all ages often like to play with magnets. Simple combinations of magnets can lead to complex behavior—for example, pushing the north poles of two magnets together and letting go causes the two magnets to move away from each other. Your teacher is going to demonstrate another complex phenomenon where two magnets are connected to a battery and then placed on a sheet of aluminum foil. Figure L17.1 shows the setup of the magnets and battery.

FIGURE L17.1

A battery-and-magnet "car"



Electricity and magnetism were viewed as two different things prior to the 19th century. The work of scientists including André-Marie Ampère (1775–1836), Hans Christian Ørsted (1777–1851), and Michael Faraday (1791–1867), among others, led to the eventual development of a *unified theory of electromagnetism* (Giancoli 2005). One of the fundamental postulates of the unified theory of electromagnetism is that an electric current will produce a magnetic field surrounding the current-carrying object (often a wire, but not always). Another important idea of the unified theory of electromagnetism is that a change in the magnetic field near an electrical conductor will cause a current to flow through the conductor. Other findings related to the unified theory of electromagnetism have shown that a moving point charge (such as an electron) produces a magnetic field and that a magnetic field exerts a force on a charged object moving through the magnetic field. These findings are important for the working of electrical infrastructure and many modern electronic devices, such as magnetic resonance imaging (MRI) machines.

Besides underlying the working of many of our modern technologies, knowledge of electromagnetism can also help us explain many other observed phenomena and inform the way we design tools. Our understanding of magnetic fields helps explain why two north poles will push each other apart. And our understanding of electric currents informs the design of power strips, leading to power strips being wired in parallel and not in series.

Your Task

Use what you know about electromagnetism, forces, rotational motion, systems and system models, and stability and change to design and carry out an investigation to develop a model that explains the movement of the battery-and-magnets "car." Your model should allow you to make predictions about variables such as the total mass of the car, the voltage of the battery, and the strength of the magnets. There may be other variables that influence the movement of the car that your model will want to account for as well.

The guiding question of this investigation is, ***Why does the battery-and-magnet "car" roll when it is placed on a sheet of aluminum foil?***

Materials

You may use any of the following materials during your investigation:

Consumables
- AA batteries
- C batteries
- D batteries
- Duct tape
- Aluminum foil
- Wax paper
- Butcher paper

Equipment
- Safety glasses with side shields or goggles (required)
- Neodymium magnets
- Ceramic magnets
- Voltmeter
- Ammeter
- Multimeter
- Meterstick
- Stopwatch
- Electronic or triple beam balance

If you have access to the following equipment, you may also consider using a video camera, a digital magnetic field sensor, and a digital current sensor and/or digital voltage sensor with an accompanying interface and a computer or tablet. Also, your teacher may give you an electronic pole identifier, which will allow you to determine the north and south poles of your magnets if they are not already labeled.

Safety Precautions

Follow all normal lab safety rules. In addition, take the following safety precautions:

1. Wear sanitized safety glasses with side shields or safety goggles during lab setup, hands-on activity, and takedown.
2. Never put consumables in your mouth.

3. Wire and other metals with electric current flowing through them may get hot. Use caution when handling components of a closed circuit.
4. Us caution in working with sharp objects (e.g., wires) because they can cut or puncture skin.
5. Neodymium magnets should be at least 30 cm away from sensitive electronic and storage devices. These strong magnets could affect the functioning of pacemakers and implanted heart defibrillators.
6. Big magnets have a very strong attractive force. Unsafe handling could cause jamming of fingers or skin in between magnets. This may lead to contusions and bruises.
7. Neodymium magnets are brittle. Colliding magnets could crack, and sharp splinters could be catapulted away for several meters and injure eyes.
8. Sharp splinters could be catapulted away for several meters and injure eyes.
9. Wash your hands with soap and water when you are done collecting the data.

Investigation Proposal Required? ☐ Yes ☐ No

Getting Started

To answer the guiding question, you will need to design and carry out an investigation to determine the mechanisms underlying the movement of the car. You will need to develop a conceptual model that allows you to describe the motion of the car and to predict if a particular arrangement of the battery and magnets will result in the car moving when placed on a certain surface. Furthermore, your model should also allow you to predict how a change in the arrangement of the battery and magnets will result in a change to the motion of the car. Before you can design your investigation, however, you must determine what type of data you need to collect, how you will collect it, and how you will analyze it.

To determine *what type of data you need to collect*, think about the following questions:

- What are the boundaries and components of the system?
- How do the components of the system interact with each other?
- When is this system stable and under which conditions does it change?
- How could you keep track of changes in this system quantitatively?
- What forces, if any, are acting on the objects in the system?
- Which factor(s) might control rates of change in this system?

To determine *how you will collect the data*, think about the following questions:

- What scale or scales should you use when you take your measurements?

- How will you make sure that your data are of high quality (i.e., how will you reduce error)?
- How will you keep track of and organize the data you collect?
- What are the boundaries of this phenomenon or system?
- What are the components of this phenomenon or system and how do they interact?
- How will you measure change over time during your investigation?

To determine *how you will analyze the data*, think about the following questions:

- What type of calculations, if any, will you need to make?
- What types of patterns might you look for as you analyze your data?
- What type of table or graph could you create to help make sense of your data?
- How could you use mathematics to describe a change over time?

Connections to the Nature of Scientific Knowledge and Scientific Inquiry

As you work through your investigation, you may want to consider

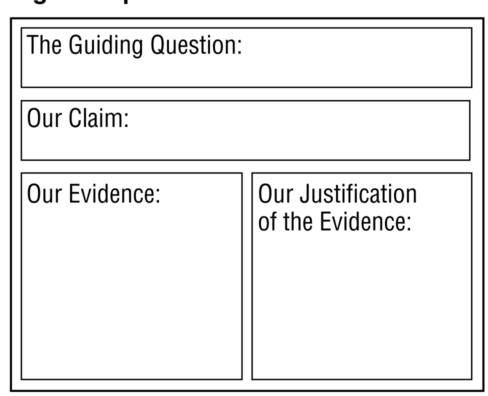
- how scientific knowledge changes over time, and
- how scientists use different methods to answer different types of questions.

Initial Argument

Once your group has finished collecting and analyzing your data, your group will need to develop an initial argument. Your initial argument needs to include a claim, evidence to support your claim, and a justification of the evidence. The *claim* is your group's answer to the guiding question. The *evidence* is an analysis and interpretation of your data. Finally, the *justification* of the evidence is why your group thinks the evidence matters. The justification of the evidence is important because scientists can use different kinds of evidence to support their claims. Your group will create your initial argument on a whiteboard. Your whiteboard should include all the information shown in Figure L17.2.

FIGURE L17.2

Argument presentation on a whiteboard



Argumentation Session

The argumentation session allows all of the groups to share their arguments. One or two members of each group will stay at the lab station to share that group's argument, while the other members of the group go to the other lab stations to listen to and critique the other arguments. This is similar to what scientists do when they propose, support, evaluate, and refine new ideas during a poster session at a conference. If you are presenting your group's argument, your goal is to share your ideas and answer questions. You should also keep a record of the critiques and suggestions made by your classmates so you can use this feedback to make your initial argument stronger. You can keep track of specific critiques and suggestions for improvement that your classmates mention in the space below.

Critiques about our initial argument and suggestions for improvement:

If you are critiquing your classmates' arguments, your goal is to look for mistakes in their arguments and offer suggestions for improvement so these mistakes can be fixed. You should look for ways to make your initial argument stronger by looking for things that the other groups did well. You can keep track of interesting ideas that you see and hear during the argumentation in the space below. You can also use this space to keep track of any questions that you will need to discuss with your team.

Interesting ideas from other groups or questions to take back to my group:

Once the argumentation session is complete, you will have a chance to meet with your group and revise your initial argument. Your group might need to gather more data or design a way to test one or more alternative claims as part of this process. Remember, your goal at this stage of the investigation is to develop the best argument possible.

Report

Once you have completed your research, you will need to prepare an investigation report that consists of three sections. Each section should provide an answer to the following questions:

1. What question were you trying to answer and why?
2. What did you do to answer your question and why?
3. What is your argument?

Your report should answer these questions in two pages or less. This report must be typed, and any diagrams, figures, or tables should be embedded into the document. Be sure to write in a persuasive style; you are trying to convince others that your claim is acceptable or valid!

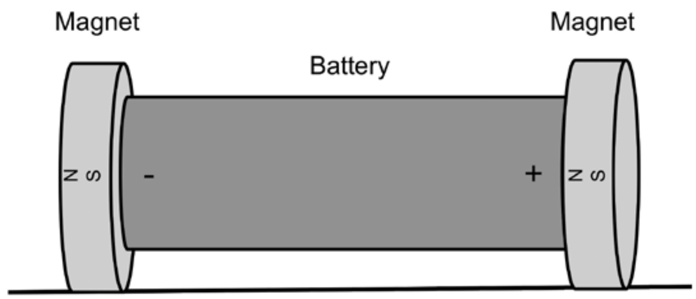
Reference

Giancoli, D. G. 2005. *Physics: Principles with applications.* 6th ed. Upper Saddle River, NJ: Pearson.

Checkout Questions

Lab 17. Electromagnetism: Why Does the Battery-and-Magnet "Car" Roll When It Is Placed on a Sheet of Aluminum Foil?

Use the picture below to answer questions 1–3.



1. The magnet car is set up so that two magnets of equal strength **B** have the north pole facing to the left. When placed on a piece of aluminum foil, they begin rolling. If the two magnets were replaced with magnets of equal mass but with a magnet field strength of 3**B** with both north poles facing to the left, how would this affect the motion of the car?

   a. The car would roll slower.
   b. The car would roll faster.
   c. The car would not roll at all.
   d. The car would roll the same.

   How do you know?

2. Assume now that the magnet on the right is flipped, so that its north pole faces to the right. How would this affect the motion of the car?

    a. The car would roll slower.
    b. The car would roll faster.
    c. The car would not roll at all.
    d. The car would roll the same.

    How do you know?

3. Assume now that the magnets both have the north poles facing to the left. However, the magnet on the left has a strength of **B** while the magnet on the right has a strength of 3**B**. How would this affect the movement of the car?

    How do you know?

4. Scientific knowledge does not change—that is why we still learn about Newton's laws over 300 years after he published them.

   a. I agree with this statement.
   b. I disagree with this statement.

   Explain your answer, using examples from this investigation and at least one other investigation you have conducted.

5. Scientists have always used the same method for investigating questions regarding the interaction between electricity and magnetism.

   a. I agree with this statement.
   b. I disagree with this statement.

   Explain your answer, using examples from this investigation and at least one other investigation you have conducted.

6. Why is it useful to understand factors that influence rates of change in systems? In your answer, be sure to use examples from this investigation and at least one other investigation you have conducted.

7. Why is it useful to assume that you are studying a closed system during an investigation? In your answer, be sure to include examples from your investigation about the battery-and-magnet car and one other investigation you have carried out.

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Page numbers printed in **boldface** type refer to figures or tables.

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