PREPARING TEACHERS FOR Three-Dimensional Instruction

Jack Rhoton, Editor

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National Science Teachers Association

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Arlington, Virginia

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Contents

Contents

Contents

Contents

Foreword

Bruce Alberts

The recent U.S. election cycle has made scientists strikingly aware of the potential dangers that society faces when a major segment of the population no longer accepts findings that have been arrived at through scientific consensus. Currently, a widespread distrust of experts and a preference for "alternative facts" threatens democracies. This realization raises the stakes for our education systems: We urgently need to provide future generations with a much-improved science education that empowers adults to function as effective problem solvers and make wise decisions for themselves, their families, and their nation.

I especially admire the clear recognition in this volume that we are all in this together. Both the college faculty who teach undergraduate science classes and the K–12 science teachers in our nation's schools must make substantial changes not only to the goals that they have for their students but also to the pedagogies that they use to teach them. And at all levels, science education cannot primarily be considered an effort to produce more scientists, as it was in the post-*Sputnik* years, when the United States felt technologically threatened by the Soviet Union. Instead, our main goal must be to produce citizens who can "think like a scientist," basing the many important decisions that they must make in their lives on evidence and logic rather than on emotions and "magical thinking."

The challenge in education today is how to produce adults who are effective, rational thinkers able to contribute to (and cope with) our complex and constantly changing societies. To have any chance of success, science courses, including those at the postsecondary level, must discard the all-too-frequent aim of "covering" an entire field like physics, chemistry, Earth sciences, or biology. Only in this way can teachers provide their students with the time they'll need to delve deeply into a few scientific problems and actually employ scientific reasoning based on evidence. Students will also need to learn how scientific knowledge is built up over time through the combined efforts of thousands of independent scientists, enabling them to appreciate the consensus views of the scientific community on issues such as climate change and vaccine safety. Thus, conveying the essence of "science as a way of knowing" needs to become an explicit goal for all science courses.

Consider my own field of biology. Although scientific study of life on Earth should be especially fascinating for all students, this area of scientific research has accumulated such a vast amount of knowledge that introductory courses are often rendered almost useless by attempts to "cover" all that is known. Because of such demands, I find the textbooks used to introduce biology at every level incredibly dull. Even in a very large book, there is rarely enough space to reflect what's really exciting about any one subject. Instead of merely being given the answer to an important biological problem, students should first be forced to struggle with the same challenges that puzzled the best scientists before they were able to solve it.

If we are to produce adults who can use scientific thinking effectively in their daily lives, science teachers at all levels must greatly reduce the number of facts that we cover in class. The *Next Generation Science Standards* (NGSS Lead States 2013) call on K–12 teachers to teach in a manner very different from the way most of them were taught in college. As a result, huge amounts of teacher professional development will be needed to create the type of science education that we seek. Only by teaching very differently at the college level can we ever hope to introduce the same shifts in K–12 classrooms. We are all truly in this together, as this book directly demonstrates.

When I was unexpectedly selected to become the full-time president of the National Academy of Sciences in 1993, I resisted at first because it would require that

I close my research laboratory at UCSF. The Academy's Nomination Committee was finally successful in recruiting me to Washington, D.C., only because they promised that I could become an "education president." Over the course of my 12-year presidency (1993–2005), the academy would in fact publish well over a hundred reports on education, including the first-ever *National Science Education Standards* (NRC 1996). We also partnered vigorously with the Smithsonian Institution to spread inquiry-based elementary and middle school science education through workshops and curricula produced by the National Science Resources Center (now the Smithsonian Science Education Center). Some members of the academy disagreed with this focus, claiming that science education at the K–12 level had nothing to do with postsecondary teacher education but was rather the job of textbook publishers, school boards, and teachers unions. As the contents of this book demonstrate, these critics were clearly quite wrong.

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Preface

The arrival of the *Next Generation Science Standards* (*NGSS*; NGSS Lead States 2013) emanating from the vision established in *A Framework for K–12 Science Education* (*Framework*; NRC 2012) has changed the conversation about best practices for science teaching and learning in our nation's classrooms. This renewed dialogue has not only permeated K–12 science education but also heightened the conversation around changes that need to take place in higher education, both in the experiences that preservice science teachers receive in the science disciplines and in their teacher education programs. These changes extend to designing professional development strategies that help established science teachers understand and embrace the *NGSS.* State policies and regulations will also influence both the pace of implementation of the standards and the manner and fidelity with which they are implemented. The *NGSS* will affect all areas of teaching and learning, including "curriculum, teacher development, and assessment and accountability measures" (Bybee 2014, p. 214). The ultimate goal of these changes is to improve student learning.

The recommendations of the *Framework* and the *NGSS* are shaped by years of research on teaching and learning (NRC 2007). Central to the vision of both is the integration of disciplinary core ideas, science and engineering practices, and crosscutting concepts, which is referred to as three-dimensional learning. In order to achieve this goal, many science teachers will need to change their instructional approaches (Banilower et al. 2013). Chief among the changes is the need for educators to move away from teaching isolated facts and toward practices that engage students in building models through investigations, asking questions, finding solutions to problems, and making sense of phenomena (NRC 2012).

Several states have already adopted the *NGSS,* and additional states are expected to follow. Additionally, some of the states that have chosen not to adopt the new standards in their entirety have adapted much of the language and vision of the *NGSS* into their own state science standards. The vision laid out in the *Framework* and the new science standards has already begun to influence the way science is taught in our nation's schools and will likely drive science education reform for decades to come, affecting the vast majority of science students in the United States.

The purpose of this book is to showcase some instructional approaches that instructors at all levels of education are using to unlock the vision of these new standards, as well as the ways in which both preservice and established teachers are being trained. At the heart of this book is an attempt to showcase shifts, some incremental in nature, that are being made by K–12 science teachers, higher education science faculty, teacher education faculty, other science educators, and policy makers in order to implement the new standards. Fully implementing the vision of the *NGSS* will be a daunting, complex, and time-consuming task. There is no magic wand for achieving the vision. Instead, educators will need to apply a variety of approaches and efforts over an extended period of time. If these new standards are to be implemented with fidelity, we must be willing to shift educational experiences away from the often formulaic methods that many students are now experiencing and support them as they take on the role of practitioners of science.

The science education community is demonstrating that it is ready to meet the challenge of implementing the *NGSS*. In order to do so, science teachers will need to know more than just the proficiency expectations. Merely reading through the new standards and correlating their content to an established curriculum is not sufficient. Preparation for implementing the *Framework*'s vision of teaching and learning will be most effective if it begins during undergraduate coursework and is continuously

Preface

supported through an effective professional development agenda designed to bring about real change in the classroom. Even teachers with years of experience will benefit from extensive support and professional learning experiences, as well as from receiving constructive feedback on what it means to develop motivating lessons and engage students in experiments and investigations that allow them to make sense of core concepts and identify relationships among ideas.

In this volume, we consider a broad range of highly significant topics that affect science teachers and science teacher preparation. We discuss strategies and approaches used by science instructors at various levels, including K–12 science teachers, teacher education faculty, and undergraduate science faculty, and that align with the vision of the *Framework* and the *NGSS.* We also describe professional development programs and approaches for updating practice to meet the goals established in the *NGSS.* Additionally, we discuss the need for state policies and regulations to level the playing field for teachers so that the *NGSS* can be implemented on a wider scale, and we offer examples of successful partnerships among K–12 education, higher education, businesses, and informal science education that can be addressed through STEM education.

The eighteen chapters in this book are organized into five major sections, each with a general theme. The intent is to show how practitioners at various levels are beginning to capture the vision of the *Framework* and the *NGSS.* We believe that the contents of this volume will serve as a motivating resource for the science education community that helps them to harness skills, expertise, and passion as they look to revitalize science instruction. The major themes of this book are highlighted below.

Shifts in Teacher Knowledge and Practice: Models of Teaching to Meet the Intent of the *NGSS*

Teachers represent the critical link between the curriculum and students. Their ability to effectively engage students in three-dimensional learning is key to helping students "think like a scientist." This section describes the changes that some of the nation's outstanding science teachers are making in their classrooms to address the vision called for in the *Framework* and the *NGSS*, such as shifting from teaching science as inquiry to teaching science as practice. Science and engineering practices, crosscutting concepts, and disciplinary core ideas are addressed in this section, as are issues related to *NGSS*-aligned curriculum planning and methods of assessment.

Professional Development Strategies That Support the Implementation of the *Framework* and the *NGSS*

Teachers and administrators must recognize that student learning, classroom teaching, curriculum materials, and student assessment all play a role in ongoing professional development that promotes effective implementation of the *NGSS*. This section describes examples of professional development strategies for helping K–12 science teachers address specific subject matter while learning more about instructional activities that have been proven effective at promoting critical thinking and depth of understanding. These strategies show teachers how to develop content-specific learning opportunities that allow students to engage in argumentation and develop science models in the context of their science lessons rather than in isolation. The type of professional development discussed in this section offers many opportunities for active learning and problem solving in the classroom.

Teacher Preparation Courses

This section discusses the ways in which education faculty are supporting future teachers' understanding of disciplinary core ideas, science and engineering practices, and crosscutting concepts. As teacher education programs adjust to the shifts called for in the *Framework* and the *NGSS*, preservice teachers need opportunities to build capacities and demonstrate their knowledge as they construct explanations, analyze and interpret data, develop models, and engage in argumentation. Future teachers need to be involved in designing lessons, assessing students, implementing strategies, evaluating outcomes, and reflecting with expert guidance on both the content they are learning and the most effective learning opportunities for students. This section also outlines the state and district policies necessary for smooth implementation of the *NGSS*.

Undergraduate Science Courses for Prospective Teachers

In their undergraduate science courses, preservice teachers see science teaching in action and gain the confidence and skills needed to implement educational shifts within their own classrooms. For this reason, teaching candidates need to experience models of context and content in their undergraduate science courses and in their teacher education preparation programs that fit within the elements of the *Framework* and the *NGSS*. In this section, higher education instructors describe some of the changes they have made to ensure that this is the case, as well as some of the challenges they have confronted. We cannot expect future science teachers to embrace the paradigm shift called for in the *Framework* and the *NGSS* if they have never seen these models applied. Building stronger partnerships between disciplinary departments and schools of education in colleges and universities will help all students attain higher standards.

Harnessing the Business Community and Other Entities to Support the Vision of the *NGSS*

The last section in this volume describes partnerships between industry and education to achieve common objectives aligned to the *Framework* and the *NGSS*. Successful partnerships ensure that K–12 students receive the skills and knowledge they'll need to succeed in both higher education and the workforce, emphasize the relationship between classroom learning and science careers, and support teachers as they strive to build stronger content knowledge and pedagogical expertise. Specifically, this section explores the work of East Tennessee State University's Center of Excellence in Mathematics and Science Education as well as the ETSU Northeast Tennessee STEM Hub. The section also provides guidelines that leaders can use to form new partnerships, establish common goals, and encourage continuing contributions to meeting those goals.

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Acknowledgments

My interest in STEM (science, technology, engineering, and mathematics) education can be traced to early experiences growing up on a farm in rural Scott County, Virginia, during the 1950s and 60s. These experiences ranged from animal husbandry to machinery maintenance. When equipment broke or malfunctioned, it had to be repaired in order for the work to continue. Because replacement parts were not always readily available, creative problem solving, ingenuity, and mechanical skills were essential to bringing the broken farm implements back to functionality. One can argue that such experiences, obtained at an early age, are akin to the three-dimensional learning called for by *A Framework for K–12 Science Education* (*Framework*; NRC 2012) and the *Next Generation Science Standards* (*NGSS*; NGSS Lead States 2013). At a rudimentary level and without knowing it, I was integrating all three dimensions—disciplinary core ideas, science and engineering practices, and crosscutting concepts—on the farm to better explain phenomena and solve problems.

When the Soviet Union launched the *Sputnik* space satellite in October 1957, my interest in science and technology was further galvanized. I have distinct memories of crawling out of my bedroom window and onto the roof late at night to lie on my back and watch *Sputnik* glide through the sky. I was 14 years old and a freshman at Rye Cove High School in Clinchport, Virginia. It was as though I had a front-row seat to the beginning of the space age. The excitement surrounding the *Sputnik* launch changed by life, and in subsequent years I experienced the deep influence that this event had on STEM education in our nation's schools.

I mention these early experiences because I am so grateful for the K–12 teachers who nurtured my interest in STEM. These educators actively engaged their students in the process of learning science. Similarly, I am indebted to the higher education science and science education professors who instilled in me their passion for teaching and learning. In particular, I want to thank Franklin Robinson of Hiwassee College; the late William "Bill" Pafford and Hubert Armantrout of East Tennessee State University; the late Ertle Thompson of the University of Virginia; Daniel Sonenshine of Old Dominion University; and the late A. Paul Wishart of the University of Tennessee. These caring and compassionate scientists and teachers modeled best teaching practices and provided me with life-changing experiences. A host of other individuals on the national stage, too numerous to mention here, has also influenced me and my work in STEM education.

I also wish to express my sincere appreciation to the individuals who made this publication possible. The anonymous reviewers who assessed the book proposal and offered valuable feedback early on in the process have my gratitude. Thanks as well to Gerry Madrazo for his encouragement and assistance.

I would especially like to thank the authors who contributed to this book. No volume is any better than the chapters within it, and I appreciate the time and efforts of those whose work you'll find here. I believe the team of authors assembled to write this book provides a blend of knowledge and skills that contributes uniquely to its purpose. In particular, I would like to thank Amy Selman, my former graduate assistant, for applying her expert guidance to each manuscript. She went above and beyond the call of duty in providing helpful feedback. I also wish to thank my former colleagues at the East Tennessee State University Center of Excellence in Mathematics and Science Education for their continued support and encouragement.

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CHAPTER 12

Constructing Explanatory Arguments Based on Evidence Gathered While Investigating Natural Phenomena in a Methods Course for Middle School Teachers

Frackson Mumba, Laura Ochs, Alexis Rutt, and Vivien M. Chabalengula

The effective implementation of the science and engineering practice "engaging in argument from evidence" will depend on teachers' experiences constructing explanatory arguments based on evidence, their understanding of the process of scientific argumentation, and their pedagogical knowledge about the role of argumentation in science teaching. In this chapter, we discuss ways to engage preservice science teachers in evidence-based argumentation and discuss how to assess their science content knowledge, argumentation skills, and ability to plan instructional activities centered on argumentation. Finally, we review lessons learned and further suggestions for engaging teachers in evidence-based argumentation.

Introduction

Science is social in nature, and advancements in scientific knowledge are most often achieved through collaboration among scientists (Asterhan and Schwarz 2007; McDonald 2010). Through collaboration, scientists use the process of argumentation to evaluate competing scientific ideas and to arrive at conclusions about natural phenomena (Ozdem et al. 2013). Engineers also engage in argumentation as they investigate natural phenomena, test design solutions, and use evidence to evaluate their solutions.

A Framework for K–12 Science Education (*Framework*; NRC 2012) and the *Next Generation Science Standards* (*NGSS*; NGSS Leads States 2013) have identified construction of explanatory arguments based on evidence as one of the eight essential science and engineering practices. According to the *NGSS*, scientific argumentation is the process used to develop evidence-based conclusions and explanations. In addition, the practice supports critical thinking and promotes a deeper understanding of science content knowledge and the nature of science (Cavagnetto 2010). Because the collaborative and social nature of the argumentation process appeals to many students (Osborne 2010), it is an effective strategy for motivating them to learn about science.

Sampson and Blanchard (2012) found that teachers cited lack of time, low student ability levels, and their own lack of knowledge about the argumentation process as common obstacles to implementing the practice in their classes. Many teachers receive no formal training in scientific argumentation in their undergraduate science courses or preservice science methods courses. If training in evidence-based argumentation is present in teacher education at all, it usually focuses on *teachers'* argumentation skills (e.g., Aydeniz and Ozdilek 2015) or on argumentation as an instructional strategy (e.g., Simon, Erduran, and Osborne 2006). It is rare for teachers to receive firsthand instruction on the scientific use of explanatory argumentation (e.g., Asterhan and Schwarz 2007; Kaya 2013). This is unfortunate, because the willingness and ability of teachers to implement the practice in classrooms depends largely on their personal experience with and understanding of it.

Clearly, there is a need to engage preservice teachers in the construction of explanatory arguments based on evidence (e.g., McNeill and Knight 2013). There are four main rationales for doing this:

1. It helps teachers to develop an understanding of the need for empirical evidence in scientific inquiry.
2. It offers teachers insights about the process through which scientists develop new knowledge.
3. It shows teachers how to engage their students in constructing scientific explanations based on evidence.
4. It teaches preservice educators how to develop and utilize instructional materials for teaching the practice.

Description of Science Methods Courses

We engage our preservice teachers in constructing explanatory arguments in two consecutive science methods courses. The first course, in the fall semester, is designed to increase preservice teachers' understanding of science content knowledge, inductive instructional approaches, scientific argumentation, the nature of science, technology integration, and assessment. After preservice teachers have learned about the essential features of inquiry, they are ready to learn about argumentation. In the inquiry lessons, teachers learn to use data analysis to formulate explanations. We present each instructional strategy by teaching a science lesson to preservice teachers, who participate as students, then debriefing the lesson by highlighting characteristics of the strategy. Next, the preservice teachers develop their own lesson plans or activities for each instructional strategy, then work in pairs to teach their lessons either in our class or during their clinical experiences at local schools.

The spring semester science methods course is designed to teach preservice teachers about project-based and problem-based learning, argumentation in engineering design solutions, and integration of engineering design into science teaching. The course also teaches how to incorporate these strategies into science units. This course addresses several of the science and engineering practices listed in the *NGSS* by using an informed engineering design approach (Burghardt and Hacker 2004) to engage preservice teachers in design projects that integrate science and engineering. Emphasizing the intelligent nature of engineering design helps motivate students to learn science and engineering concepts.

The activities in the course focus on specific STEM concepts. For example, a challenge might require students to design models for minimizing energy transfer as a way of learning about thermodynamics concepts. Once the context, specifications, and constraints of the problem have been made clear, the participants engage in short, focused activities related to the relevant content knowledge. Next, they use this knowledge to design a solution to the problem. Through the process of addressing the design challenge, participants also learn about the ways in which engineers use argumentation to investigate phenomena and how to test solutions using evidence to evaluate the claims made by others.

Instructional Models for Engaging Teachers in Scientific Explanatory Arguments

Scientists and engineers generate new knowledge in two main ways: by collecting, analyzing, and interpreting their own data, and by analyzing and interpreting data collected by others. We engage our preservice teachers in these two processes by using modified versions of the Generate an Argument and Evaluate Alternatives models developed by Sampson and Gerbino (2010).

The main difference between the two models is that the Generate an Argument model has learners use data collected by others, whereas the Evaluate Alternatives model has them collect the data themselves. Both models require participants to analyze the data to answer research questions. Because these models were developed for use with K–12 students, we have modified both of them to meet the needs of preservice teachers by adding three steps: an initial explanation, a connection to scientific knowledge, and an assessment of content knowledge, argumentation skills, and the ability to use the model to plan a lesson.

Modified Instructional Model for Generating an Argument

Step 1: Identify the problem and research question. Small groups of preservice teachers are given a handout that includes a description of the problem, scientifically oriented research questions to be answered, and instructions for presenting the evidence to support teachers' claims and explanations. The teachers are asked to identify the problem and research questions presented in the description.

Step 2: Generate a tentative claim. Each group uses prior knowledge to develop a tentative argument. These argument statements are presented on a poster that shows the tentative claim, evidence, and research question.

Step 3: Develop an initial explanation. Each group uses prior knowledge to provide explanations that support their tentative claims. While formulating their initial explanations, groups are not allowed to use any outside resources. The goal is to identify background and related knowledge as well as any misconceptions.

Step 4: Analyze the data and formulate an explanation. Each group analyzes the data provided by the instructor. Sometimes explicit analysis instructions are provided; other times, it is up to the group to determine which data are most important and what types of analysis are needed. Then, each group interprets its analysis and formulates explanations that support or refute the tentative claim.

Step 5: Connect the explanations to scientific knowledge. Each group uses additional scientific resources to compare accepted scientific knowledge to the explanations formulated in Step 4. Summaries of related theories or resources may be supplied by the instructor or teachers may be tasked with locating them. The goal is for teachers to determine whether their claims and explanations are consistent with accepted scientific explanations.

Step 6: Engage in argumentation. Using a round-robin structure, groups present their claims, evidence, and explanations to the class. One person in each group stays with the poster and presents the group's argument while the others circulate to learn about the arguments developed by other groups (Sampson and Berdino 2010). Participants communicate their ideas and evidence, evaluate explanations, and ask or answer questions. This step helps preservice teachers to understand that the goal of scientific argumentation is not to win, but to develop a better understanding of the scientific concepts under investigation.

Step 7: Reflect. After the presentations, groups review the peer feedback and any new evidence they may have encountered to revise their claims and explanations. We wrap up the instruction by summarizing the problem or research question, the nature of the data analyzed, and the claims presented by the groups before explicitly connecting the activity to the main science concepts that the lesson was designed to address. Preservice teachers are then required to write individual summaries of the main science concepts employed throughout the activity and to describe how they might modify the activity for middle or high school students.

Step 8: Assess content knowledge and argumentation skills. The revised claims submitted by each group and the summaries submitted by individual participants are scored to evaluate argumentation skill, understanding of the science content, and the ability to use this model to plan lessons. (This step is discussed in further detail following the description of the second instructional model.)

For a lesson using this model to study climate change, a handout might read as follows:

> Stories abound in the media about the effects of climate change on our planet. Extreme weather, melting glaciers, and habitat loss are just a few of the consequences that scientists attribute to the continuous warming of our climate. Although most scientists agree that our climate is changing, reasons for this change remain a source of contention. Some scientists claim that the change in climate is part of a natural cycle of the Earth's warming and cooling. Other scientists argue that climate change as we see

it now is largely caused and accelerated by human activity. Your team of scientists has been charged with analyzing the data provided to evaluate these two competing explanations of the cause of climate change.

The guiding research question for this lab is: "What causes climate change?" Your argument should include a claim about the reasons for climate change, evidence to support your claim, and a justification of your evidence. Due to the contentious nature of this question, it is imperative that you use the data provided to you. You also have access to the internet and the school library to locate any additional data that supports your claim.

Once you have made your claim, compiled your evidence, and written a justification of the evidence, you must organize the research question, your claim, your evidence, and the justification on a display board. Make sure that your claim is well supported and that the evidence you are using makes sense and is closely related to your claim. Be sure to compare your explanations to accepted scientific knowledge about climate change

We will use a round-robin approach to share the arguments and claims. One person in your group will remain at your table to share your argument while the remaining members will circle around and critique other arguments. As a critic, you will need to determine the credibility of other groups' arguments based on their evidence, explanation, sources, and justification. Does their explanation make sense? Do they provide enough supporting evidence to convince you that their explanations are empirically based and consistent with accepted scientific knowledge on climate change?

After completing the round robin, you will be provided with additional instructions for submitting a reflection of your individual experience with this activity.

Modified Instructional Model for Evaluating Alternatives

Step 1: Introduce the scientific phenomenon. The instructor describes observations pertaining to a phenomenon and provides several possible explanations for them.

Step 2: Write or review research questions. Participants are either asked to use the information presented in the first step to write research questions that will guide testing of the possible explanations, or they are provided with a set of research questions to review and possibly refine.

Step 3: Select a claim and provide an initial explanation of it. Groups are asked to choose one of the claims and use prior knowledge to provide supporting explanations for it. While selecting a claim to support, the groups are not allowed to use outside resources. The goal is to identify their background and related knowledge as well as any misconceptions.

Step 4: Gather evidence. The groups design experiments and collect data to test their claims. To ensure that all safety issues have been considered, each group's experiment is approved by the instructor.

Steps 5–9 of this model are the same as steps 4–8 of the modified Generate an Argument model.

For a lesson using this model to study carbon dioxide, a handout might read as follows:

> Scientists have many concerns about the increasing amounts of greenhouse gases, like carbon dioxide, that are getting into our atmosphere. But what exactly does carbon dioxide do?
>
> The guiding research question for this lab is "How does carbon dioxide affect the Earth's atmosphere?" Scientists have provided two competing answers to this question. One group of scientists claims that atmospheric carbon dioxide operates as a thermostat that controls the temperature of Earth. The other group attributes carbon dioxide gas to natural causes, such as global temperature increase. In your groups, evaluate these claims and select one to support with evidence. You will justify this explanation using supporting evidence to the class.
>
> First, however, you will design and conduct an investigation for assessing the difference between a closed system with heavy amounts of carbon dioxide and a closed system with typical atmospheric air. Lab supplies include three dry 16-ounce water bottles, clay, a straw, baking soda, vinegar, and wireless temperature probes. You will also have access to sunlight.
>
> Once you have designed and completed your investigation, use your data and any background

knowledge you have to make a claim about the research question. Don't forget to provide convincing evidence and a justification. After making your claim, compiling your evidence, and writing a justification, you must organize the research question, your claim, your evidence, and the justification for your evidence on a display board. Make sure that your claim is well supported and that the evidence you are using makes sense and is closely related to your claim.

We will use a round-robin approach to share our arguments. One person in your group will remain at your table to share your argument while the remaining members circle around and critique others' arguments. As a critic, you need to determine the credibility of other groups' arguments based on their evidence and justification. Does it make sense? Do they provide enough supporting evidence to convince you that what they are saying is true?

Table 12.1 shows that these example labs not only engage preservice teachers in constructing explanatory arguments based on evidence but also address other science practices, core ideas, and crosscutting concepts.

Assessment

Our assessment focused on establishing the extent to which preservice science teachers had increased their understanding of the scientific phenomena under investigation, improved their argumentation skills, and gained pedagogical knowledge about the use of argumentation in science teaching. To assess understanding of science content, we use a model developed by Zohar and Nemet (2002) that involves examining the quality and accuracy of the content knowledge presented in the participants' claims, evidence, justifications, and explanations. The quality of explanations and justifications are scored as follows: *no consideration of scientific*

Table 12.1. Matrix of Argumentation Activities and the *Framework*

A Framework for K–12 Science Education	**Climate Change**	**CO_2 Lab**
Science and Engineering Practices		
Asking questions	x	x
Developing and using models		
Planning and carrying out investigations		x
Using mathematics and computational thinking	x	x
Constructing explanations	x	x
Engaging in argument from evidence		
Obtaining, evaluating, and communicating Information	x	x
Crosscutting Concepts		
Patterns	x	x
Cause and effect: Mechanism and explanation	x	x
Scale, proportion, and quantity		x
Systems and system models	x	x
Energy and matter: Flows, cycles, and conservation	x	x
Structure and function		
Stability and change	x	
Disciplinary Core Ideas		
Human impacts on Earth systems	x	x
Global climate change	x	x
Natural resources	x	x

knowledge, inaccurate scientific knowledge, nonspecific scientific knowledge, or *correct scientific knowledge*.

To assess preservice science teachers' argumentation skills, we use a model developed by Sampson and Gerbino (2010) that involves determining the extent to which the empirical evidence is relevant and fits with the claim, the extent to which the claim is sufficient and consistent with accepted scientific theories and laws, and whether the data analysis was conducted using appropriate methods.

To assess teachers' ability to plan instruction centered on argumentation, we require each of them to use the two instructional models described in this chapter to develop two science lesson plans of their own. We then analyze their plans and assess their fidelity to the models. We also use open-ended prompts to assess understanding of science content knowledge and scientific argumentation and of the difference between scientific argumentation and scientific explanation.

Conclusions, Challenges, and Recommendations

We have learned that engaging preservice science teachers in explanatory arguments based on evidence increases their science content knowledge, argumentation skills, understanding of the nature of science, and ability to plan instruction centered on argumentation. We have also observed that preservice teachers tend to demonstrate higher levels of interest and motivation while learning about instructional strategies centered on scientific argumentation and that some preservice teachers engage in more argumentation if the phenomena under investigation are applicable in K–12 science classrooms. However, some teaching candidates demonstrate resistance to learning science through argumentation, and others exhibit challenging knowledge gaps when it comes to science concepts. It is also difficult to develop activities that are relevant to all teachers regardless of grade level or science discipline. We try to overcome these challenges through individual accommodations and flexible instruction. Often, we are able to leverage the challenges to initiate discussions about interdisciplinary core ideas and prompt deeper reflection among prospective teachers.

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Index

Page numbers printed in **boldface type** indicate tables or figures.

Index

Index

Index

PREPARING TEACHERS FOR
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