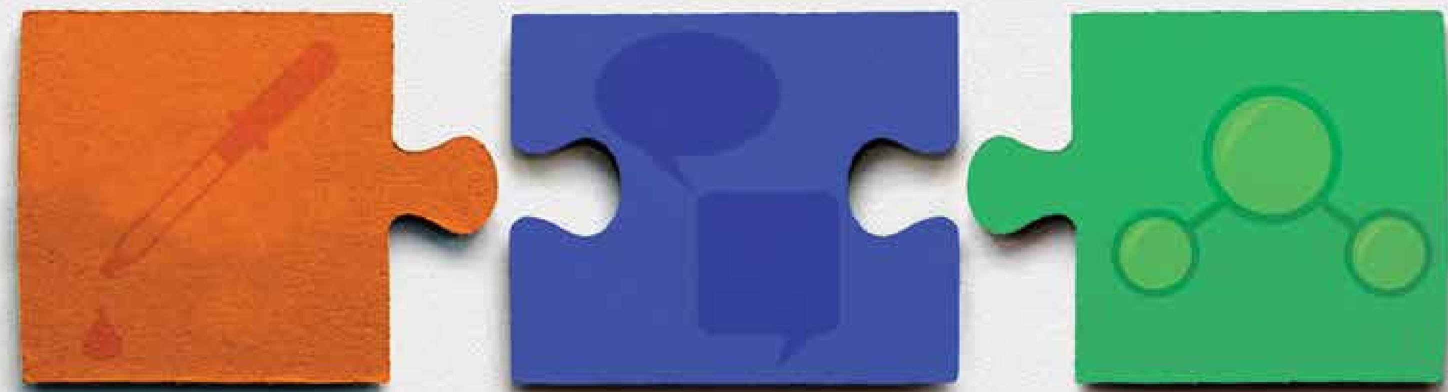
Argument-Driven Inquiry in CHEMISTRY



LAB INVESTIGATIONS for GRADES 9–12

Victor Sampson, Peter Carafano, Patrick Enderle, Steve Fannin, Jonathon Grooms, Sherry A. Southerland, Carol Stallworth, and Kiesha Williams

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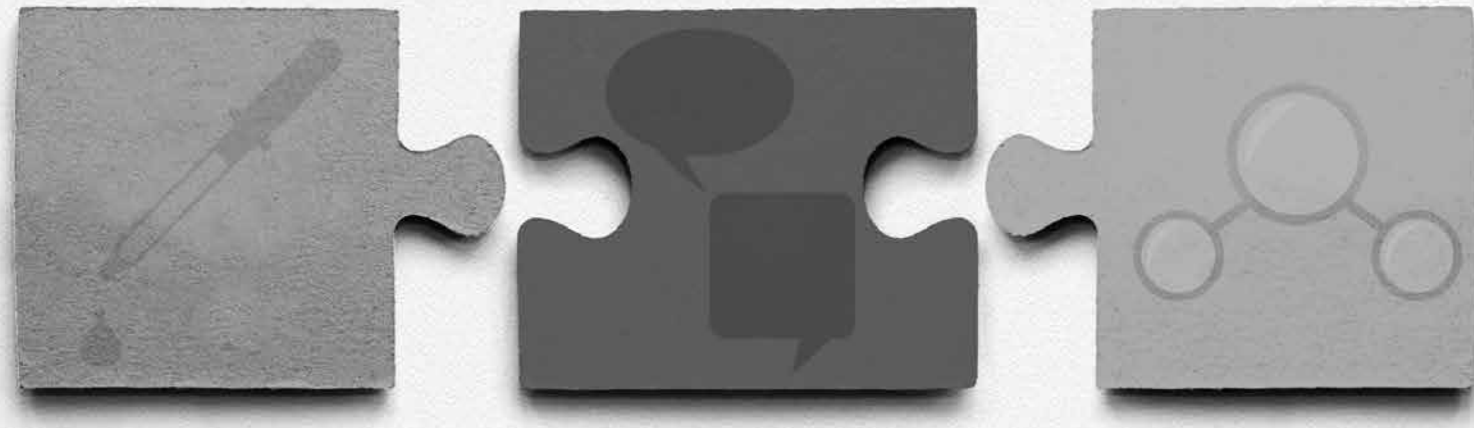

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NSTA press
National Science Teachers Association
Arlington, Virginia

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18 17 16 15 4 3 2 1

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Library of Congress Cataloging-in-Publication Data
Sampson, Victor, 1974- author.
Argument-driven inquiry in chemistry : lab investigations for grades 9-12 / Victor Sampson [and 7 others].
pages cm
Includes bibliographical references and index.
ISBN 978-1-938946-22-6 -- ISBN 978-1-938946-54-7 (e-book) 1. Chemistry--Study and teaching (Secondary)--Activity programs. 2. Chemistry--Experiments. I. National Science Teachers Association. II. Title.
QD43.S16 2014
540.78--dc23
2014029558

Cataloging-in-Publication Data for the e-book are also available from the Library of Congress.
e-LCCN: 2014030242

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PREFACE

There is a push to change the way science is taught in the United States, called for by a different idea of what it means to know, understand, and be able to do science. As described in *A Framework for K–12 Science Education* (National Research Council [NRC] 2012) and the *Next Generation Science Standards* (NGSS Lead States 2013), science education should be structured to emphasize ideas *and* practices to

> ensure that 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. (p. 1)

Instead of teaching with the goal of helping students learn facts and concepts, science teachers are now charged with helping their students become *proficient* in science by the time they graduate from high school. To allow for this proficiency, the NRC (2012) suggests that students need to understand four core ideas in the physical sciences, be aware of seven crosscutting concepts that span across the various disciplines of science, and learn how to participate in eight fundamental scientific practices in order to be considered proficient in science. These important practices, crosscutting concepts, and core ideas are summarized in Figure 1.

FIGURE 1

The three dimensions of the framework for the *NGSS*

Scientific Practices	Crosscutting Concepts
• Asking questions and defining problems	• Patterns
• Developing and using models	• Cause and effect: Mechanism and explanation
• Planning and carrying out investigations	• Scale, proportion, and quantity
• Analyzing and interpreting data	• Systems and system models
• Using mathematics and computational thinking	• Energy and matter: Flows, cycles, and conservation
• Constructing explanations and designing solutions	• Structure and function
• Engaging in argument from evidence	• Stability and change
• Obtaining, evaluating, and communicating information	

Physical Sciences Core Ideas
• PS1: Matter and its interactions
• PS2: Motion and stability: Forces and interactions
• PS3: Energy
• PS4: Waves and their applications in technologies for information transfer

Source: Adapted from NRC 2012, p. 3.

As described by the NRC (2012), new instructional approaches are needed to assist students in developing these proficiencies. This book provides 30 lab activities designed using an innovative approach to lab instruction called argument-driven inquiry (ADI). This approach and the labs based on it are aligned with the content, crosscutting concepts, and scientific practices outlined in Figure 1. Because the ADI model calls for students to give presentations to their peers, respond to questions, and then write, evaluate, and revise reports as part of each lab, 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). Use of these labs, as a result, can help teachers align their instruction with current recommendations for making chemistry more meaningful for students and more effective for teachers.

References

National Governors Association Center for Best Practices and Council of Chief State School Officers (NGAC and CCSSO). 2010. *Common core state standards.* Washington, DC: NGAC and CCSSO.

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

The development of this book was supported by the Institute of Education Sciences, U.S. Department of Education, through grant R305A100909 to Florida State University. The opinions expressed are those of the authors and do not represent the views of the institute or the U.S. Department of Education.

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INTRODUCTION

The Importance of Helping Students Become Proficient in Science

The new aim of science education in the United States is for all students to become proficient in science by the time they finish high school. It is essential to recognize that science proficiency involves more than an understanding of important concepts, it also involves being able to *do* science. *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 designing and carrying out investigations and arguing from evidence) and communicate in a manner that is consistent with the norms of the scientific community.

In the past decade, however, the importance of learning how to participate in scientific practices has not been acknowledged in the standards of many states. Many states have also attempted to make their science standards "more rigorous" by adding more content instead of designing them so they emphasize core ideas, scientific practices, and crosscutting concepts as described by the National Research Council (NRC) in *A Framework for K–12 Science Education* (NRC 2012). Unfortunately, the large number of benchmarks along with the pressure to cover them that results from the use of high-stakes tests has forced teachers "to alter their methods of instruction to conform to the assessment" (Owens 2009, p. 50). Teachers, as a result, tend to focus on content and neglect the practices of science inside the classroom. Teachers also tend to move through the science curriculum quickly to ensure that they "cover" all the standards before the students are required to take the high-stakes assessment. This trend takes us far afield from developing students' proficiency in the practices of science.

The current focus on covering all the standards, however, does not seem to be working. For example, *The Nation's Report Card: Science 2009* (National Center for Education Statistics 2011) indicates that only 21% of all 12th-grade students who took the National Assessment of Educational Progress in science scored at the proficient level. The performance of U.S. students on international assessments is even bleaker, as indicated by their scores on the science portion of the Programme for International Student Assessment (PISA). PISA is an international study that was launched by the Organisation for Economic Co-operation and Development (OECD) in 1997, with the goal of assessing education systems worldwide; more than 70 countries have participated in the study. The test is designed to assess reading, math, and science achievement and is given every three years. The mean score for students in the United States on the science portion of the PISA in 2012 is below the international mean (500), and there has been no significant change in the U.S. mean score since 2000; in fact, the U.S. mean score in 2012 is slightly less than it was in 2000 (OECD 2012; see Table 1). Students in countries such China, Korea, Japan, and Finland score significantly higher than students in the United States. These results suggest that U.S. students are not learning what they need to learn to become proficient in science, even though teachers are covering a great deal of material.

TABLE 1

PISA scientific literacy performance for U.S. students

Year	U.S. mean score*	U.S. rank/Number of countries assessed	Top three performers
2000	499	14/27	Korea (552) Japan (550) Finland (538)
2003	491	22/41	Finland (548) Japan (548) Hong Kong–China (539)
2006	489	29/57	Finland (563) Hong Kong–China (542) Canada (534)
2009	499	15/43	Japan (552) Korea (550) Hong Kong–China (541)
2012	497	36/65	Shanghai–China (580) Hong Kong–China (555) Singapore (551)

*The mean score of the PISA is 500 across all years.
Source: OECD 2012.

In addition to the poor performance of U.S. students on national and international assessments, empirical research in science education indicates that a curriculum that emphasizes breadth over depth and neglects the practices of science can actually hinder the development of science proficiency (Duschl, Schweingruber, and Shouse 2007; NRC 2005, 2008). As noted in the *Framework* (NRC 2012),

> 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)

Based on their review of the available literature, the NRC recommends that science teachers spend more time focusing on key ideas to help students develop a more enduring understanding of science content. They also call for science teachers to start using instructional strategies that give students more opportunities to learn how to participate in the practices of science. Without this knowledge and these abilities, they argue, students will not be able to engage in public discussions about scientific issues related to their everyday lives, to be consumers of scientific information, and to have the skills needed to enter a science or science-related career. We think the school science laboratory is the perfect place to focus on key ideas and engage students in the practices of science and, as a result, help them develop the knowledge and abilities needed to be proficient in science.

How School Science Laboratories Can Help Foster the Development of Science Proficiency

Lab activities look rather similar in most high school classrooms (Hofstein and Lunetta 2004; NRC 2005). (We use the NRC's definition of a school science lab activity, which is "an opportunity for students to interact directly with the material world using the tools, data collection techniques, models, and theories of science" [NRC 2005, p. 3]). The teacher usually begins a lab activity by first introducing the students to a concept through a lecture or some other form of direct instruction. The teacher then gives the students a hands-on task to complete. To support students as they complete the task, teachers often provide students with a worksheet that includes a procedure explaining how to collect data, a data table to fill out, and a set of analysis questions to answer. The hope is that the experience gained through completion of the hands-on task and worksheet will illustrate, confirm, or otherwise verify the concept that was introduced to the students at the beginning of the activity. This type of approach, however, has been shown to be an ineffective way to help students understand the content under investigation, learn how to engage in important scientific practices (such as designing and carrying out an investigation, constructing explanations, or arguing from evidence), and develop scientific habits of mind (Duschl, Schweingruber, and Shouse 2007; NRC 2005). Thus, most lab activities, even if they are engaging or memorable, do little to promote science proficiency.

One way to address this problem is to widen the focus of lab instruction. A wider focus will require teachers to place more emphasis on "how we know" in chemistry (i.e., how new knowledge is generated and validated) in addition to "what we know" about matter and its interactions (i.e., the theories, laws, and unifying concepts). Science teachers will also need to focus more on the abilities and habits of mind that students need to have in order to construct and support scientific knowledge claims through argument and to evaluate the claims or arguments made by others (NRC 2012). The NRC calls for *argumentation* (defined as the process of proposing, supporting, evaluating, and refining claims) to play a more central role in the teaching and learning of science because argumentation is essential practice in science. The 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)

In addition to changing the focus of instruction, teachers will also need to change the nature of lab instruction to promote and support the development of science proficiency. To change the nature of instruction, teachers need to make lab activities more authentic by giving students an opportunity to engage in scientific practices instead of giving them a worksheet with a procedure to follow and a data table to fill out. These activities, however, also need to be educative for students in order to help students develop the knowledge and abilities associated with science proficiency. Students need to receive feedback about how to improve, and teachers need to help students learn from their mistakes.

The argument-driven inquiry (ADI) instructional model (Sampson and Gleim 2009; Sampson, Grooms, and Walker 2009, 2011) was designed as a way to 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 research about how people learn science (NRC 1999) and is also based on what is known about how to engage students in argumentation and other important scientific practices (Berland and Reiser 2009; Erduran and Jimenez-Aleixandre 2008; McNeill and Krajcik 2008; Osborne, Erduran, and Simon 2004; Sampson and Clark 2008).

Organization of This Book

The remainder of this book is divided into two parts. Part I begins with two text chapters describing the ADI instructional model and the development and components of the ADI lab investigations. Part II contains the lab investigations, including notes for the teacher, student handouts, and checkout questions. Four appendixes contain standards alignment matrixes, timeline and proposal options for the investigations, and a form for assessing the investigation reports.

Safety Practices in the Science Laboratory

It is important for science teachers to make hands-on and inquiry-based lab activities as safe as possible for students. Teachers therefore need to have proper safety equipment in the classroom (e.g., fume hoods, fire extinguishers, eyewash, and showers) and ensure that students use appropriate personal protective equipment (i.e., indirectly vented chemical-splash goggles meeting ANSI Z87.1 standard, chemical-resistant aprons and gloves) during all lab activities. Teachers also need to review and comply with all the local, state, and federal safety regulations as well as all safety policies and chemical storage and disposal protocols that have been established by the school district or school.

Throughout this book, safety precautions are provided for each investigation. Teachers should follow these safety precautions to provide a safer learning experience for students. The safety precautions associated with each activity are based, in part, on the use of the recommended materials and instructions, legal safety standards, and current 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 students review *Safety in the Science Classroom, Laboratory, or Field Sites* (National Science Teacher Association [n.d.]) under the direction of the teacher before working in the laboratory for the first time. The students and their parent or guardians should then sign this document to acknowledge that they understand the safety procedures that must be followed during a lab activity.

References

Berland, L., and B. Reiser. 2009. Making sense of argumentation and explanation. *Science Education* 93 (1): 26–55.

Duschl, R. A., H. A. Schweingruber, and A. W. Shouse, eds. 2007. *Taking science to school: Learning and teaching science in grades K–8*. Washington, DC: National Academies Press.

Erduran, S., and M. Jimenez-Aleixandre, eds. 2008. *Argumentation in science education: Perspectives from classroom-based research*. Dordrecht, the Netherlands: Springer.

Hofstein, A., and V. Lunetta. 2004. The laboratory in science education: Foundations for the twenty-first century. *Science Education* 88: 28–54.

McNeill, K., and J. Krajcik. 2008. Assessing middle school students' content knowledge and reasoning through written scientific explanations. In *Assessing science learning: Perspectives from research and practice,* ed. J. Coffey, R. Douglas, and C. Stearns, 101–116. Arlington, VA: NSTA Press.

National Center for Education Statistics. 2011. *The nation's report card: Science 2009.* Washington, DC: U.S. Department of Education.

National Research Council (NRC). 1999. *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academies Press.

National Research Council (NRC). 2005. *America's lab report: Investigations in high school science*. Washington, DC: National Academies Press.

National Research Council (NRC). 2008. *Ready, set, science: Putting research to work in K–8 science classrooms*. Washington, DC: National Academies Press.

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

National Science Teachers Association (NSTA). n.d. *Safety in the science classroom, laboratory, or field sites. www.nsta.org/docs/SafetyInTheScienceClassroomLabAndField.pdf.*

Organisation for Economic Co-operation and Development (OECD). 2012. OECD Programme for International Student Assessment. *www.oecd.org/pisa.*

Osborne, J., S. Erduran, and S. Simon. 2004. Enhancing the quality of argumentation in science classrooms. *Journal of Research in Science Teaching* 41 (10): 994–1020.

Owens, T. 2009. Improving science achievement through changes in education policy. *Science Educator* 18 (2): 49–55.

Sampson, V., and D. Clark. 2008. Assessment of the ways students generate arguments in science education: Current perspectives and recommendations for future directions. *Science Education* 92 (3): 447–472.

Sampson, V., and L. Gleim. 2009. Argument-driven inquiry to promote the understanding of important concepts and practices in biology. *American Biology Teacher* 71 (8): 471–477.

Sampson, V., J. Grooms, and J. Walker. 2009. Argument-driven inquiry: A way to promote learning during laboratory activities. *The Science Teacher* 76 (7): 42–47.

Sampson, V., J. Grooms, and J. Walker. 2011. Argument-driven inquiry as a way to help students learn how to participate in scientific argumentation and craft written arguments: An exploratory study. *Science Education* 95 (2): 217–257.

Teacher Notes

Lab 18. Characteristics of Acids and Bases: How Can the Chemical Properties of an Aqueous Solution Be Used to Identify It as an Acid or a Base?

Purpose

The purpose of this lab is to *introduce* students to the physical and chemical properties of acids and bases. You can use this lab at the beginning of a unit on acid-base chemistry to set the stage for future lessons and investigations. This lab gives students an opportunity to devise, test, and refine a method that can be used to classify an aqueous solution as being an acid or a base using the physical or chemical properties of the solution. Students will also learn about the difference between observations and inferences in science and the different methods used in scientific investigations.

The Content

Acids and bases have several unique physical and chemical properties. These properties, which stem from the atomic structure of the compounds, can be used to classify an aqueous solution as an acid or a base. Properties of acids include

- conducting electricity;
- reacting with active metals to form hydrogen gas and solutions of metal ions;
- reacting with carbonates to form a salt, water, and carbon dioxide gas; and
- reacting with a base to form a salt and water.

Properties of bases include

- conducting electricity,
- reacting with oils and greases, and
- reacting with an acid to form a salt and water.

In addition to these properties, acids and bases also interact with acid-base indicators. Acid-base indicators are organic dyes that change color in acidic or basic solutions. The color of an acid-base indicator depends on the concentration of H_3O^+ ions in a solution. The concentration of H_3O^+ ions in a solution is often described using the pH scale. The mathematical relationship between pH and H_3O^+ ion concentration is $pH = –log[H_3O^+]$.

The typical H_3O^+ concentration in water ranges from 1 M in a 1 M solution of a strong acid (such as hydrochloric acid [HCl]) to 10^{-14} M in a 1 M solution of a strong base (such as sodium hydroxide, NaOH). In pure water, the H_3O^+ concentration is equal to 10^{-7} M. The logarithm of the concentration is the "power of 10" exponent in these concentration terms. Thus, the negative logarithms of typical H_3O^+ concentrations are positive numbers from 0 to 14. The pH scale, as a result, ranges from 0 to 14. Acids have pH values less than 7, whereas bases have pH values greater than 7.

Within the pH range of acid solutions, a strong acid or a more concentrated acid solution will have a lower pH value than a weak acid or a less concentrated acid solution. Thus, the pH value of 0.1 M HCl (a strong acid) is 1 and the pH value of 0.01 M HCl is 2, whereas the pH value of 0.1 M acetic acid (a weak acid) is about 3. On the basic side of the pH scale, a strong base or a more concentrated base solution will have a higher pH value than a weaker or a less concentrated base solution. The pH value of a 0.1 M NaOH (which is a strong base) is 13 and the pH value of 0.01 M NaOH is 12, whereas the pH of 0.1 M ammonia (a weak base) is about 11. It is important to remember that the pH scale is logarithmic, so a solution of pH 3 is 10 times more acidic than a solution of pH 4 and 100 times more acidic than a solution of pH 5.

Although acid-base indicators are useful for broadly classifying substances as acids or bases, they are not able to distinguish among different strengths of acids and bases. By using combinations of different indicators, however, it is possible to obtain a spectrum of color changes over a wide range of acidity levels. Table 18.1 lists the colors associated with the five different indicators that the students will use in this lab investigation.

TABLE 18.1

Indicators used in this lab investigation

Indicator	Color associated with each level of pH													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Thymol blue	R	P	Y	Y	Y	Y	Y	Y	B	B	B	B	B	B
Bromphenol blue	Y	Y	Y	G	B	B	B	B	B	B	B	B	B	B
Bromthymol blue	Y	Y	Y	Y	Y	Y	G	B	B	B	B	B	B	B
Methyl red	R	R	R	P	P	Y	Y	Y	Y	Y	Y	Y	Y	Y
Phenol red	Y	Y	Y	Y	Y	P	P	R	R	R	R	R	R	R

B = blue; G = green; P = pink; R = red; V = violet; Y = yellow

Timeline

The instructional time needed to complete this lab investigation is 130–200 minutes. Appendix 2 (p. 501) provides options for implementing this lab investigation over several class periods. Option C (200 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 D (130 minutes) should be used if students are familiar with scientific writing and have 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 18.2. The consumables and equipment can be purchased from a science supply company such as Carolina, Flinn Scientific, or Ward's Science. We recommend using buffer capsules to prepare standard acid-base solutions of known pH. Buffer capsules contain preweighed amounts of stable, dry powders that dissolve in distilled or deionized water to give solutions of known, constant pH. They can be purchased separately or as a set. The buffer solutions, once prepared, can then be divided evenly between several 30 ml dropper bottles for students to use. The acid-base solutions for this lab are listed in Table 18.2.

We also recommend that you use a set routine for distributing and collecting the materials during the lab investigation. For example, the consumables and equipment for each group can be set up at each group's lab station before class begins, or one member from each group can collect them from a central table or a cart when needed during class.

Safety Precautions

Remind students to follow all normal lab safety rules. The acids are corrosive and toxic by ingestion, and the bases are body tissue irritants. You will therefore need to explain the potential hazards of working with acids and bases and how to work with hazardous chemicals. In addition, tell students to take the following safety precautions:

- Wear indirectly vented chemical-splash goggles and chemical-resistant gloves and aprons when they are collecting their data.
- Handle all glassware with care.
- Wash their hands with soap and water when they are done collecting the data.

Laboratory Waste Disposal

The solutions may be flushed down the drain with a large quantity of water according to Flinn laboratory waste disposal method 26b. Use Flinn laboratory waste disposal method 3 to dispose of any extra zinc that has been mixed with an acid. Information about laboratory

TABLE 18.2

Materials list

Item	Quantity
Consumables	
Zinc	10 ml per group (1 dropper bottle)
1 M solution of sodium bicarbonate, $NaHCO_3$	10 ml per group (1 dropper bottle)
1 M solution of HCl	10 ml per group (1 dropper bottle)
Acid solution 1 (buffer solution, pH 2)	10 ml per group (1 dropper bottle)
Acid solution 2 (buffer solution, pH 3)	10 ml per group (1 dropper bottle)
Acid solution 3 (buffer solution, pH 4)	10 ml per group (1 dropper bottle)
Acid solution 4 (buffer solution, pH 5)	10 ml per group (1 dropper bottle)
Base solution 1(buffer solution, pH 9)	10 ml per group (1 dropper bottle)
Base solution 2 (buffer solution, pH 10)	10 ml per group (1 dropper bottle)
Base solution 3 (buffer solution, pH 11)	10 ml per group (1 dropper bottle)
Base solution 4 (buffer solution, pH 12)	10 ml per group (1 dropper bottle)
Acid test solution A (buffer solution, pH 2)	10 ml per group (1 dropper bottle)
Acid test solution B (buffer solution, pH 6)	10 ml per group (1 dropper bottle)
Base test solution A (buffer solution, pH 8)	10 ml per group (1 dropper bottle)
Base test solution B (buffer solution, pH 11)	10 ml per group (1 dropper bottle)
Thymol blue	10 ml per group (1 dropper bottle)
Bromphenol blue	10 ml per group (1 dropper bottle)
Bromthymol blue	10 ml per group (1 dropper bottle)
Methyl red	10 ml per group (1 dropper bottle)
Phenol red	10 ml per group (1 dropper bottle)
Equipment and other materials	
Conductivity tester or probe	1 per group
Reaction plate	1 or 2 per group
Small beaker(s), 50 ml	1 or 2 per group
Whiteboard, 2' x 3' *	1 per group
Lab handout	1 per student
Peer-review guide and instructor scoring rubric	1 per student

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

waste disposal methods is included in the Flinn Catalog and Reference Manual; you can request a free copy at *www.flinnsci.com.*

Topics for the Explicit and Reflective Discussion

Concepts That Can Be Used to Justify the Evidence

To provide an adequate justification of their evidence, students must explain why they included the evidence in their arguments and make the assumptions underlying their analysis and interpretation of the data explicit. In this investigation, students can use the following concepts to help justify their evidence:

- The nature of chemical properties
- How atomic structure determines chemical properties

We recommend that you discuss these fundamental concepts during the explicit and reflective discussion to help students make this connection.

How 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 bias in their investigations. To help students be more reflective about the design of their investigation, you can ask the following questions:

- What were some of the strengths of your investigation? What made it scientific?
- What were some of the weaknesses of your investigation? What made it less scientific?
- If you were to do this investigation again, what would you do to address the weaknesses in your investigation? What could you do to make it more scientific?

Crosscutting Concepts

This investigation is well aligned with two crosscutting concepts found in *A Framework for K–12 Science Education*, and you should review these concepts during the explicit and reflective discussion.

- *Patterns:* A major objective in chemistry is to identify patterns. Once the patterns are identified, they are often used to guide classification systems and prompt questions about the underlying cause of the observed patterns. In this investigation, for example, students need to identify patterns in the physical and chemical properties of acids and bases and then use these patterns to classify them.

- *Structure and function:* The way an object is shaped or structured determines many of its properties and functions. The observable physical and chemical properties of acids and bases, for example, are determined by the atomic structure of these molecules.

The Nature of Science and the Nature of Scientific Inquiry

This investigation is well aligned with two important concepts related to the *nature of science* (NOS) and the *nature of scientific inquiry* (NOSI), and you should review these concepts during the explicit and reflective discussion.

- *The difference between observations and inferences*: An observation is a descriptive statement about a natural phenomenon, whereas an inference is an interpretation of an observation. Students should also understand that current scientific knowledge and the perspectives of individual scientists guide both observations and inferences. Thus, different scientists can have different but equally valid interpretations of the same observations due to differences in their perspectives and background knowledge.
- *Methods used in scientific investigations*: Examples of methods include experiments, systematic observations of a phenomenon, literature reviews, and analysis of existing data sets; the choice of method depends on the objectives of the research. There is no universal step-by-step scientific method that all scientists follow; rather, different scientific disciplines (e.g., chemistry vs. physics) and fields within a discipline (e.g., organic vs. physical chemistry) use different types of methods, use different core theories, and rely on different standards to develop scientific knowledge

Hints for Implementing the Lab

- Allowing students to design their own methods for identifying acids and bases gives students an opportunity to try, to fail, and to learn from their mistakes. Encourage students to try things out and refine their method when they uncover a flaw or weakness with it.
- Use reaction plates rather than test tubes for the tests. It is safer and limits the amount of consumables that are used during the investigation.
- Use small dropper bottles for acid solutions, base solutions, and indicators. They prevent students from using too much and decrease the chance of spills.

Topic Connections

Table 18.3 (p. 290) provides an overview of the scientific practices, crosscutting concepts, disciplinary core ideas, and supporting ideas at the heart of this lab investigation. In addition, it lists NOS and NOSI concepts for the explicit and reflective discussion. Finally, it lists literacy skills (*CCSS ELA*) that are addressed during the investigation.

TABLE 18.3

Lab 18 alignment with standards

Scientific practices	• Asking questions and defining problems • Planning and carrying out investigations • Analyzing and interpreting data • Constructing explanations and designing solutions • Engaging in argument from evidence • Obtaining, evaluating, and communicating information
Crosscutting concepts	• Patterns • Structure and function
Core ideas	• PS1.A: Structure and properties of matter • PS1.B: Chemical reactions
Supporting idea	• Properties of acids and bases
NOS and NOSI concepts	• Observations and inferences • Methods used in scientific investigations
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

Lab Handout

Lab 18. Characteristics of Acids and Bases: How Can the Chemical Properties of an Aqueous Solution Be Used to Identify It as an Acid or a Base?

Introduction

Acids and bases represent two important classes of chemical compounds. These compounds play a significant role in many atmospheric and geological processes. In addition, acid-base reactions affect many of the physiological processes that take place within the human body. Acids and bases are important in atmospheric, geological, and physiological processes because they have unique chemical properties. Acids and bases have unique chemical properties because of the atomic composition of these compounds and how these compounds interact with other atoms and molecules.

Some of the unique chemical properties of acids and bases include how they interact with metals, carbonates, and a class of compounds called acid-base indicators. A *metal* is a solid material that is hard, shiny, malleable, and ductile. Metals are also good electrical and thermal conductors. *Carbonates* are compounds that contain a carbonate ion (CO_3^{2-}), such as calcium carbonate ($CaCO_3$), potassium carbonate (K_2CO_3), and sodium bicarbonate ($NaHCO_3$). An acid-base indicator is a dye or a pigment that changes color when it is mixed with an acid or a base. People have used indicators to identify acids and bases for hundreds of years. For example, in the 17th century Sir Robert Boyle described how different indicators could be used to identify acids and bases (Boyle 1664).

In this investigation you will explore some of the unique chemical properties of acids and bases. You will then develop a method that can be used to identify acidic or basic aqueous solutions. This is important because, like all chemists, you will need to be able to determine if an aqueous solution is acidic or basic as part of your future investigations. This is an important aspect of doing acid-base chemistry.

Your Task

Devise, test, and then, if needed, refine a method that can be used to determine if an aqueous solution is acidic or a basic. For this method to be useful, it should provide consistent and accurate results but should also be simple and quick to perform inside the lab.

The guiding question for this investigation is, **How can the chemical properties of an aqueous solution be used to identify it as an acid or a base?**

Materials

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

Consumables	Indicators	Equipment	Aqueous solutions for developing a method	Aqueous solutions for testing a method
• Zinc • 1 M solution of $NaHCO_3$ • 1 M solution of hydrochloric acid, HCl	• Thymol blue • Bromphenol blue • Bromthymol blue • Methyl red • Phenol red	• Conductivity tester or probe • Reaction plate • Small beakers	• Acid solution 1 • Acid solution 2 • Acid solution 3 • Acid solution 4 • Base solution 1 • Base solution 2 • Base solution 3 • Base solution 4	• Acid test solution A • Acid test solution B • Base test solution A • Base test solution B

Safety Precautions

Follow all normal lab safety rules. All of the acids you will use are corrosive to eyes, skin, and other body tissues. They are also toxic when ingested. Your teacher will explain relevant and important information about working with the chemicals associated with this investigation. In addition, take the following safety precautions:

- Wear indirectly vented chemical-splash goggles and chemical-resistant gloves and apron while in the laboratory.
- Handle all glassware with care.
- Wash your hands with soap and water before leaving the laboratory.

Investigation Proposal Required? ☐ Yes ☐ No

Getting Started

To answer the guiding question, you will first need to learn more about the unique chemical properties of acids and bases. You will therefore need to explore how aqueous solutions that are classified as acids or as bases react with metal, a solution of sodium bicarbonate, and a solution of hydrochloric acid. You will then determine if these same solutions are able to conduct electricity. Finally, and perhaps most important, you will examine how different acidic and basic solutions interact with different indicators. You goal is to learn more about the chemical properties of aqueous solutions that are classified as being acids or bases so you can use these unique properties to classify other aqueous solutions. To accomplish this task, you will need to design and conduct a series of systematic observations.

Be sure to think about *how you will collect your data and how you will analyze the data you collect* before you begin your investigation. One way to collect data is to add a small amount (about 5 to 10 drops) of each acid or base solution to the wells in a reaction plate.

You can then add a small piece of metal or other solution to each well and observe what happens. You can also create a reaction matrix to help stay organized. A reaction matrix is a chart that allows you to record your observations (see Table L18.1 for an example). Only use the solutions found under the heading "Aqueous Solutions for Developing a Method" in the "Materials" section during this stage of your investigation.

TABLE L18.1

Example of a reaction matrix

Compound	Test				
	Zinc	Conductivity	HCl	Bromthymol blue	Methyl red
Acid solution 1	Observation 1	Observation 2	Observation 3	Observation 4	Observation 5
Acid solution 2	Observation 6	Observation 7	Observation 8	Observation 9	Observation 10
Base solution 1	Observation 11	Observation 12	Observation 13	Observation 14	Observation 15

Notice that the compounds being tested are included in the first column and each test is labeled as a header in the remaining columns. Observations made during each test can be recorded in the boxes.

Once you have made your observations about the chemical properties of acids and bases, you will need to use what you have learned to devise a method for classifying an unknown as either an acid or a base. You can then test your method using the solutions found under the heading "Aqueous Solutions for Testing a Method" in the "Materials" section. If you are able to use your method to accurately classify all four of these solutions, then you will be able to provide evidence that the method you devised will provide accurate results. If you cannot accurately classify all four of the test solutions, you will need to refine your method and test it again. Keep in mind that your method needs to be a simple and quick way to classify an unknown aqueous solution based on its chemical properties.

Connections to Crosscutting Concepts, the Nature of Science, and the Nature of Scientific Inquiry

As you work through your investigation, be sure to think about

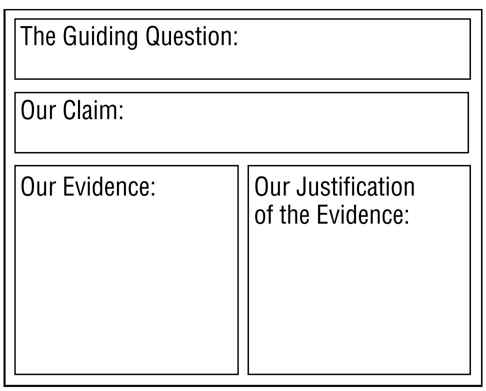
- the importance of looking for, using, and explaining patterns in science;
- the relationship between structure and function in nature;
- the difference between observations and inferences in science; and
- the different methods used in scientific investigations.

Initial Argument

Once your group has finished collecting and analyzing your data, you will need to develop an initial argument. Your argument must include a *claim*, which is your answer to the guiding question. Your argument must also include *evidence* in support of your claim. The evidence is your analysis of the data and your interpretation of what the analysis means. Finally, you must include a *justification* of the evidence in your argument. You will therefore need to use a scientific concept or principle to explain why the evidence that you decided to use is relevant and important. You will create your initial argument on a whiteboard. Your whiteboard must include all the information shown in Figure L18.1.

FIGURE L18.1

Argument presentation on a whiteboard



Argumentation Session

The argumentation session allows all of the groups to share their arguments. One member of each group stays at the lab station to share that group's argument, while the other members of the group go to the other lab stations one at a time to listen to and critique the arguments developed by their classmates. The goal of the argumentation session is not to convince others that your argument is the best one; rather, the goal is to identify errors or instances of faulty reasoning in the initial arguments so these mistakes can be fixed. You will therefore need to evaluate the content of the claim, the quality of the evidence used to support the claim, and the strength of the justification of the evidence included in each argument that you see. To critique an argument, you might need more information than what is included on the whiteboard. You might, therefore, need to ask the presenter one or more follow-up questions, such as:

- How did your group collect the data? Why did you use that method?
- What did your group do to make sure the data you collected are reliable?
- What did your group do to analyze the data, and why did you decide to do it that way?
- Is that the only way to interpret the results of your group's analysis?
- Why did your group decide to present your evidence in that manner?
- What other claims did your group discuss before deciding on that one? Why did you abandon those alternative ideas?
- How confident are you that your group's claim is valid? What could you do to increase your confidence?

Once the argumentation session is complete, you will have a chance to meet with your group and revise your original 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 most valid or acceptable answer to the research question!

Report

Once you have completed your research, you will need to prepare an *investigation report* that consists of three sections that provide answers to the following questions:

1. What question were you trying to answer and why?
2. What did you do during your investigation and why did you conduct your investigation in this way?
3. What is your argument?

Your report should answer these questions in two pages or less. The 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

Boyle, R. 1664. *Experiments and considerations touching colours first occasionally written, among some other essays to a friend, and now suffer'd to come abroad as the beginning of an experimental history of colours*. London: Henry Herringman.

Checkout Questions

Lab 18. Characteristics of Acids and Bases: How Can the Chemical Properties of an Aqueous Solution Be Used to Identify It as an Acid or a Base?

1. Describe three characteristics of acids and three characteristics of bases.

2. An unknown solution conducts electricity but the indicators thymol blue and bromphenol blue do not change color when they are added to it. Should this solution be classified as an acid or a base?

   a. Acid
   b. Base
   c. Not enough information to determine

   Explain your answer.

3. "The solution is an acid" is an example of an observation.

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

   Explain your answer, using an example from your investigation about the characteristics of acids and bases.

4. An investigation must follow the scientific method to be considered scientific.
   a. I agree with this statement.
   b. I disagree with this statement.

   Explain your answer, using an example from your investigation about the characteristics of acids and bases.

5. Scientists often look for and attempt to explain patterns in nature. Explain why patterns are important, using an example from your investigation about the characteristics of acids and bases.

6. In nature, the structure of an object is often related to function or the properties of that object. Explain why this is true, using an example from your investigation about the characteristics of acids and bases.

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PB349X2
ISBN: 978-1-938946-22-6

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NSTA press
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