VOL. 2

Uncovering Student Ideas in Physical Science

39 NEW Electricity and Magnetism Formative Assessment Probes

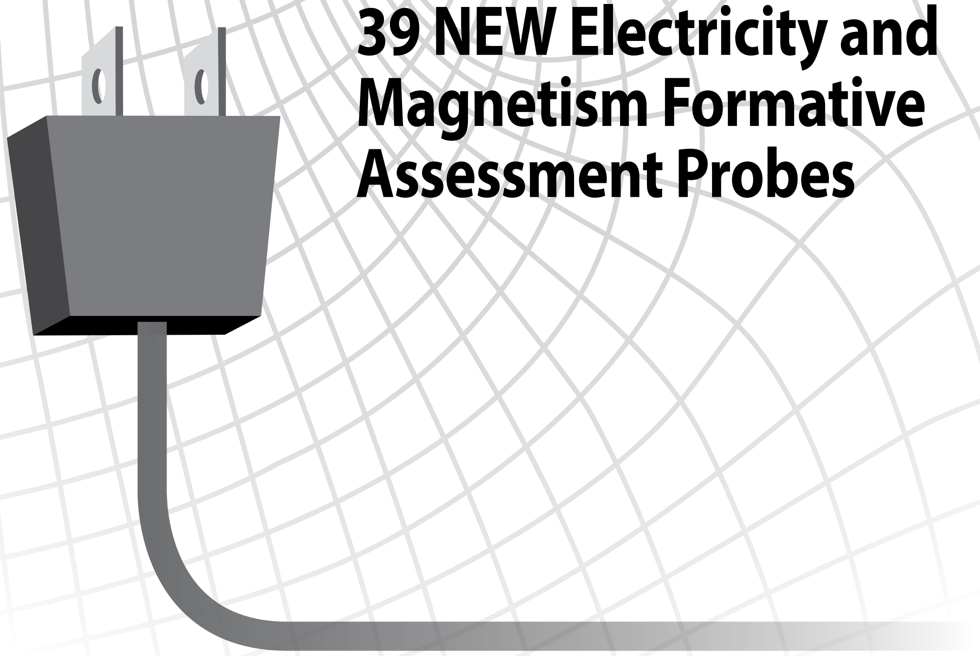
By Page Keeley
and Rand Harrington

NSTApress
National Science Teachers Association

VOL 2.

Uncovering Student Ideas in Physical Science

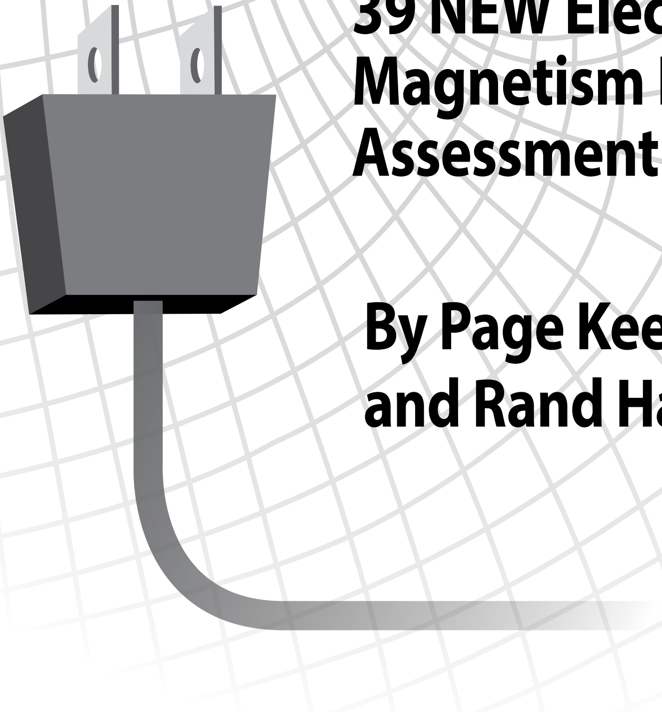
39 NEW Electricity and Magnetism Formative Assessment Probes



VOL 2.

Uncovering Student Ideas in Physical Science

39 NEW Electricity and Magnetism Formative Assessment Probes



By Page Keeley
and Rand Harrington

NSTApress
National Science Teachers Association
Arlington, Virginia

NSTApress®
National Science Teachers Association

Claire Reinburg, Director
Wendy Rubin, Managing Editor
Andrew Cooke, Senior Editor
Amanda O'Brien Associate Editor
Amy America, Book Acquisitions Coordinator

ART AND DESIGN
Will Thomas Jr., Director
Cover, Inside Design, and Illustrations by Linda Olliver

PRINTING AND PRODUCTION
Catherine Lorrain, Director

NATIONAL SCIENCE TEACHERS ASSOCIATION
David L. Evans, Executive Director
David Beacom, Publisher

1840 Wilson Blvd., Arlington, VA 22201
www.nsta.org/store
For customer service inquiries, please call 800-277-5300.

17 16 15 14 4 3 2 1

NSTA is committed to publishing material that promotes the best in inquiry-based science education. However, conditions of actual use may vary, and the safety procedures and practices described in this book are intended to serve only as a guide. Additional precautionary measures may be required. NSTA and the authors do not warrant or represent that the procedures and practices in this book meet any safety code or standard of federal, state, or local regulations. NSTA and the authors disclaim any liability for personal injury or damage to property arising out of or relating to the use of this book, including any of the recommendations, instructions, or materials contained therein.

PERMISSIONS

Book purchasers may photocopy, print, or e-mail up to five copies of an NSTA book chapter for personal use only; this does not include display or promotional use. Elementary, middle, and high school teachers may reproduce forms, sample documents, and single NSTA book chapters needed for classroom or non-commercial, professional-development use only. E-book buyers may download files to multiple personal devices but are prohibited from posting the files to third-party servers or websites, or from passing files to non-buyers. For additional permission to photocopy or use material electronically from this NSTA Press book, please contact the Copyright Clearance Center (CCC) (*www.copyright.com*; 978-750-8400). Please access *www.nsta.org/permissions* for further information about NSTA's rights and permissions policies.

Library of Congress Cataloging-in-Publication Data
Keeley, Page.
45 new force and motion assessment probes / by Page Keeley and Rand Harrington.
p. cm. -- (Uncovering student ideas in physical science ; v. 1)
Includes bibliographical references and index.
ISBN 978-1-935155-18-8
1. Force and energy--Study and teaching. 2. Motion--Study and teaching. 3. Educational evaluation. I. Harrington, Rand. II. Title. III. Title: Forty-five new force and motion assessment probes.
QC73.6.K44 2010
530.071--dc22
2010010354

eISBN 978-1-936137-70-1

The ISBN for this title is 978-1-936137-37-4 and the e-ISBN is 978-1-938946-60-8.

Contents

Section 1. Electric Charge

Section 2. Electric Current

Section 3. Magnets and Electromagnetism

Preface

This book is the second book in the *Uncovering Student Ideas in Physical Science* series and the ninth book in the full *Uncovering Student Ideas* series. Like its predecessors, this book provides a collection of questions, called formative assessment probes, designed to uncover preconceptions about ideas students bring to their learning as well as identify misunderstandings students may develop during instruction that sometimes go unnoticed by the teacher. Each probe is carefully researched and developed to surface K–12 students' (and teachers') ideas about electric or magnetic phenomena or concepts. A "best answer" is provided along with distractors designed to reveal research-identified commonly held ideas. In areas where there is a lack of or no research, the authors have used their experience with students and teachers to develop likely responses. The second part of each probe asks students to justify their answer choice, which provides a way for teachers to gain insight into students' thinking.

These probes are designed to be used for formative assessment rather than for summative purposes (e.g., grading). Ideally they are used to provide non-judgmental and valuable feedback to the student as well as the teacher that will inform the selection and design of instructional experiences and lessons that target students' ideas about electricity and magnetism. In addition, the probes are intellectually engaging questions that stimulate student thinking and involve students in productive discussions as they grapple with their own ideas and consider the ideas of others.

Other *Uncovering Student Ideas* Books That Include Electricity and Magnetism–Related Probes

This volume specifically targets ideas related to electricity and magnetism. In addition, there are other books in the *Uncovering Student Ideas in Science* series that include related probes as well as background information on formative assessment that can build your assessment literacy. These books include:

- ***Uncovering Student Ideas in Science, Volume 1*** (Keeley, Eberle, and Farrin 2005): This first book in the series contains 25 formative assessment probes in life, physical, and Earth and space science. The introductory chapter of this book provides an overview of what formative assessment is and how it is used. This chapter is free for downloading from the NSTA Press website. Teachers are strongly encouraged to read this chapter if they are new to using formative assessment probes. The "Is It Matter?" probe in this book is useful for determining whether students distinguish between matter and energy.
- ***Uncovering Student Ideas in Science, Volume 2*** (Keeley, Eberle, and Tugel 2007): This second book in the series contains 25 formative assessment probes in life, physical, and Earth and space science. While there are no probes related to electricity and magnetism in this volume, the introductory chapter of this book will help you understand the link between formative assessment and instruction and can be downloaded for free from the NSTA Press website.

- ***Uncovering Student Ideas in Science, Volume 3*** (Keeley, Eberle, and Dorsey 2008): This third book in the series contains 22 formative assessment probes in life, physical, and Earth and space science. The introductory section addresses how formative assessment probes can be used for individual or group learning. It provides valuable information for teacher leaders, preservice instructors, and professional developers and can be downloaded for free off the NSTA Press website. It also contains three nature of science probes. Since many of the electricity and magnetism probes involve investigation, the "Doing Science" probe reveals misunderstandings students may have about "the scientific method" and experimentation. "What Is a Hypothesis" is designed to reveal misunderstandings related to the use of hypotheses in investigations. "Is It a Theory?" not only reveals students' ideas about what a theory is, but also reveals how students distinguish between theories and laws. Since there are many laws related to electricity and magnetism (Ohm's Law, Coulomb's Law, Planck's Law, and so on), this probe may be used to integrate nature of science into electricity and magnetism instruction. This book also includes the probe, "Batteries, Bulbs, and Wires" which can be used with grades 3–12.
- ***Uncovering Student Ideas in Science, Volume 4*** (Keeley and Tugel 2009): This fourth book in the series contains 23 formative assessment probes in life, physical, and Earth and space science. The introductory chapter, which can be downloaded for free off the NSTA Press website, describes the link between formative and summative assessment. It also includes two probes that target the crosscutting concepts of models and systems. Conceptual models and representations are included in several of the electricity and magnetism probes. The "Is It a Model?" probe can be used to learn more about how students think about models and how they are used. Since many of the electric and magnetic phenomena used in the probes involve components of a system, the "Is It a System?" probe will help you determine how your students think about systems and the interaction of parts within a system. This book also includes a probe that can be used with grades 3–8, "Magnets in Water" to reveal whether students think magnets work in water.
- ***Uncovering Student Ideas in Primary Science, Volume 1*** (Keeley 2013): This eighth book in the *Uncovering Student Ideas* series contains 25 formative assessment probes in life, physical, earth and space science specifically geared toward primary grades students (grades K–2). The probes use a visual format and are designed to be used with "science talk." The introductory chapter can be downloaded for free off the NSTA website and includes way to use "Talk Moves" with the probes. These talk moves can be used with any grade level. One of the probes in this book, "Big and Small Magnets," reveals whether students use a "more A–more B" intuitive rule to decide if big magnets are always stronger than smaller magnets.

In addition, the third book in this series, *Uncovering Student Ideas in Physical Science, Volume 3: Matter and Energy* (tentatively due to be published in 2015) will include probes related to electrical energy, work, and power.

Website

There is also a website where you can get more information about the series and access additional resources. Visit *www.uncoveringstudentideas.org.*

Preface

Format of This Book

This book contains 39 probes for grades 3–12 (and for teacher learning) organized in three sections: Section 1, Electric Charge (8 probes); Section 2, Electric Current (13 probes); and Section 3, Magnets and Electromagnetism (18 probes). The format is similar to *Uncovering Student Ideas in Physical Science, Volume 1: 45 New Force and Motion Assessment Probes.*

Each section begins with a concept matrix that identifies the main concepts related to the probe and the suggested grade level. Grade levels can be moved up or down depending on your curriculum and knowledge of your students. The suggested grade levels are based primarily on state and national standards.

Related ideas from the 2009 updated version of the *Benchmarks for Science Literacy* (which also includes ideas from the *Atlas of Science Literacy)* are included. "Related" means the probe is either connected to the learning goal as a precursor, is a contributing idea, or it may be aligned. Since many states have not yet adopted the *Next Generation Science Standards* (*NGSS*), it is important to include these *Benchmarks* learning goals, as they formed the basis for most states' standards. They also bring precision and clarity to understanding learning goals in any curriculum.

Links to related the *Next Generation Science Standards (NGSS)* are also included in three ways: (1) related disciplinary core ideas (DCIs) that describe the content for a given grade span based on the *Framework for K–12 Science Education* (NRC 2012); (2) Crosscutting concepts that relate to electricity and magnetism; and (3) the related performance expectation from the *NGSS* (NGSS Lead States 2013). The performance expectation is included to show what assessment might look like but is not intended to limit curriculum and instruction. In some cases the probe will align to the performance expectation. In other cases it will contribute to achieving the performance expectation.

The last part of each section includes related NSTA resources: books, journal articles, and collections from NSTA's Learning Center. In searching for resources, we found that electricity and magnetism, especially electric charge, is an area where NSTA lacks a variety of instructional resources. Hopefully this collection will grow as teachers, researchers, and curriculum developers recognize the importance of these fundamental concepts and contribute to the research base, develop new resources, and publish new articles related to electricity and magnetism.

Each probe includes teacher background notes. It is essential to examine the background information for each probe prior to using it. The teacher notes include:

1. Purpose

This section describes the purpose of the probe—ideas the probe is designed to uncover. It begins by describing the overall concept elicited by the probe, followed by the specific idea the probe targets. Before choosing a probe you must be clear about what the probe is intended to reveal. Taking time to read the purpose will help you decide if the probe fits the learning target you have in mind.

2. Related Concepts

Each probe is designed to target one or more concepts related to electricity or magnetism. A concept is a one-, two- or three-word mental construct used to organize the related ideas addressed by the probe and the related national standards. These concepts are also included on the matrix charts that precede the probes on pages 10, 48, and 108.

3. Explanation

A brief scientific explanation accompanies each probe and provides clarification of the scientific content that underlies the probe. The explanations are designed to help the teacher identify what the "best" or most scientifically acceptable answers are as well as clarify any misunderstandings about the content. The explanations are not intended to provide detailed background knowledge about the content or designed to be shared with the student (although the explanations may be appropriate for high school students). The explanation is for the teacher. In writing these explanations, the authors are careful not to make them so technical that only a science specialist would understand them, as many elementary and middle grades teachers have limited coursework or professional development in science. At the same time the authors try not to oversimplify the science. The intent is to provide the information a science novice would need to understand the content of the probe. If you have a need or desire to learn more about the content, refer to the NSTA resources listed for each section or use your own instructional materials and resources to build or enhance your content knowledge. Sometimes the answer is not black and white—there may be exceptions depending on how the student considers the context. Therefore we always say the *best* answer is ___ rather than the *correct* answer is ___. *Always* read the explanation before using the probe!

4. Administering the Probe

Guidance is provided for administering the probe to students, including suggested grade levels, ways to demonstrate the probe scenario, modifications for different learners, or use of different formative assessment classroom techniques (FACTs) to gather the assessment data. For more information on these strategies as well as other techniques you can use with the probes, refer to *Science Formative Assessment: 75 Practical Strategies for Linking Assessment, Instruction, and Learning (*Keeley 2008). FACTs that can be used with the probes include:

- *Card Sorts:* Answer choices are printed on cards that students sort into two groups: examples and non-examples. As students sort the cards, they discuss their reasons for why they think it is or is not an example according to the probe prompt. The teacher can circulate during the card sort and listen to students as they engage in argumentation and construct their own explanations about the phenomena or concepts.
- *Lines of Agreement:* This strategy is used when there are two answer choices. Students stand in two lines facing each other. Each line represents an answer choice. Students engage in argumentation. After a student shares their argument to support their answer to the probe, the other line can make a rebuttal or offer an alternative argument. At any time, if a student changes their thinking based on a compelling argument from the other side, they may cross over to the other line.
- *P-E-O:* This technique can be used to launch into an investigation after responding to the probe. First, students predict (P) what they think the outcome will be by committing to an answer choice (a claim). Second, they explain (E) their thinking to support their claim. Third, they test their ideas by making observations (O). When their observations do not match their claim, they need to revise their original prediction and construct a new explanation based on the evidence from their investigation.

5. Related Research

Each probe is informed by related research (if available). A lot of research studies have been published about K–12 understanding of electric circuits and a moderate amount of research on children's ideas about magnetism exists. However, there is much less available research on K–12 students' ideas about electric charge and electromagnetism. Although many of the research summaries describe studies that have been conducted in past decades, and studied children not only in the United States but in other countries as well, most of the results of these studies are considered timeless and universal. Whether students develop their ideas in the United States or other countries, research indicates that many of these commonly held ideas are pervasive regardless of geographic boundaries and societal and cultural influences. Even though your students may have had different experiences and contexts for learning, the findings from the research can help you better understand the intent of the probe and the kinds of thinking your students are likely to reveal when they respond to the probe. As you use the probes, you are encouraged to seek new and additional published research, or engage in your own action research to learn more about students' thinking and share your results with other teachers to extend and build upon the research summaries in the teacher notes. To learn more about conducting action research using the probes, read the *Science and Children* article "Formative Assessment Probes: Teachers as Classroom Researchers" (Keeley 2011).

6. Suggestions for Instruction and Assessment

Uncovering and examining the ideas children bring to their learning is considered diagnostic assessment. Diagnostic assessment becomes formative assessment when the teacher uses the assessment data to make decisions about instruction that will move students toward the intended learning target. Therefore, in order for the probe to be considered formative assessment, the teacher needs to think about how to design, choose, or modify a lesson or activity to best address the ideas students bring to their learning as well as ideas that surface or develop during the learning process that are partially developed or not scientifically correct. If you use a probe and then continue to teach as you always have without addressing students' ideas, then you are not using the probe formatively. As you carefully listen to and analyze your students' responses, the most important next step is to decide on the instructional path that would work best in your particular context, based on your students' thinking, the materials you have available, and the different types of learners you have in your classroom.

The suggestions provided in this section have been gathered from the wisdom of teachers, the knowledge base on effective science teaching, and research on specific strategies used to address commonly held ideas. These are not lesson plans but rather brief suggestions that may help you plan or modify your curriculum or instruction in order to help students grapple with difficult or misunderstood ideas. It may be as simple as realizing that you need to be aware of the drawbacks of the analogy you have been using or there may be a specific strategy or activity that you could use with your students. Learning is a very complex process and most likely no single suggestion will help all students learn. But that is what formative assessment encourages—thinking carefully about the variety of instructional strategies and experiences needed to help students learn scientific ideas. As you become more familiar with the ideas your students have and the multifaceted factors that may have contributed to their conceptual development, you will identify additional strategies that you can use to teach for conceptual change. In addition, this section also points out other probes in the *Uncovering Student Ideas in Science* series that can be modified or used as is to further uncover and address the concepts targeted by the probe.

7. Safety

Safe science should be practiced in the science classroom at all times. This section provides suggestions, where necessary, by NSTA's science safety consultant for safely conducting activities related to each of the probes.

8. References

References are provided for the standards, research summaries, and several of the instructional suggestions provided in the teacher notes. You might use this section to access and read the full research paper cited in the Related Research section of the teacher notes.

References

American Association for the Advancement of Science (AAAS). 2009. Benchmarks for science literacy online. *www.project2061.org/publications/bsl/online*

Keeley, P. 2008. *Science formative assessment: 75 practical strategies for linking assessment, instruction, and learning.* Thousand Oaks, CA: Corwin Press.

Keeley, P. 2011. Formative assessment probes: Teachers as classroom researchers. *Science and Children* 49 (3): 24–26.

Keeley, P. 2013. *Uncovering student ideas in primary science, vol. 1: 25 new formative assessment probes for grades K–2.* Arlington, VA: NSTA Press.

Keeley, P., F. Eberle, and C. Dorsey. 2008. *Uncovering student ideas in science, vol. 3: Another 25 formative assessment probes.* Arlington, VA: NSTA Press.

Keeley, P., F. Eberle, and L. Farrin. 2005. *Uncovering student ideas in science, vol. 1: 25 formative assessment probes.* Arlington, VA: NSTA Press.

Keeley, P., F. Eberle, and J. Tugel. 2007. *Uncovering student ideas in science, vol. 2: 25 more formative assessment probes.* Arlington, VA: NSTA Press.

Keeley, P., and R. Harrington. 2010. *Uncovering student ideas in physical science, vol. 1: 45 force and motion assessment probes.* Arlington, VA: NSTA Press.

Keeley, P., and J. Tugel. 2009. *Uncovering student ideas in science, vol. 4: 25 new formative assessment probes*. Arlington, VA: NSTA Press.

National Research Council (NRC). 2012. *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas.* Washington DC: National Academies Press.

NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states.* Washington, DC: National Academies Press. *www.nextgenscience.org/next-generation-science-standards*.

Acknowledgments

We would like to thank the teachers and science coordinators we have worked with for their willingness to field-test probes, provide feedback on the format and structure of these probes, share student data, and contribute ideas for assessment probe development. In particular, we want to acknowledge the many dedicated researchers in the field of physics education whose work forms the basis for many of the probes included in this book. We would also like to thank our reviewers for providing timely and useful feedback to improve the manuscript. We would especially like to thank Linda Olliver for translating our ideas into illustrations. And of course our deepest appreciation goes to all the dedicated staff at NSTA Press who continue to support formative assessment resources and professional development, encourage the continuation of this series, and publish the best books in K–12 science education.

……

Dedication

This book is dedicated to our sons: Nathaniel and Christopher Keeley and Joey and Max Harrington who fill our lives with joy, pride, and meaning.

……

About the Authors

Page Keeley recently retired from the Maine Mathematics and Science Alliance (MMSA) where she was the senior science program director for 16 years, directing projects and developing resources in the areas of leadership, professional development, linking standards and research on learning, formative assessment, and mentoring and coaching. She has been the principal investigator and project director of three National Science Foundation grants: the Northern New England Co-Mentoring Network, PRISMS: Phenomena and Representations for Instruction of Science in Middle School; and Curriculum Topic Study: A Systematic Approach to Utilizing National Standards and Cognitive Research. She has also directed state Math-Science Partnership projects including TIES K–12: Teachers Integrating Engineering into Science K–12 and a National Semi-Conductor Foundation grant, Linking Science, Inquiry, and Language Literacy (L-SILL). She also founded and directed the Maine Governor's Academy for Science and Mathematics Education Leadership, a replication of the National Academy for Science and Mathematics Education Leadership of which she is a Cohort 1 Fellow.

Page is the author of 16 national bestselling books, including four books in the *Curriculum Topic Study* Series, nine volumes in the *Uncovering Student Ideas in Science* series, and three books in the *Science Formative Assessment: 75 Practical Strategies for Linking Assessment, Instruction, and Learning* series. Currently she provides consulting services to school districts and organizations throughout the United States on building teachers' and school districts' capacity to use diagnostic and formative assessment. She is a frequent invited speaker on formative assessment and teaching for conceptual change.

Page taught middle and high school science for 15 years before leaving the classroom in 1996. At that time she was an active teacher leader at the state and national level. She served two terms as president of the Maine Science Teachers Association and was a District II NSTA Director. She received the Presidential Award for Excellence in Secondary Science Teaching in 1992, the Milken National Distinguished Educator Award in 1993, the AT&T Maine Governor's Fellow in 1994, the National Staff Development Council's (now Learning Forward) Susan Loucks-Horsley Award for Leadership in Science and Mathematics Professional Development in 2009, and the National Science Education Leadership Association's Outstanding Leadership in Science Education Award in 2013. She has served as an adjunct instructor at the University of Maine, was a science literacy leader for the AAAS/Project 2061 Professional Development Program, and serves on several national advisory boards. She is a science education delegation leader for the People to People Citizen Ambassador Professional Programs, leading the South Africa trip in 2009, China in 2010, and India in 2011.

Prior to teaching, she was a research assistant in immunology at the Jackson Laboratory of Mammalian Genetics in Bar Harbor, Maine. She received her BS in life sciences from the University of New Hampshire and her MEd in secondary science education from the University of Maine. In 2008 Page was elected the 63rd president of the National Science Teachers Association (NSTA).

Dr. Rand Harrington is the head of school for The Kent Denver School in Denver (as of July 1, 2014). He began his teaching career in 1980 as a middle school science teacher in California after receiving a degree in environmental science at Western Washington University. In 1985, after teaching and traveling throughout the world, he returned to school and received a second bachelor's degree in physics and then completed both his master's degree and PhD in physics at the University of Washington.

As a science teacher, Rand had long been interested in understanding how people learn, and he soon joined the Physics Education Research Group at the University of Washington under the leadership of Lillian McDermott. While working with this group, he taught and helped develop curriculum materials for *Physics by Inquiry,* a curriculum for preservice teachers, as well as *Tutorials in Introductory Physics*, which is used in many introductory physics courses. Rand was able to pursue his own interests in electricity and magnetism and eventually wrote his PhD dissertation on identifying and addressing the difficulties students have with understanding electric phenomena.

After graduation from the University of Washington, Rand accepted an assistant professor appointment at the University of Maine, where he founded the Physics Education Group (originally called LRPE) and collaborated with the Maine Mathematics and Science Alliance (MMSA) in their NSF-funded Statewide Systemic Initiative. In 1998 he was awarded a Higher Education SEED Foundation grant from MMSA and the Maine Department of Education to work with preservice teachers and to reform the introductory physics courses for nonscience majors at the University of Maine. In addition he received a National Science Foundation grant to examine best practices in science teaching. He has served on the ETS Physics SAT II test construction committee and on the American Association of Physics Teachers committee on research in physics education.

In 1999, he left Maine to help start a "Physics First" high school science program at the Harker School in San Jose, California. During that time, he adapted materials for a high school curriculum based on modeling, *Tutorials in Introductory Physics*, and *Physics by Inquiry*. He also became interested in computer-based tutorials and the effectiveness of online homework such as WebAssign and Mastering Physics. In 2005, Rand assumed a position as the K–12 science coordinator at The Blake School in Minneapolis and later served at their assistant head of school. He has served as a consultant for several independent schools, is a reviewer for the *American Journal of Physics*, teaches a summer course for undergraduate science and engineering majors at the University of Minnesota, received the Juliet Nelson Award for Excellence in Teaching, and has taught physics to Tibetan monks as part of the Science for Monks program in Dharamsala, India. His most recent interests are finding effective methods to "extend the thinking" of students at all grade levels and to use the computer as a tool for effective learning.

Introduction

It is winter in Minnesota, but still warm enough to play outside. Lindsay is a third grade student, and today she is wearing her warm, woolen pants, knowing that she will get a chance to use the outdoor playground. She runs to her favorite slide, a long blue slide made of plastic. She climbs the ladder and then slides to the bottom with great joy. When she reaches the bottom of the slide, she notices that her hair is standing up and she has a peculiar tingly feeling on her skin. Her best friend races to help her up and as their hands touch, there an audible "zap" and a small spark erupts between their outstretched hands. Ouch!

Where did the spark come from and what is it made of? Is this spark related to the electricity that is used to light our houses? And where do magnets fit into this picture? We are surrounded daily by the phenomenon produced by electric charge—these charges are what makes things work including all the electronic devices we own, from cell phones to copy machines to computers. Yet most of us have only a vague notion of what electric charge is and even less of an understanding of where these charges come from, where they go, and how they move around.

The concept of electric charge is a prerequisite for understanding why matter "sticks together" (all of chemistry); and subsequently, many of the interactions that are studied in a typical biology course (such as photosynthesis and cellular respiration). However, few science courses address electric concepts sufficiently. At most, elementary school and middle school students are introduced to electric phenomena through a single unit on electric circuits, but get no exposure to the topic of electric charge itself (sometimes called electrostatics). Yet, in spite of the central importance of electric charge to the understanding of our world, the appearance of electric concepts in national and state standards remains sparse.

Historical Background

Around 600 BC ancient Greeks discovered that small pieces of amber (a hardened natural resin) would attract light objects like feathers after being rubbed with cloth. (It is interesting to note that the Greek name for amber is "elektron"). There is also evidence that many years before the Greeks discovered electricity, the Chinese discovered magnetic interactions. They observed that certain types of rocks called "lodestones," displayed an attraction toward each other. (A lodestone is a naturally occurring mineral called magnetite.) The fact that these two different effects are related is subtle and difficult to understand as evidenced by the fact that it took another 2,000 years for scientists to learn the details of how magnetism is related to electricity. To develop an understanding of these effects, it was not necessary to understand what was happening at the atomic scale. In fact, it is interesting to note from both a historical and a pedagogical point of view that the discovery of the electron (one of the fundamental particles with the property of electric charge) came at the end of the 19th century, *after* the invention of the battery, electric circuits, the lightbulb, and electromagnets. Even the famous electric and magnetic experiments of Michael Faraday and subsequent mathematical formulations by James Clerk Maxwell occurred prior to the discovery of the electron.

A careful examination of the historical development of ideas often provides a useful road map for understanding student ideas. This is certainly true of the topics of electricity and magnetism whose long history of discovery includes decades of unsuccessful attempts to connect electrostatics to magnetism. Historically, engineers and inventors rushed headlong into developing technologies that made use of the electric and magnetic phenomena, even as the science behind these effects remained a mystery. An excellent example that helps to illustrate this point is the story of the installation of the first transoceanic telegraph cable. This cable was installed before people knew what it was that was flowing through the wires and their misconceptions of electricity resulted in a catastrophic failure (Bodanis 2005).

Common Instructional Difficulties Related to Teaching About Electricity and Magnetism

Misconceptions and lack of knowledge regarding electric effects are common and research shows that few students have even a rudimentary understanding of electricity. One example of this lack of understanding is illustrated in the video series *Minds of Our Own*, where Harvard graduates struggle and often fail to connect a single lightbulb, a wire, and battery such that the bulb will light up (Harvard Smithsonian Center for Astrophysics 1997). Additional difficulties, just as profound, can be elicited by asking people to account for why a balloon (when rubbed on your hair) can "stick" to a wall. In traditional physics courses, instruction tends to focus on the mathematical models used to represent electrical interactions. However, research indicates that students continue to struggle with even the most basic concepts even as they become more proficient with calculations.

Research on Student Ideas Related to Electric and Magnetic Phenomena

As compared to the topics of force and motion, there is considerably less research on student ideas related to electric and magnetic phenomena. Much of the research has been devoted to an examination of college level students (Harrington 1999; Kanim 1999; Rainson and Viennot 1992, 1999). Most of the research on younger students' ideas has been on the topic of simple circuits containing batteries and lightbulbs. The results from this work show that students predictably use a simple cause-and-effect model to explain the lighting of a lightbulb—that the battery is the source of the "electricity" and the "electricity" is then used to produce light. In interviews, students rarely differentiate between the words *charge, electricity, energy, voltage,* or *current*. (McDermott and Shaffer 1992; Millar and Beh 1993; Millar and King 1993). Students also tend to reason "locally" rather than "globally." This means that is it very difficult for students to recognize that a change in the circuit at one location can result in changes everywhere else in the circuit (including the battery). Students also tend to believe that the battery is a source of electric charge, that when the battery "runs out," it is running out of charge, and that the battery is unaffected by what is connected to the battery.

Identifying student difficulties with electric charge is even more difficult because one can only observe the effects of charge interactions, not of charge itself. This requires a certain level of inferential and abstract reasoning, which is made even more difficult by the inconsistency of common everyday language used to describe these interactions. For example, it is common to talk about charge as a verb: someone gets "charged up," which can appear as if charge is an "excited state" rather than as a property of matter. This incorrect view is then reinforced when students discover that they can create a charged object by rubbing (for example rubbing a plastic ruler with a piece of wool). This gives the impression that charge can be "created" and that this "excited state" is somehow related to heat and friction. The language used to describe the two different types of charge is also problematic, as some students confuse the words *negative* with "not charged" and *positive* with "yes, it is charged." Again, this is inadvertently reinforced by the observations that charged objects attract neutral objects (this is because the two different types of charge in the neutral object separate and not because a neutral object is "opposite of the charge of a charged object"). As a result, it is not uncommon to hear students use the words "neutral charge."

Representations of Charge

Because we cannot see electric charge, we must pay particular attention to how this property of matter is represented in drawings or pictures. In some curriculum materials, the two types of charge are given colors such as red or blue. It is more common to see the symbols "+" or "–" written on top of or near objects that are either positively or negatively charged.

In one study, students in fifth grade observed the interaction between a balloon rubbed with fur and the wall (Harrington 1996). They were then asked to draw pictures to show why the balloon is attracted to the wall. Specifically they were asked to draw what they could imagine as happening if they could see the interaction. Overall, the student drawings fit one of four different categories: lines, arrows, dots, or zigzags. Most students referred to the interaction as due to "static" and the most common representation that students choose to illustrate why the balloon sticks to the wall was straight lines. When asked about how many types of charges there are, not one of the students understood that there are only two types of charge and most thought there were many different types of charge, an answer consistent with the idea that charge is an interaction rather than a property of matter (See Probe 4, "What Happens When You Bring a Balloon Near a Wall?" p. 27).

These difficulties illustrate how tricky it is to understand what students are thinking based on the words they use. In some cases, students use the word "static" to indicate a physical quantity analogous to a scientist's notion of charge. In other cases, the word *static* seemed to be more indicative of the interaction itself rather than as the causal agent responsible for the interaction. For example, most of the student drawings could be interpreted as a representation of ideas related to an electric field (an effect) rather than to electric charge itself (the cause). Difficulty with differentiating between cause and effect in the context of learning science has been widely documented with students from a wide range of ages.

There is little research available on student ideas related to magnetic effects. Maloney and others have documented the confusion that students have distinguishing between magnetic poles and electric charge (Maloney 1985). In addition, several graduate students in physics education have examined student understanding of magnetism and have discovered similar difficulties that extend to college level students (Johnson 1997; Krauss 1998). Krauss found that these difficulties were quite difficult to overcome, even after professors in a college-level physics course addressed these difficulties specifically in their lectures and demonstrations.

Conceptual Framework for Understanding Charge

We have identified seven key concepts that scientists generally agree are basic to an understanding of electric charge. These concepts provide our starting points for developing the probes contained in this book. Most of these concepts are accessible to students from a wide range of age groups including our youngest students. The seven key concepts are:

- Charge is a property matter.
- There exist two different types of charge called “positive” and “negative.”
- Charges that are the same type will repel each other and charges that are the opposite type will attract each other.
- The interaction between charges decreases as the distance between the charges is increased.
- Neutral materials are composed of equal amounts of both types of charge. (*Note:* This concept is directly related to the idea that all matter is composed primarily of charged particles.)
- Electric charge cannot be created or destroyed. (*Note:* There are exceptions to this relevant only for physicists who operate high-energy particle accelerators.)
- Charged particles move easily through some materials (conductors) but not as easily through other materials (insulators).

Understanding Electricity

Mass and electric charge are two fundamental properties of matter. Most particles that exist have both of these properties. *Mass* is important in that it is the property that is responsible for gravitational force (the observed force that we call weight) and it is the property that resists changes in motion as described by Newton’s second law, $F_{net} = ma$ (where F is the net force, m is the mass and a is the acceleration of the object). The property of matter called *electric charge* is responsible for much larger forces (as compared to gravitational force) and is the property of matter that holds atoms and molecules together and gives matter, which is mostly composed of space, its feeling of “solidness.” All electronic devices work by managing the motion of particles that have this charge property. Batteries move these particles around, capacitors store the separation of this property into its two different “flavors,” and the movement of these charged particles produces light.

Conceptual Framework for Understanding Electric Circuits

Understanding the movement of electric charge through wires that are connected to batteries requires students to make a few simple assumptions, such as the belief that there is a flow and the belief that the brightness of a light bulb is an indicator of the amount of flow. In many cases, the difficulties that students experience with electric circuits can be traced back to a lack of understanding of what it is that is flowing and the lack of understanding of charge conservation (that electric charge cannot be created or destroyed). The language of “flow” can also be deceptive even though it is common for teachers to use a water analogy when trying to help teach students how circuits work. The difficulty with the words *flow* and *current* is that the common definitions of these words are associated solely with the *speed* of whatever is flowing. This implies that higher speeds can be described as a faster current. However, in the context of electric circuits, electric current refers only to the number of electric charges that pass a given point in a given amount of time. This means that a lot of charge moving slowly can be the same “current” as a small amount of charge that is moving fast. One of the principles of electric circuits is “current conservation,” which means that the amount of current going into a device (like a lightbulb or a battery) must be the same as the amount of current that is coming out of the device. In fact, it is neither current nor electric charge that is “used up” in a circuit—a misconception that is continually reinforced in the media and in books when they refer to electric power plants as producing charge (they don't) and batteries as storing charge (they don't). It is unfortunate that when we "energize" a battery it is called "charging the battery" and that these devices are called "battery chargers." A battery stores chemical energy that is used to separate charge and does not produce or store charge (the net charge of a battery remains zero—it contains equal numbers of both types of charge). In our homes, electric current is rapidly switching directions (called AC or alternating current). Students are surprised to learn that this means the electric charges that were in the lightbulb when it was first purchased remains in the lightbulb throughout its lifetime (the charge does not "come from" the power plant!).

For the purpose of writing the probes contained in this book, we have identified the following foundational concepts related to understanding electric circuits:

- There is a flow around a circuit. This flow is called the electric current and is measured in amperes. For the flow to exist there must be a complete conductive path connecting one side of the battery to the other.
- Conductors are materials that contain charges that are free to move if pushed. (These charges are already present in the wires and bulbs and do not come from the battery.)
- The battery is the agent that causes the charges that are already in the wires to move through the circuit. This "push" on the charges is measured in units of volts. (The current flows *through* the battery, not *from* the battery.) Voltage is a measure of the energy required to move charged particles (like electrons) when these particles are near other charged particles.
- The amount of current that flows through a circuit depends on the total resistance in that circuit. If the resistance is decreased, the flow increases. If the resistance is increased, the flow decreases.
- A lightbulb represents resistance to the flow in a circuit
- Connecting bulbs in series (one after the other) increases the resistance to the flow and causes the total flow through the circuit to decrease.
- Connecting bulbs in parallel (side by side) reduces the resistance in the circuit and causes the total flow through the circuit to increase.

Understanding Magnetism

The study of magnetism is complicated if examined at the microscopic level; however, the phenomenon itself is quite accessible to everyone. In fact, it is easier to conduct experiments with magnets than it is to conduct experiments with electric charge. This is because the two different types of electric charge that exist are strongly attracted to each other and can move around fairly easily (without being seen). This means that a positively charged object will soon become neutral because negative charges will rush to be near the positive charges, essentially canceling out any observed effects. However, permanent magnets are strong, inexpensive, and common. Their magnetic effects do not easily subside with time, and students enjoy feeling the almost magical force of attraction and repulsion "at a distance" between two magnetic poles. Because electric charges will also attract and repel each other, it is easy for students to confuse these two distinct effects, making the teaching of basic magnetic and electric concepts all the more difficult.

The Connection Between Electric and Magnetic Effects

Magnetic effects are related to but are different than electric effects, and as such are often confused by students (as well as textbook writers!). The primary source of the confusion arises from the general difficulty that people have distinguishing between a quantity and a change in that quantity. This is because electric effects are produced by the *presence* of electric charge and magnetic effects are produced by the *movement* of electric charge.

For example, a balloon that is rubbed with fur (or your hair) can cause the two different types of charges that already exist on the balloon and in your hair to separate, leaving more of one type of charge on the balloon. It is the presence of this charge that people called "static electricity." However in a magnet, it is the movement of charges in circles that causes the magnetic effects (in a permanent magnet, this motion occurs on the atomic scale). This is why we can make a "magnet" by wrapping wire in a circle and connecting the wire to a battery. The battery pushes the electric charges through the wire, making the charges move in a circle. This means that a magnet is not "charged" in the same way that a balloon is charged.

It is easy to observe that a balloon that is charged by rubbing will attract a piece of paper but a magnet will not interact with the paper. This observation provides evidence that the poles of a magnet are not charged. Regardless of this simple observation, it is common to see bar magnets incorrectly labeled with the two symbols for electric charge (positive and negative) rather than the correct labels of North and South. The North and South labels originated from the observation that magnets, when allowed to hang freely, would inevitably point (approximately) toward the "north geographic" pole of the Earth. This end of the magnet was labeled as "North Seeking." Eventually this label turned into "North magnetic pole" and is usually labeled with the letter N. (It is a source of confusion to students who study the Earth's magnetic poles to learn that the North geographic pole of the Earth is actually a South magnetic pole. This is because a "north seeking" magnetic pole would be magnetically attracted to a south magnetic pole, but would be repelled by a north magnetic pole.)

Conceptual Framework for Magnetism

In constructing the probes related to magnetic effects, we have identified the following essential ideas around magnetism:

- The movement of electric charge produces magnetic effects.
- Magnetic poles come in pairs called north and south (you cannot separate a north pole from a south pole because they are two sides of the same phenomena).
- The same type of magnetic pole (for example, two north poles) will repel each other and opposite magnetic poles (for example a north pole and a south pole) will attract each other.
- The interaction between magnetic poles decreases as the distance between the poles increase.
- Magnets are not electrically charged (they do not have more of one type of charge than another).
- Magnets interact with magnetic materials. Some of these materials are permanent magnets with poles. Other types of magnetic materials (like iron) attract both the north pole of a magnet and the south pole of a magnet (but do not repel a magnet).
- Magnets do not interact with non-magnetic materials such as aluminum, paper or plastic.
- The size of a magnet is not necessarily related to the strength of a magnet.
- You can make a magnet with poles by making electric charges move in a circle (for example, a wire wrapped in circles around a nail connected to a battery). The magnet can be made stronger by increasing the movement of electric charge (called electric current) through the wire.

Stepping Stones: Emerging Concepts and Language

There are many challenges to teaching science, but one of the most difficult choices we face as teachers is to know when to accept an emerging concept, called a "stepping stone" versus a core scientific idea (those that most physicists would agree are important and correct from a scientific point of view). Stepping stone concepts are actually central to effective learning. Yet they are not always what come to physicists' mind when they are asked about important ideas in physics. In a recent symposium at the National Academy of Sciences where a reorganization of K–12 science education around core ideas was looked at to inform the development of the *Next Generation Science Standards*, it was proposed that candidates for core ideas include both stepping stone ideas (emerging ideas) and core scientific ideas (Weiser and Smith 2009).

When looked through the eyes of more advanced students, some of these emerging ideas could be judged as being incorrect or downright wrong. An example of a stepping stone concept is the use of the word *electricity* by young students in place of the word *current* or *voltage*. With older students, these concepts are often confused, so it is tempting to differentiate these ideas at a young age. However, learning research has shown that it is sometimes best to wait to differentiate stepping stone concepts from scientific concepts until upper elementary grades or middle school. With the support of well-crafted curriculum and effective teaching, students can experience progressively more sophisticated ways of thinking about a concept and thus are in a better position cognitively to understand the scientific idea. Learning progressions, which are empirically tested, will provide the much needed research that will inform teachers as to when to use a stepping stone in lieu of a core scientific idea (Weiser and Smith 2009).

In constructing the probes for the first volume in this series, *Uncovering Student Ideas in Physical Science: 45 New Force and Motion Assessment Probes* (Keeley and Harrington 2010), we have tried to follow this guide: *weight, distance*, and *time* are generally used as stepping stone concepts for probes designed for younger student while *mass, position, displacement*, and *time interval*, the scientifically preferred terminology, are used with probes for older students. However, teachers should be encouraged to use those terms that best match their own learning goals and student readiness regardless of the wording that was chosen for any individual probe. We encourage the same approach with the electricity and magnetism concepts in this volume.

Implementing the Electricity and Magnetism Probes

The probes contained in this book can be used as a window into student thinking before, during, or after instruction as a reflection on their prior thinking. However, if used before instruction, teachers must plan their curricula carefully so students have an opportunity to develop the relevant ideas. If a probe is administered before instruction and there is not immediate follow-up, students may feel frustrated at not knowing the "correct answer" and teachers may feel compelled to provide students with direct answers without the necessary background or experiences. Conversely, if the probes are used during or after instruction, then the teacher must also plan accordingly so there is time to revisit selected instructional activities as necessary and build in time for reflection. The advantage of using the probes after instruction, yet still formatively as opposed to a summative assessment, is that students are better prepared to participate in a classroom discussion. To be effective, students must feel comfortable sharing their ideas, and the teacher must carefully manage these discussions so that all ideas are valued.

Classroom discussions are also a wonderful opportunity to reinforce the necessary components of a scientific explanation by requiring students to state their claim, the evidence in support of that claim, and the reasoning that connects the claim to the evidence (McNeill and Krajcik 2012). If conducted during or after instruction, then students will have better access to direct evidence to support their claims.

Regardless of the who, why, and when decisions to use these probes during an instructional cycle, it is important to remember the probes are not formative unless the information is used to inform your teaching, provide feedback to the learner, and promote learning throughout the process. By starting with where the student is in his or her thinking, your challenge is to use that information to build a conceptual bridge from where the student is to where he or she needs to be on a trajectory of learning and understanding.

References

Bodanis, D. 2005. *The electric universe: The shocking true story of electricity.* New York: Crown.

Harrington, R. 1996. An investigation of student understanding of electric concepts in the introductory university physics course. Unpublished diss., University of Washington.

Harrington, R. 1999. Discovering the reasoning behind the words: An example from electrostatics. *American Journal of Physics* 67 (7): S58–S59.

Harvard Smithsonian Center for Astrophysics. 1997. *Minds of their own*. Available at *www.learner.org/resources/series26.html*

Johnson, A. 1999. Students' Development of Models of Magnetic Materials, Patterns of Group Activity, and Social Norms in a Physics Classroom. Unpublished diss., San Diego State University and University of San Diego.

Kanim, S. 1999. Investigation of student difficulties in relating qualitative understanding of electrical phenomena to quantitative problem-solving in physics. Unpublished diss., University of Washington.

Keeley, P., and R. Harrington, 2010. *Uncovering student ideas in physical science, vol. 1: 45 new force and motion assessment probes.* Arlington, VA: NSTA Press.

Krauss, P. 1999. Promoting active learning in lecture-based courses: Demonstrations, tutorials, and interactive tutorial lectures. Unpublished diss., University of Washington.

Maloney, D. 1985. Charge poles? *Physics Education* 20: 310.

McDermott, L., and P. S. Shaffer. 1992. Research as a guide to curriculum development: An example from introductory electricity. Part I: Investigation of student understanding. *American Journal of Physics* 60 (11): 994–1003.

McNeill, K., and J. Krajcik. 2012. *Supporting grade 5–8 students in constructing explanations in science.* Boston, MA: Pearson.

Millar, R., and K. Beh. 1993. Students' understanding of voltage in simple parallel electric circuits. *International Journal of Science Education* 15 (4): 351–361.

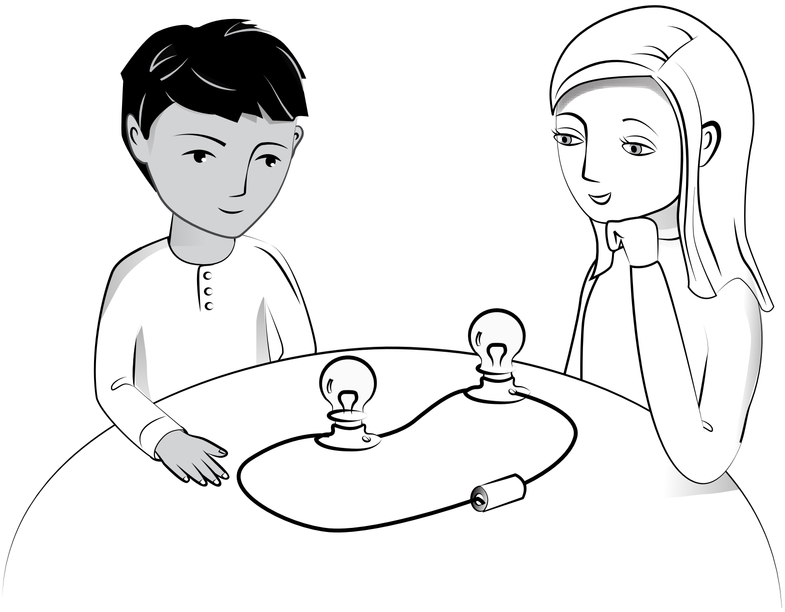
Millar, R., and T. King. 1993. Students' understanding of voltage in simple series electric circuits. *International Journal of Science Education* 15 (3): 339–349.

Rainson, S., and L. Viennot. 1992. Students' reasoning about superposition of electric fields. *International Journal of Science Education* 14 (4): 475–487.

Rainson, S., and L. Viennot. 1999. Design and evaluation of a research-based teaching sequence: the superposition of electric field. *International Journal of Science Education* 21 (1): 1–16.

Weiser, M., and C. Smith. 2009. How does cognitive development inform the choice of core ideas in the physical sciences? Paper commissioned for the NRC Conference: Expert Meeting on Core Ideas in Science, Aug. 17, Washington DC: National Academy of Sciences.

How Bright Will the Bulbs Be?



Two students made a circuit with a battery, wires, and two identical lightbulbs. Before they connected their circuit, they made a prediction about the brightness of the two bulbs. This is what they said:

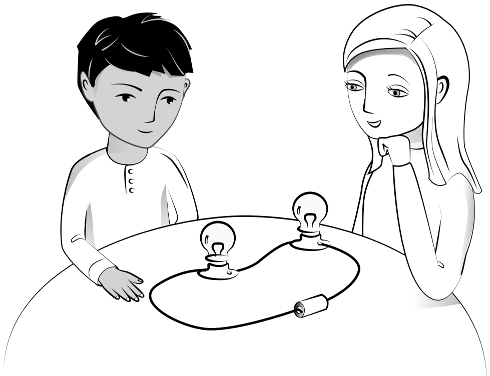
Herman: I think both bulbs will have the same brightness.

Molly: I think one lightbulb will be brighter than the other.

With which student do you agree the most? _______________ Explain why you agree with one student and not the other.

How Bright Will the Bulbs Be?

Teacher Notes



Purpose

The purpose of this assessment probe is to elicit students' ideas about series circuits. The probe is designed to determine what students think will happen to the brightness of lightbulbs as more lightbulbs are added to a circuit.

Related Concepts

current, series circuit, resistance, circuit

Explanation

The best answer is Herman's: "I think both bulbs will have the same brightness." The circuit shown is a series circuit. A series circuit is a circuit in which resistors (i.e., the lightbulbs) are arranged in a chain, so the current has only one path to take. All the current that goes through the first bulb must also go through the second bulb, so the bulbs are the same brightness. (*Note:* It is important that the two bulbs must be identical for the same current to create the same brightness. Bulbs with different ratings could have a different brightness with the same current.) In a series circuit, every lightbulb (or other device) must function for the circuit to be complete. A burned out bulb in a series circuit breaks the circuit and acts like an open switch, which turns the circuit off. The concept of "current" in electric circuits refers to the number of electric charges that pass through the wire in a given amount of time. A lot of charges moving slowly or a few charges moving fast could be the same "current." This is different from the flow of water where "current" usually refers to the speed of the water.

Although the two bulbs will have the same brightness when compared to each other, they will be dimmer than the brightness of a single bulb circuit. This is because adding a second bulb in series will increase the resistance in the circuit, which decreases the current through the circuit.

Administering the Probe

This probe is best used with upper elementary, middle, and high school students. Make sure students understand they are comparing the brightness of the two bulbs to each other, not to a bulb in a single bulb circuit. This probe can be used with the P-E-O strategy described on page xii (Keeley 2008).

Related Research

- Students who choose Molly tend to have a "consumption model" of current. They see some of the current being used up by the first bulb so there is less going to the second bulb (Driver et al. 1994).
- Several misconceptions related to the concept of current have been noted by researchers such as confusing current with electrical energy; current being used up as it flows through a resistor such as a lightbulb; a lack of recognition that all the parts of a circuit influence each other; and a belief that current flows "downstream" like a river, through the different parts of a circuit (Shipstone 1984; Borges and Gilbert 1999).
- Some students think current is actually something physical that flows through a circuit. This notion leads to the misconception that current gets weaker or used up as it moves from one part to another (Borges and Gilbert 1999).
- Student often confuse electric current and voltage. Student difficulties with voltage can often be traced back to their difficulty understanding the concept of energy. (Millar and King 1993).

Suggestions for Instruction and Assessment

- If using this probe with elementary students, the emphasis should be observational. At middle and high school, students can be asked to construct an explanation to describe what happens to the bulbs.
- Some researchers have suggested using the heart and blood circulation analogy to help move students away from the "consumption model." The blood circulates through the heart but does not get used up in the process (Osborne and Freyberg 1985).
- Although the probe does not ask for how the brightness of the single bulb changes when you add an additional bulb, students can also predict and observe that the bulbs are dimmer in a two-bulb series circuit than a single bulb in a circuit.. The correct inference is that the resistance to the flow must have increased by adding a second bulb in series.
- The probe can be extended by asking students what would happen if a third bulb is added to the circuit.
- One of the most effective models for a series circuit is a string tied into a large circle. Have three students stand in a circle and hold onto the string lightly. One student is the "battery." This student pulls the string around the circle. The other students let the string slide through their hands. The "flow" of the string is the same everywhere around the circle. If the "battery" always pulls the string around with the same "pull," the string slows down as more students are added to the circle. Students also feel the heat from the string sliding through their hands, which is like the resistance that each bulb adds to a series circuit.
- There are several inquiry-oriented curriculum guides that introduce the concept of electric current. One set of materials is the Electric Circuit Module of *Physics by Inquiry* (Pearson). This curriculum was designed specifically for the professional development of elementary school teachers. For a summary of these instructional strategies, see Shaffer and McDermott (1992).
- This probe can be followed by using "Which Burns Brighter," in which students compare the brightness of bulbs in a series circuit versus a parallel circuit.

NSTA Safety Notes for Follow-up Instructional Activities

1. Use caution in handling wires. The bare wire ends are sharp and can cut or puncture skin.
2. Use only batteries which are in good condition. Leaking batteries can burn skin.
3. Use caution in handling glass bulbs. They are fragile and if broken can cut skin.
4. Use caution in handling batteries, bulbs and wires that remain connected in circuits. They can become hot and burn skin.

References

Borges, A., and J. Gilbert. 1999. Mental models of electricity. *International Journal of Science Education* 21 (1): 95–117.

Driver, R., A. Squires, P. Rushworth, and V. Wood-Robinson. 1994. *Making sense of secondary science: Research into children's ideas.* London: RoutledgeFalmer.

McDermott, L. C., and P. S. Shaffer. 1992. Research as a guide for curriculum development: An example from introductory electricity, Part I: Investigation of student understanding. *American Journal of Physics* 60: 994–1003.

Millar, R., and T. King. 1993. Students' understanding of voltage in simple series electric circuits. *International Journal of Science Education* 15 (3): 339–349.

Osborne, R., and P. Freyberg. 1985. *Learning in science: the implications of children's science.* Auckland, NZ: Heinemann.

Shaffer, P. S., and L. C. McDermott. 1992. Research as a guide to curriculum development: An example from introductory electricity. Part II: Design of instructional strategies. *American Journal of Physics* 60 (11): 1003–1013.

Shipstone, D. M. 1984. A study of children's understanding of electricity in simple DC circuits. *European Journal of Science Education* 6 (2): 185–198.

Index

Index

Index

Index

Index

Index

Index

Index

VOL. 2
Uncovering
Student Ideas
in Physical Science

39 NEW Electricity and Magnetism Formative Assessment Probes

> "I have used this entire series for assessing student understanding, for small- and large-group class discussions, and to fill those five- or 10-minute 'unexpected' moments that arise during the day. The prompts are so popular that students beg to do them. … This series is so helpful that I would not consider teaching without it."
>
> —A teacher review of the *Uncovering Student Ideas in Science* series from the NSTA Science Store

If you and your students can't get enough of a good thing, Volume 2 of *Uncovering Student Ideas in Physical Science* is just what you need. It offers 39 new formative assessment probes, this time with a focus on electric charge, electric current, and magnets and electromagnetism. It can help you do everything from demystify electromagnetic fields to explain the real reason balloons stick to the wall after you rub them on your hair.

Like the other eight wildly popular books in the series, *Uncovering Student Ideas in Physical Science, Volume 2*:

- Provides a collection of engaging questions, or formative assessment probes. Each probe in this volume is designed to uncover what students know—or think they know—about electric or magnetic phenomena or identify misunderstandings they may develop during instruction.
- Offers field-tested teacher materials that provide "best answers", along with distracters designed to reveal misconceptions that students commonly hold.
- Is easy to use by time-starved teachers like you. These teacher-friendly, ready-to-reproduce materials fit easily into all stages of an instructional cycle. In addition to explaining the science content, the teacher materials note links to national standards and suggest grade-appropriate ways to present material to help your students develop deeper conceptual understanding.

By helping you detect and then make sound instructional decisions to address students' misconceptions, this new volume has the potential to transform your teaching.

PB274X2
ISBN: 978-1-936137-37-4

GRADES K–12

NSTA press
National Science Teachers Association