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# Teaching Early and Elementary STEM

Alissa A. Lange
*East Tennessee State University*, langea@etsu.edu

Laura Robertson
*East Tennessee State University*, robertle@etsu.edu

Jamie Price
*East Tennessee State University*, pricejh@etsu.edu

Amie Perry (Craven)
*East Tennessee State University*, perryaa@etsu.edu



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# Teaching Early and Elementary STEM

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By Alissa A. Lange, Laura Robertson, Jamie Price, & Amie (Craven) Perry

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An open-access textbook for early childhood and elementary education pre-service courses focused on STEM education.

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# About Us

**The Early Childhood/Elementary STEM Collaboration - Author Team**

Dr. Alissa A. Lange, Associate Professor of Early Childhood Education, ETSU, Johnson City, TN
Dr. Laura Robertson, Associate Professor of Science Education, ETSU, Johnson City, TN
Dr. Jamie Price, Associate Professor of Math Education, ETSU, Johnson City, TN
Mrs. Amie Perry (Craven), PhD student, Early Childhood Education, ETSU, Johnson City, TN

**External Reviewers**

Dr. Lori Meier, Professor of Education, CUAI and JPL/NASA Solar System Ambassador, ETSU, Johnson City, TN
Cindy Hoisington, Early Childhood science educator, Education Development Center Inc., Waltham, MA
Dr. Kristin Rearden, Clinical Professor of STEM Education/Science, University of Tennessee, Knoxville, TN

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Thank you to other STEM collaboration team members for input on the content and scope of this text, including Dr. Ryan Nivens and Qiuju Tian.

We would like to thank David Harker, philosophy professor at ETSU, who authored part of our section on "Why Science and STEM?" His work on the philosophy of science and how the public understands scientific knowledge can be found here. Thanks also to Chris Bowen, for contributing to the section on equity in early and elementary STEM education found here. In addition, we appreciate our external reviewers listed above, who spent their time giving us valuable feedback on drafts of this textbook.

**More on the STEM Collaboration in Appendix A**

## Overview

**Purpose**

This OER was written to support pre-service early childhood and elementary teachers in their journey to become facilitators of science, technology, engineering, and math, or "STEM," in their future classrooms. Students who read and use this text will deepen their understanding of "STEM" and "integrated STEM," learn what early childhood and elementary students need to know and be able to do in relation to STEM, and understand ways to create activity plans and implement current research-based approaches to teaching and pedagogy.

**Format**

This resource was created in Microsoft Word and will be available as an Adobe PDF file, so that it can be downloaded and edited. We will also have a version available to be viewed online on a page dedicated to this collaboration that is a part of Dr. Lange's EC STEM Lab website.

**Accessibility**

Our OER was created with attention to those with disabilities. We used a template for Microsoft Word that enables the resource to be used with a screen reader. Online portions will include best practice in accessibility, such as using Alt Text for images and using hyperlinks. We worked with ETSU staff to ensure that our resources comply with these standards for the PDF and online versions. These tools address issues of equity and affordability and allow access for many students within and outside of our programs.

**History**

Our Early/Elementary STEM Collaboration team has been working together since 2017 with the intention of increasing the quality of teacher preparation in STEM across early childhood and elementary education. The team is composed of math and science education professors and classroom teachers in pre-school through fifth grade. The collaboration also depends on the pre-service teachers enrolled in each year in STEM education courses. We are driven by the values of collaboration, strengths-based approaches to teaching and learning, constructivist philosophy of teaching and learning, and applied STEM experiences to increase access and equity. Our model of preparing pre-service teachers has been published elsewhere in more detail (Robertson, Nivens, & Lange, 2019), but we describe the approach components briefly below.

We have worked across early childhood and elementary education departments and have found significant overlap in our goals and approaches through the lens of STEM, even when other philosophical differences often characterize these programs (File & Gullo, 2002). However, we have not found a text that would support pre-service teachers across preservice teacher education departments in STEM and teaching that covers the full grades of interest, including preschool through 5th grade. We built this open access product to include the following: 1) completely new content that includes input from our team as well as examples of integrated STEM learning experiences; 2) adaptations of existing resources, and; 3) compilations of existing free resources (e.g., Next Generation Science Standards).

## Unit 1: Introduction to STEM

**What is STEM?**

We want to start with a definition of the domains of STEM and what we mean by integrated STEM education. A 2018 brief focused on NSF-funded early STEM projects provides a concise definition of each domain.

***Science*** *is the study of the natural world, seen and unseen. Science includes what scientists and children who are doing science learn (concepts and crosscutting ideas) and how they go about learning it (the practices of science). Science is connected to math, technology, and engineering in many ways.*

***Technology*** *involves the application of scientific knowledge for practical purposes, such as to improve productivity, make things, or provide services. It includes all human-made objects—basic and advanced, non-digital and digital— that support us in work and in our daily lives. Again, it is inextricably linked with the other STEM domains, like how we create technology using engineering.*

***Engineering*** *is the process of designing to meet human needs and wants under various constraints such as time, money, available materials, and the laws of nature. Engineering has strong connections to many other disciplines, particularly mathematics, science, and technology.*

***Mathematics*** *is the study of quantity, structure, shape, and change. It provides a foundation for many aspects of daily life, including for much of science, technology, and engineering. Math is used in science, technology, and engineering. The mathematical sciences include more than numbers and arithmetic—they also deal with such topics as geometrical figures and structures, measurement, and logical argumentation. Mathematicians and children doing math use the practices of mathematics to identify crosscutting patterns and structures and to understand and explain phenomena.*

(Adapted from Sarama et al., 2018)

As in the 2018 report noted above, we use STEM to refer to each of the individual domains as well as the ways in which the domains can be linked to one another when we teach and learn. The science and engineering practices described below are a good illustration of the overlap between the four disciplines. We talk about integrated STEM in this text to describe efforts specifically to teach two or more of these domains, S.T.E., and M., at the same time. STEM is an acronym because of the special ways that these subjects can be - and are - linked. Another national report published by National Academies Press (2012) discusses how integrated STEM education is not one thing. It may look very different in different contexts, or when the teacher has different aims. We discuss integrated STEM in more detail in Unit 3: Integration.

**"I was not taught science and math this way"**

When many of us were in school, we learned science by memorizing a bunch of facts and had to recall them on multiple-choice tests. Old ways of learning math were similar. We had to memorize procedures without understanding the reason behind the procedure. We did not do what scientists or mathematicians did for the most part. We sometimes did labs, where the procedures were pre-determined as well as the outcome. And the labs usually occurred after we had taken the required notes and defined the key terms. This is no longer regarded as best practice in science teaching.

> *"…traditional views of science learning focused on individual learners' mastery of factual knowledge. As a result, lecture, reading, and carrying out pre-planned laboratory exercises to confirm already established findings were common instructional strategies (National Research Council, 2007, 2012a). Contemporary views of science learning and teaching instead emphasize engaging students in the practices of a science framework including asking questions, developing and using models, carrying out investigations, analyzing and interpreting data, constructing explanations, and engaging in argumentation…"*
> (National Academies of Sciences, Engineering, and Medicine, 2018; p. 145)

In our courses, we will learn about the current thinking in science and math teaching and how we need to ensure students have a chance to DO the science and math and engage with the practices and processes for themselves. We must give our students the chance to find out answers for themselves through meaningful opportunities to explore, learn, explain, and collaborate. Through projects such as those you will find in the chapters that follow, we aimed for our prior pre-service teachers to learn this way too…to create projects like Unit Plans or interactive notebooks, and to the extent possible, actually *deliver* them to small groups of students prior to the typical "placement" or "residency," in order to see for themselves how to teach this way and how this approach might help students learn science, math, and integrated STEM. In past years, we have used the term "microteaching" to describe these small, applied teaching experiences. This might sound like it draws from constructivism, which we discuss below. In our courses, we want you to create a project that you will draw from to teach real students, and that practicing teachers may eventually use in their own classrooms.

**Why STEM?**

## We Need our Planet

Science education is critical for our early and elementary-age students for many reasons. First, there are a number of significant issues facing the survival of our species and other life on Earth right now. One notable issue is that of climate change. Although the issue has become political, the majority of the scientific community agrees that this is a real phenomenon that will have devastating impacts on our lives and the lives of our children, and sooner than we think (see evidence). For more information about climate change, read about the work of the young environmental activist, Greta Thunberg.

Another issue related to life on our planet is the fact that ecosystems are interconnected. Our planet is delicately balanced such that changes to one species or habitat can cause huge disruptions across the globe. For example, bees play a large role in life on earth, and their numbers are shrinking. If this continues, our whole food chain could be negatively impacted. Another issue is deforestation. Trees are critical to producing oxygen among other benefits to humans and animals, and we need to know what the threats to our trees are and how to protect them.

It is imperative that we have a scientifically-literate citizenry (see here for a detailed definition) that is both able and motivated to 1) identify and understand these issues, and 2) address and solve the current and future problems. Some of our young students will become future scientists while others will use science to make personal and civic decisions based on scientists' recommendations; both groups need to be prepared to use science. One colleague's favorite definition of scientific literacy is, "the ability to read and understand the New York Times science pages." This part is also important for your future students! Whether or not they choose STEM careers, they all need to have some degree of scientific literacy.

Likewise, students' abilities to apply mathematics and analyze the data that provide evidence for scientific findings are critical to future decisions in personal, professional, and political realms. These are not problems that are coming in hundreds of years, but they are already here. How can we support life on earth for ourselves, our children, and other life on Earth as the climate gets warmer? How can we protect the Amazon rain forest, which has been under attack since the COVID-19 pandemic? What can ordinary citizens do to take care of each other, their neighborhood, and our planet?

### Our Technological Future

Another reason that STEM education is so critical for early childhood and elementary students is that we are increasingly dependent on technology (or the contribution of the "T" in STEM) in our country and across the globe. This is only likely to increase and to be even more prevalent in our daily lives over time. We need people who can do and understand computer programming, who can use technology and teach others to use it, and who have the habits of mind, approaches to learning, and specific and systematic approaches to solving problems - like flexible thinking, creativity, computational thinking, and a growth mindset - to use and create technology in the future (see more on digital citizenship from ISTE). Employers are increasingly looking for staff who have these types of characteristics. (Technology goes beyond only smartphones or computers – see Unit 8: Engineering and Technology.)

### The Nature of Science and Society

We all need to learn about science including what it is AND what it is not. Science impacts our lives every day. We need to understand the nature of science, what we do and do not learn and know from the practice of science and use this information to make good decisions (e.g., about immunizations). The section below was written by David Harker, philosophy professor at East Tennessee State University:

> *"It's rewarding to know a little bit about the world we inhabit, whether it's the different parts of a plant, the planets in our solar system, or the processes by which canyons and mountain ranges are formed. Children are curious, and curiosity is something that should be encouraged and cultivated. No matter how much we each learn, however, there will always remain an extraordinary amount that we don't know. The pace of scientific progress and the degree of specialization ensures that we can only ever come to know a tiny fraction of what others have learned.*
>
> *It's partly for this reason that students [and pre-service teachers] should also think about how science is conducted, how problems are investigated, how scientists support their conclusions*

*and theories with evidence and argument, and how the sciences are as concerned with correcting prior mistakes as they are with exploring new ideas. We can emphasize for students [and pre-service teachers] the importance of asking good questions, finding suitable methods, and seeking out relevant evidence, but we should also be mindful that scientists spend their careers refining and improving their questions, methods and analyses. Attempts to reduce all of science to a concise sequence of steps serves no-one well.*

*The scope of modern science, both in terms of its subject matter and its methods, reminds us that science is, and must be, a collaborative enterprise. Teams of scientists work together, bringing different skillsets to the table. Scientists trust one another. They trust one another to report data and observations carefully and honestly. They look to other disciplines and research programs for corroborating evidence, opportunities for partnership, and alternative perspectives on shared interests. Science is the product of vast networks of individuals, not the lone geniuses that are so often given credit. When we study science, we benefit from the labor and talents of large communities of scientists, working collectively to identify and develop the best and most promising methods and ideas. Recognizing that trust plays a pivotal role within the sciences, furthermore, needn't imply that scientific ideas aren't rigorously questioned and scrutinized; rather, it underscores how scientists learn from each other, as much as they learn from experiments and observations.*

*Trust is important for scientists, but it's also important for the public understanding of science. Whether for financial or ideological ends, many special interest groups seek to undermine scientific conclusions, either because those conclusions are inconvenient or unpalatable. Science detractors promote their own agenda by magnifying uncertainty surrounding the science, creating the appearance of scientific controversy where no substantive controversy actually exists, and generally seeking to confuse the public about the current state of scientific knowledge. All this can lead to poor decision-making and undue sympathy for conspiracy theories and unsubstantiated rumors. Science education is critical, because all our futures are improved if students learn to listen most carefully to those who are best informed."*

- David Harker, 2020

## The Role of Math in our Future

Similarly, we need a solid mathematical foundation for many reasons. In order to make sense of the big data that are now a part of life, we need a workforce and the general public to understand data analysis that gets used to making major policy decisions. Math is critical to the practices of science and engineering, as they help us make sense, measure, and understand the phenomena we observe. Math is a part of our everyday lives as well, and contributes to our abilities to function and make sense of the world around us.

**Key Resources**

- Standards
  - *Next Generation Science Standards* ([NGSS]; NGSS Lead States, 2013)

  - *Common Core State Standards for Mathematics* ([CCSS]; National Governors Association, 2010)
  - *Tennessee State Science Standards* (TN Board of Education, 2018)
  - *Tennessee Math Standards* (TN Board of Education, 2018)
- Integration
  - *STEM integration in K-12 education: Status, prospects, and an agenda for research* (Honey, Pearson, & Schweingruber, 2014)
- Books
  - *STEM in early childhood education: How science, technology, engineering, and mathematics strengthen learning*. (Cohen & Waite-Stupiansky, 2019)
  - *Teaching STEM in the Preschool Classroom: Big Ideas for 3- to 5-year-olds* (Lange, Brenneman, & Mano, 2019)
  - *Elementary Science Methods: A Constructivist Approach (What's New in Education)* 6th Edition (Martin, D.J., 2011)
- Other OERs
  - *Astronomy for Educators* (Barth, D. E., 2019)
- Practitioner Journals
  - NSTA's *Science and Children*
  - NAEYC's *Teaching Young Children*

**Reflection Questions**

1. Take a survey of self-efficacy, attitudes, beliefs about science (e.g., STEBI-B) and/or math (e.g., MTEBI). Look at your responses. Why do you think you responded in that way?
2. What was your most positive memory of science/math in school? Why? If you don't have any, or you only have negative memories of your own science/math educational experiences, why do you think that is?
3. Read this article on STEM and gender equity. What might the young children's decisions in the story at the start of the article have to do with you and your future classroom?
4. Read David Harker's section above. Talk with a small group or peer about what the content means to you. What issues in science are the topic of debate in the public, but are mostly agreed in consensus among scientists?

# Unit 2: Theory & Framework

**The "what" of Science and STEM Education**

*"From its inception, one of the principal goals of science education has been to cultivate students' scientific habits of mind, develop their capability to engage in scientific inquiry, and teach them how to reason in a scientific context."* (NRC, 2012).

The Framework for K-12 Science Education Practices, Crosscutting Concepts, and Core Ideas was used to develop the national standards in science, as noted previously. The Tennessee Academic Standards for Science are also based on these national standards and this underlying framework. The Framework for K-12 Science Education focuses on fewer core ideas than did past standards, in order to avoid the coverage of multiple disconnected topics, which is referred to as a "mile wide and an inch deep" (p. 25; National Research Council, 2012). This means that too many different topics used to be covered in science education, which meant that students had to do a lot of memorization in order to keep up. Since we now want students to spend more time exploring phenomena and related concepts directly for themselves, engaging in the activities that scientists do, more time per concept is needed. Thus, having fewer concepts to learn allows for deeper engagement over time with the concepts that are included for a given grade. The introduction of the Common Core State Standards for Mathematics and the Tennessee state math standards echoes this effort. In order to help students to develop deeper conceptual understandings and procedural fluency with math, students spend time exploring ideas and making connections to make sense of the mathematics.

The Framework for K-12 Science describes the following three **dimensions** of science education, which are important in understanding the NGSS and TN State standards: Science and Engineering Practices (SEPs), and Crosscutting Concepts (CCCs), and Disciplinary Core Ideas (DCIs). Each of these components can be understood as working together to comprise the standards, in terms of what we want students to know or understand, and what we want them to be able to do.

*Science and Engineering Practices (SEPs)*. The NGSS Science and Engineering Practices (SEPs) describe the activities of scientists and engineers and that we want students to engage with as they are learning and doing science. Each practice includes a host of specific skills. For example, developing and using models requires that a student understands what a model is, what makes a good model, knows how to use them. In science education, the focus should be on supporting students' scientific thinking rather than on memorizing facts and information. Bybee's 2011 article includes descriptions of how the practices below translate for young children. The practices are:

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

For new science educators, the practices can at first seem intimidating. Their language is not always clear nor their implications for young students. All SEPs can be used with students as young as preschool. The language of the practice may be adapted for younger students, and it can be helpful to give students examples of what the practice might look like in their classrooms. In a kindergarten classroom, a teacher might ask students "How can we test this?" thus, leading students through the practice of planning and carrying out investigations. In a unit on floating and sinking (TN K.PS1.2), the class discussion might result in students selecting a tub, filling it with water with help from an adult, selecting items to test, and dropping items into the water to see if they sink or float. In the *TN Science Standards Reference*, a helpful table is included on pages 27-34 that breaks down what each practice looks like in early elementary (K-2), late elementary (3-5), middle school (6-8), and high school (9-12). This table is a useful starting place when planning for the science and engineering practices in a lesson or unit.

*Crosscutting concepts (CCCs)*. "Crosscutting concepts have application across all domains of science. As such, they are a way of linking the different domains of science." (NGSS). These concepts can help students see how the concepts (DCIs, below) are interrelated. A webpage with definitions is available online, along with a document available for free download from NSTA. The document includes definitions and examples of what each crosscutting concept looks like across grade bands in elementary school.

1. Patterns
2. Cause and Effect
3. Scale, Proportion, and Quantity
4. Systems and System Models
5. Energy and Matter
6. Structure and Function
7. Stability and Change

Similar to the SEPs, the crosscutting concepts can, at first glance, be overwhelming to new science educators, and their language may be adapted when working with young students. For example, when addressing the crosscutting concept of scale, proportion, and quantity a teacher might use phrases like "how big" or "how many". The CCs are powerful ideas that young students can and should be introduced to in an age-appropriate manner. The *TN Science Standards Reference* includes a table breaking down the CCs by grade bands on pages 20-26.

*Disciplinary Core Ideas (DCIs).* The DCIs focus on science curriculum, instruction, and assessment on the most important aspects of science or "the big ideas" of science. These ideas are grouped into four domains including the physical sciences, the life sciences, the earth and space sciences, and engineering, technology, and application of science. These are discussed in a more detail below in the units with example integrated projects.

**Habits of Mind**

Habits of mind and approaches to learning are critical to young students' abilities to thrive in early and elementary science and STEM education. And they are valuable outside of these areas too! Habits of mind (HOM) have been connected to skills that current students will need as our society becomes increasingly technological (see graphic here). One version of HOM includes 16 of them, like persistence and thinking flexibility (see description here). Approaches to learning both incorporate and support habits of mind. Their importance is supported by the fact that the most recent national math and science standards both dedicate sections of their frameworks to these aspects of teaching and learning, even though they may not be explicit components of the standards themselves.

Because they are so important, we include some information about a few aspects here. However, there are more to these than we have space to include, and your professors may assign additional readings and activities to expand your thinking and reflections about them. Before you can support strong habits of mind, approaches to learning in your future students, you have to *at least* reflect on them in yourself as a learner (even if you do not feel they are fully developed!). Take a moment and reflect on the following questions before you continue reading. Write your answers down, so you can refer back to them in the following sections.

- What does it mean to be a flexible thinker?
- Do you view yourself as a flexible thinker?
- Can you remember a time when you changed your thinking/position on an idea based on new learning?
- Do you think of yourself as particularly good or bad at science or math?
- Do you think all children are naturally curious?

Mindsets. Do you think that someone is born either intelligent or not intelligent? Do you think that intelligence is fixed? If you do, you may have a fixed mindset. If you believe that actually we can change intelligence, we can impact our performance and skills by practice and by making mistakes and learning from them, you may have a growth mindset. Carol Dweck popularized these ideas in her work and research related to the impact of our mindsets on learning, teaching, and even performance in sports. We can think about how mindsets might apply to early and elementary science, math, and integrated STEM thinking and learning.

Curiosity. This may not be the first attribute you think about when you think about teaching science to your future students. But imagine what it is like to learn complex and sometimes abstract concepts about our world or universe, if you are not interested or curious. How can we encourage students to *engage* with doing the work to find out for themselves if the eraser will fall at the same rate as the textbook, if they are not curious about the phenomenon? Not all students will be curious about all the science topics you cover in a year, but if you figure out what they are curious about, that can be a starting point. If you figure out what YOU are curious about, and try to model that for them, you may be surprised at how your students' curiosity grows. For example, in a unit on observable patterns caused by the earth's rotation around the sun (TN 4.ESS1.2), a teacher might begin by asking students if their shadows are always the same length. She might follow-up by providing students with chalk and time outside at different times of the day to trace their shadows. Student observations of the phenomenon of changes in shadow length could lead to discussions of other patterns caused by the earth's orbit around the sun, further explorations, and the development of models. This would likely be a more engaging approach to the topic than with a reading from a textbook and study of a figure showing the earth's movement around the sun. Most children are born curious (and thus driven to learn from birth!), but it is also the onus of educators to nurture and sustain that curiosity – it is one of the primary drivers of science exploration. How has curiosity driven your own learning?

**Inquiry**

Inquiry is related to what the Framework and the NGSS now call "practices." We can think of practices as "unpacking" inquiry. The practices are an attempt to more specifically identify the activities that scientists and engineers actually engage in, like asking questions, or creating and testing prototypes. In early childhood, we use inquiry to refer to the ways in which we want children to engage with content - even outside of STEM - to construct their own meaning about the world (see Constructivism below). Here is one definition of inquiry as it relates to science teaching from the Exploratorium (see more here):

> *"Good science education requires both learning scientific concepts and developing scientific thinking skills. Inquiry is an approach to learning that involves a process of exploring the natural or material world, and that leads to asking questions, making discoveries, and testing those discoveries in the search for new understanding. Inquiry, as it relates to science education, should mirror as closely as possible the enterprise of doing real science."*

Teachers need to have at least a grade-level knowledge of the phenomena kids are investigating, the concepts they are trying to teach, and how the two connect to facilitate inquiry effectively. Teachers should also be immersed in their own facilitated inquiry as a prerequisite to being able to teach in this way. Regarding inquiry when teaching STEM, Banchi and Bell (2008) describe four levels of inquiry, ranging from the most teacher-directed, in which the teacher has total control over the questions, methods, and outcomes of the experience, to the least teacher-directed, in which the students have control over all of these aspects of an activity. Often, we want our learners to have hands-on, minds-on opportunities with materials, so that they are manipulating them, and coming to conclusions on their own.

> *"Hands-on science has not always been minds-on science. The opportunity to ask questions, manipulate materials, and conduct investigations—a major emphasis of inquiry-based science—has not always resulted in deeper conceptual learning. That is because the learning is not in the* ***materials or investigations themselves, but in the sense children make out of their experiences*** *as they use the materials to perform investigations, make observations, and construct explanations."* (Keely, 2013, p. 27)

Our approach is that there is room for *all* of these types of inquiry to different extents, in different early and elementary school classroom contexts. One is not necessarily better than the other. As a teacher, you will need to decide which approach is best for a lesson by considering the content being covered, the abilities of your students, and their prior knowledge. Sometimes, it is valuable to start with a more open exploration (e.g., students explore light by playing with flashlights, mirrors, and other materials) and move to a more focused investigation (e.g., students are challenged to use materials to reflect light on a specific target). At other times, the level of inquiry might move from more teacher-directed to more open. For example, a teacher might provide a specific question for students to address and then allow students to generate their own questions for the next round of testing. However, in science teaching, we do want to make sure that students have *some* input over their science experiences, regardless of the level of inquiry being used. This is in line with current thinking in science teaching (see the Framework above). But it may also feel like a very different approach that you have been learning in your other courses.

Inquiry-based teaching is often challenging for many in-service and pre-service teachers. Therefore, we want to make sure readers get a chance to think about what these types of learning experiences look like, and the inherent challenges in them (e.g., potential stress as a teacher that you do not know the outcome of an experiment that students design). Barriers to facilitating these types of learning experiences may include the following: 1) fear of a mess, 2) concern that the teacher may not know the answer to unplanned student questions, 3) lack of resources or feasibility of testing a student question, 4) worries about time considering on demands or requirements, and 5) lack of control. Other barriers can be teachers' own misunderstanding of the nature of science—viewing science as a static body of knowledge (in which answers are always right or wrong) vs. as a continuous process of collecting data and refining understanding based on new evidence. Many of us do not view science learning on a developmental continuum, like we do with literacy. We would never give a first grader Romeo and Juliet but in science we continually present young kids with information that is beyond them because we don't ground it in observable phenomena or consider how their developmental levels come into play. By paying attention to children's levels of development, we can better meet them where they are at.

These barriers are very real, and they may feel debilitating even when only allowing for minimal inquiry in one's classroom. If this happens, know that you are not alone. And this approach is different than many early or elementary school teachers or pre-service teachers have experienced or even than they have been taught in other courses.

The approaches we discuss in this text are based on sound research about how kids learn and how science is best taught and learned. Our advice is that you will ultimately need to find your own comfort level, but you have to trust us that going through an experience with young children in which you push yourself to be open to their responses, and to follow their lead (as much as is feasible in your context), will be a great source of professional growth. You will see what it is like, and then you will find your own way. Learning by doing it will, at minimum, give you a chance to see the strengths and limitations of this way of teaching science and integrated STEM, and to find your own path.

**The "how" of teaching science in early childhood and elementary school classrooms**

The teachers' role is critical in supporting students' science learning, with an emphasis on supporting students' thinking versus a focus on correct answers. There are many frameworks that have been developed for teachers to help organize students' inquiry-based/practices-based experiences. Below, we discuss two of them: the 5Es and the CER. There are examples of projects that use the 5Es in Units 5-9.

### The 5E Model of Instruction

One of the ways to help in planning more hands-on, interactive science and STEM learning experiences is the 5E lesson-planning model, developed by the Biological Sciences Curriculum Study (BSCS) (Bybee et al., 2006). The 5Es are engage, explore, explain, elaborate, and evaluate. Science learning experiences should follow each of these Es in order and should not rush each stage. The approach is a valuable tool for current and future teachers to understand and use when designing science and STEM learning experiences that occur over time. The framework has been evaluated in research studies and the authors have published many articles and resources to support teaching that uses this framework. Some of the articles published in the Science and Children periodical follow this 5Es framework, including some papers that our collaboration team members, researchers, teachers, and pre-service teachers, have published. As noted above, this is not the only way to frame early/elementary science and integrated STEM experiences, but research suggests that it can be effective.

### Claims, Evidence, Reasoning (CER) Framework

The claims, evidence, reasoning framework, published by Zembal-Saul and coauthors (2013) is another tool that teachers can use when designing science and STEM experiences for learners. This framework suggests that teachers organize students' experiences around claims, evidence, and their reasoning. The claim is a summary statement that describes the relationship between the factors or variables that were investigated; it is based on the analysis of the evidence. The evidence is the data that support the claim. An example for grade one might be a claim (light can't pass through a piece of cardboard); evidence (when I put the cardboard in front of a flashlight, I see a dark shadow in the shape on the wall); reasoning (the cardboard blocks the light and makes a shadow).

Students may collect multiple types of data that can be cited as evidence. Math skills and analysis are essential to this step. The reasoning links the claim and evidence to a scientific principle (e.g., light interacts differently with different materials). From our experience, the reasoning is typically the most challenging piece of the CER for students to write (or to orally explain, for younger students); however, it is also very important. It connects the investigative work of the student to the key science learning. Note that the sophistication of students' claims, evidence, and especially their reasoning is dependent on age/developmental level/ and experience with the phenomenon/concept at hand. In addition, the focus is not on correct claims/evidence/reasoning but on supporting kids to back up their claims with evidence and explain their reasoning. Learners will become more adept at doing this over time and across many experiences. See the figures below for an example of a CER from a fifth-grade investigation of apparent brightness in stars.

There are a variety of ways for teachers to support their students in defining and describing their own CER for scientific phenomenon. These include prompts, target responses, sentence stems, and peer-to-peer interactions. Prompts should be provided for students to guide their thinking and writing about the phenomenon (or big idea) that is being studied. As a teacher, it is important to draft target responses before implementation, so that you are clear on what students should be able to communicate and can best scaffold their work. The strategies below can support learners who need additional support:

- Sentence stems can be provided to help students organize their thinking and writing
- While thinking through CERs, students benefit from opportunities to discuss their thoughts with peers.
- One teacher in our collaboration has students draft responses to each section of the CER in small groups on post-it notes. She then shares the work of small groups with the whole class and together they come to a consensus on the final version of content. Each student then records the final version in their science notebook.
- Zembal-Saul et. al. (2013) includes rubrics for assessing CER responses, videos of teachers using the CER framework in elementary classrooms, and other helpful resources.
- Figure 1 provides an example of CER materials from a unit designed to help students understand the relationship between star brightness and distance from the Earth. It is also possible to use claims and evidence in a more open way in which students communicate their own thinking.

# Star Brightness Lab - CER

Claim - Write a sentence that explains how the distance from a light source affects its brightness.

Student prompt

If the distance to the light source is **closer**, then the light source appears ___________.

Target response sentence stem

Alternative Sentence Stem

If the distance of the light source is ____________________ **(closer/farther away)**, then the light source appears ____________________ **(brighter/dimmer).**

# Star Brightness Lab- CER

Evidence - Provide evidence from two data points on your graph that support your claim. Include measured distances from the wall and the diameter of the beam for each data point.

When the flashlight was _______ inches away, the diameter of the beam was _______ inches. However, when flashlight was _______ inches away, the diameter of the beam was _______ inches.

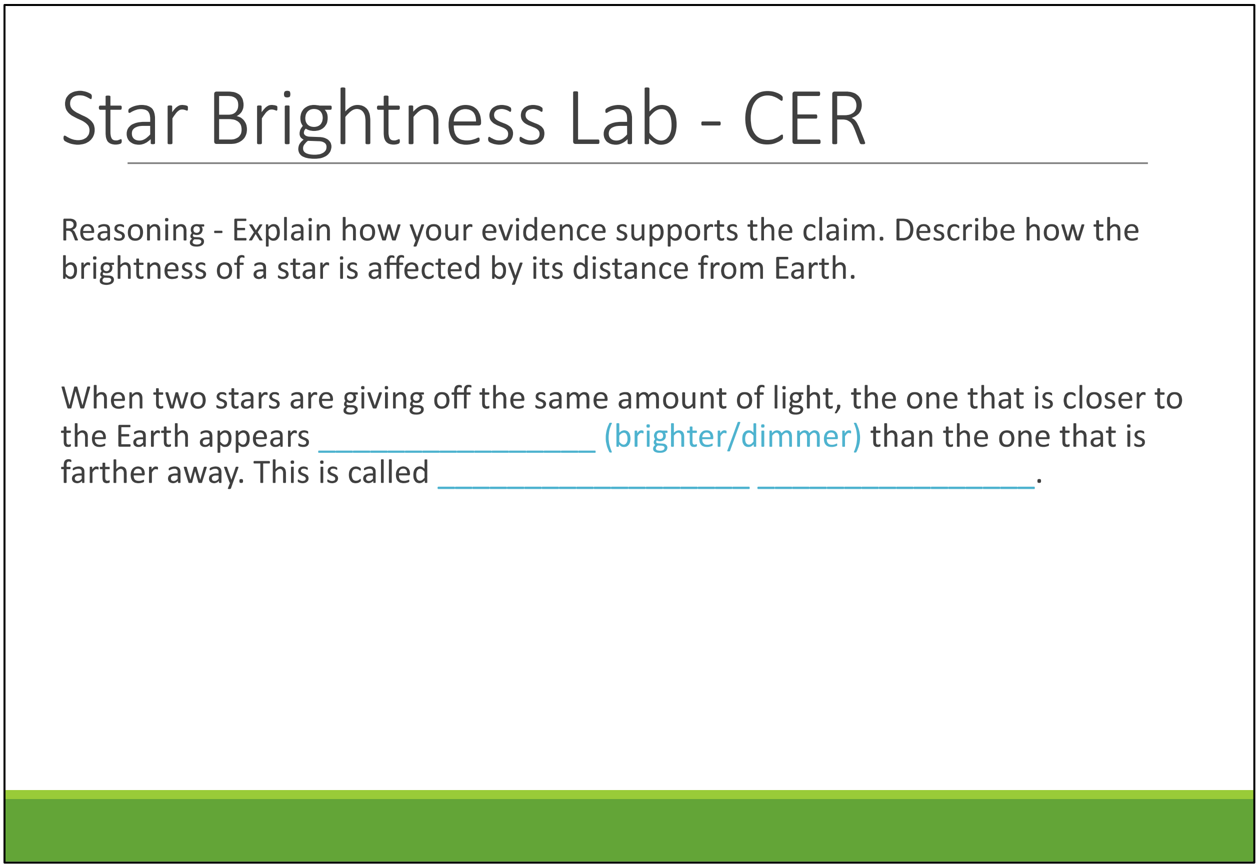



**Figure 1. CER Example**

**Theory**

Constructivism is a learning theory focused on allowing the learner to build their knowledge of a subject through their own experiences and often hands-on explorations. The learner may draw upon prior knowledge of a subject and then work to integrate new information that they learned through investigation. This idea is supported by theorists such as John Dewey and Jean Piaget who believed that young students build their knowledge by experiencing the world around them (Mooney, 2013).

The teacher's role is especially important in this theory. Teachers must be facilitators of learning, rather than only a source of facts. This means that teachers should ensure that each unique student is being appropriately challenged in their learning while also providing social learning opportunities with peers. Although constructivism as a theory of learning has been around for a while, taking a more dominant role in science education is a shift from what STEM education looked like in the past (or even science and math education separately), as we noted above, when teachers were expected to provide students with information that the students should then memorize.

Teachers can utilize the 5Es framework or similar frameworks to incorporate constructivism in science or integrated STEM education. The frameworks discussed here (and others that are similarly research-based) provide students with ample opportunities to build their knowledge and understanding of scientific phenomena through experience and work with peers, which are core aspects of constructivism. Teachers can also find inspiration in writings about the role of inquiry in science and STEM (see Inquiry section above).

**STEM and Equity**

> *"There is increasing recognition that the diverse customs and orientations that members of different cultural communities bring both to formal and to informal science learning contexts are assets on which to build—both for the benefit of the student and ultimately of science itself."* (p. 28; National Research Council, 2012)

To get started, grab a piece of paper and draw a picture of a scientist. STOP reading here and come back when that is done. Once everyone is ready, share and describe your drawings, talking with the class about what you drew and why. What are the similarities and differences among the drawings? Why did we ask you to do this? What does your drawing reveal about your definition of a scientist? We include this experience to illustrate what researchers have found for years about children's and adults' ideas of what it is to be a scientist (similar studies have been done with engineers and mathematicians). Although women appear more frequently in these drawings than they used to, they still appear less often than males. And those from racial and ethnic minority groups appear even less often. This reflects what we find in STEM careers as well, with females making up less than 16% of engineers (U.S. Bureau of Labor Statistics, 2020). It is promising that representation is increasing in some fields (check out the diverse backgrounds represented across the 18 astronauts chosen by NASA in late 2020 to train for the next mission to the moon). However, there is much work to be done.

> "A Framework for K-12 Science Education *stresses that "all science learning can be understood as a cultural accomplishment" (NRC, 2012). Therefore, STEM education and culture are intertwined and should be inclusive of students' diverse cultural backgrounds in instructional planning and delivery. All students should see themselves represented throughout the STEM curriculum, including printed text, videos, guest speakers, classroom libraries, activities, and classroom decorations (e.g., posters, photographs, etc.). Students should learn about the contributions of diverse scientists, engineers, and mathematicians of different genders, races, ethnicities, and abilities. When STEM learning experiences are combined with their own cultural perspectives, students are more engaged in their learning, positive science identities are nurtured, and STEM career aspirations are formed."*
> – Chris Bowen, 2020

Science, in and of itself, historically has taken a white, male, privileged approach that has typically not recognized the science contributions, knowledge, and perspectives of other ethnic and cultural groups (Bianchini, 2013). We must be aware of the history in order to provide context for the suggestions and strategies we discuss and so that we can as educators try to address these issues. The most important thing to focus on is that science has social, personal, and cultural components and assumptions, and our future students may experience and express science-related phenomena and understanding in different ways too. As a culturally competent teacher, it is important to pay attention to who your students are and how their lived experiences and meaning-making may differ from your own.

- **Strengths-based approaches.** Research increasingly suggests the importance of us as researchers and educators to focus on how different aspects of students' lives, experiences, and background should be viewed and treated as strengths, rather than weaknesses. This is contrasted with deficit models of education, in which a student with a disability or a student who speaks a language at home other than English might be viewed as being "deficient" or having a weakness to be overcome. This is related to the funds of knowledge [see more here on funds of knowledge] that students bring to the table. This shift in mindsets can have huge implications for us as educators as well as for the students in our classrooms.

- **Appreciating cultural and linguistic diversity.** It is extremely important to understand children's backgrounds and home experiences and how these can be strengths on which to build in creating science and STEM experiences that invite engagement for all students. This connection will increase engagement with the content and each other in the classroom. For more tips, see related resources from tolerance.org.

**Unit Reflection Questions**

1. Find a resource online related to equity and early or elementary STEM education. Be ready to share what the issue is, why it is important, and what you can do as future teachers to avoid such issues.

2. What do you think would be challenging about the following scenario? Would you feel comfortable being the teacher in this experience? Why or why not?

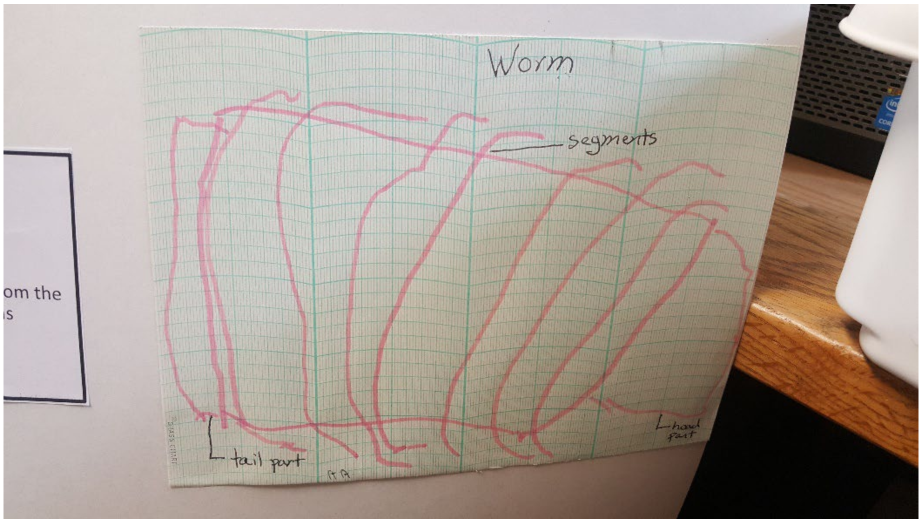
    a. **Scenario**. The children in a kindergarten class are interested in colors. They ask how purple is made. The teacher remembers that the names of the colors, knowing how to mix colors to make new ones, and the types of colors (like primary and secondary) are mentioned as learning goals for children by the end of the year. However, instead of telling children that mixing blue and red together makes purple, she asks children, "Well, what do you think? How do you think we make purple? How can we find out?" The children design the exploration, engage in the experience in the way they want to, and ultimately may or may not actually get to the answer of the questions of what makes purple. At least not on this day. They decide to use paints, and different children ask for different colors and even different materials (like chalk dust). Kids mix materials, talk about what they're doing, and make observations. The teacher comes back at the end and asks if anyone figured out how to make purple. They realize that they still don't know, but they know how to make orange. They also have some ideas to try tomorrow to further the exploration.

    b. Taking it further: Read this article by Susan Engle on curiosity and discuss the connection between this paint mixing activity and promoting curiosity in the classroom.

3. What strategies might you use to engage students from culturally or linguistically diverse backgrounds in the science topic of physical science related to changes in matter by adding heat, like in cooking?

## Unit 3: Integration




A 4-year-old child's drawing and words (transcribed by the teacher) that describe a worm's body parts (Example of literature and STEM integration in preschool). Photo credit: Lynn Lodien, 2018

In early childhood and elementary school classrooms, teachers are often responsible for teaching many subjects. Therefore, there is a great opportunity for integration. When thinking about this in our STEM teaching, we need to consider, a) what integrated STEM education is, b) why we should integrate STEM, and c) how we can integrate STEM.

**What is integrated STEM education?**

The Integrated STEM education report from the National Research Council (2014) acknowledges that integration can mean very different things. "Far from being a single, well-defined experience, integrated STEM education includes a range of different experiences that involve some degree of connection. The experiences may occur in one or several class periods, throughout a curriculum, be reflected in the organization of a single course or an entire school, or be encompassed in an out-of-school activity. Each variant of integrated STEM education suggests different planning approaches, resource needs, implementation challenges, and outcomes." (p. 2: NRC, 2014).

Therefore, they define integration as, "working in the context of complex phenomena or situations on tasks that require students to use knowledge and skills from multiple disciplines." (p. 51, NRC, 2014). The NRC report goes on to discuss three elements in determining scope and nature of integration:

- type of STEM connections
- disciplinary emphasis, and
- duration, size, and complexity of initiative.

*"Regarding the nature of connection, integrated STEM education may bring together concepts from more than one discipline (e.g., mathematics and science, or science, technology, and engineering); it may connect a concept from one subject to a practice of another, such as applying properties of geometric shapes (mathematics) to engineering design; or it may combine two practices, such as*

*science inquiry (e.g., doing an experiment) and engineering design (in which data from a science experiment can be applied).*

*In integrated STEM education it is frequently the case that one STEM subject has a dominant role—the explicit or implicit focus of a project, program, or school is to develop students' knowledge or skill mainly in one content area, such as mathematics...The inclusion of concepts or practices from other subjects is often intended to support or deepen learning and understanding in the targeted subject.*

*In terms of scope, integrated STEM education initiatives exhibit a variety of relevant parameters, such as duration, setting, size, and complexity. Initiatives may occur as a single hour-long project or over one or several class periods, or they may be reflected in the organization of a single course, a multicourse curriculum, or an entire school. Most of the programs we examined have very small footprints, existing as pilot efforts involving just a few students. But some have been implemented much more broadly, some-times across several schools or states, engaging hundreds or thousands of participants."*

(NRC, 2014)

## Levels of Integration

Once we determine the type of STEM connection, disciplinary emphasis, and scope, we also must consider the level of integration in an individual activity. We can think of integrated STEM education in terms of levels or depth of integration. Look at Figure 2. Note that the top is the least integrated, and as we move down, the integration is more meaningful and deeper, and the content of one domain depends more heavily on the content in the other. Integrating subjects can be labor intensive in planning and implementation, so consider how likely the integration is to extend student learning when making instructional choices about when and what to integrate. For the greatest impact on student learning, comprehension of the content in one subject area should be dependent on the content from the other subject area(s). For example, if students are exploring the best designs to solve an engineering problem, their abilities to measure results and arrange them in a graphical form are essential to their understanding of the engineering. Likewise, the math skills are best used and understood within the context of the real-world engineering problems.

If, on the other hand, integration is surface level (related but inconsequential), the impact of the integration on student understanding is low; therefore, it might be preferable to teach specific topics or skills separately. Regardless of depth of integration, there are often times when discipline-specific skills need to be taught directly. Taking time to review or practice the process for two-digit subtraction, for example, may be best accomplished with a focus on math. Then students can apply that skill within the context of an integrated STEM activity.

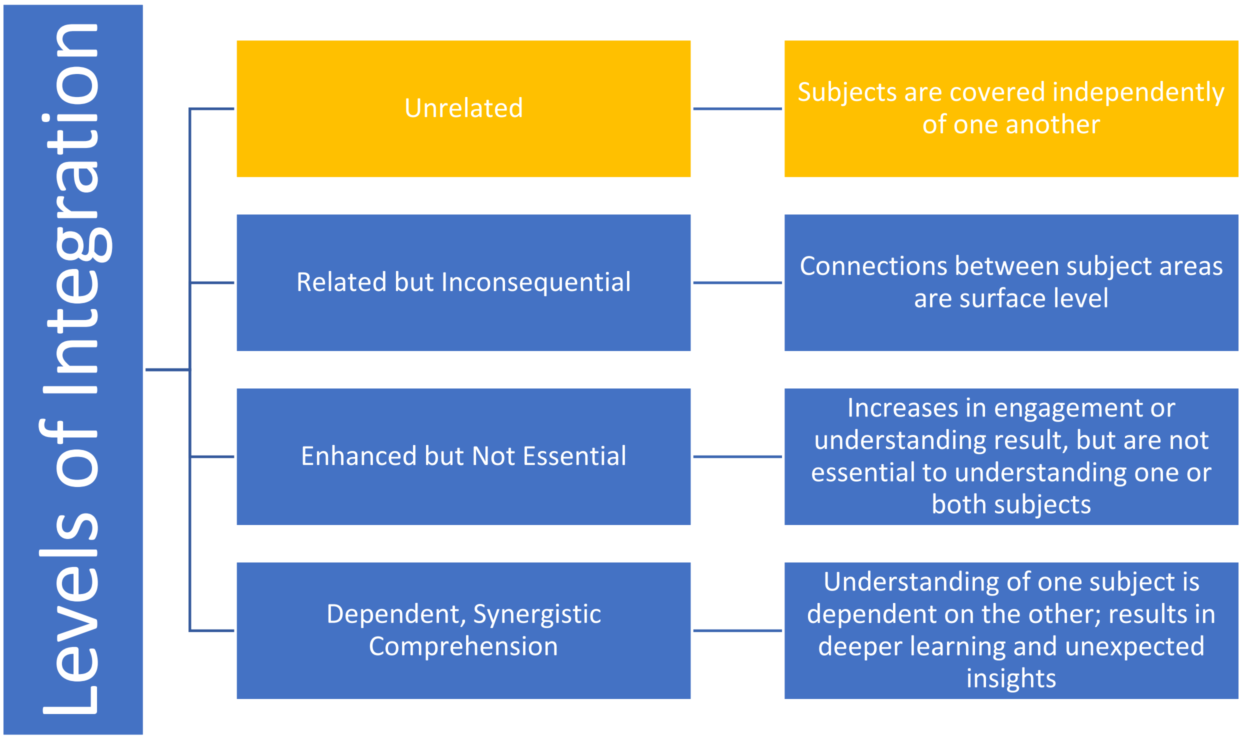



**Figure 2. Levels of integration graphic**

**Why Integrated STEM?**

Teaching integrated STEM, both within STEM domains - or with other domains like literacy or social studies has many benefits. Benefits include meeting demands of teacher preparation and evaluations, saving time, represent content authenticity, and promoting powerful learning. Below, we describe each benefit in more detail.

### Important Part of Teacher Preparation

First, many teaching proficiency exams require that students demonstrate that they can create and implement an integrated lesson plan that has clear learning objectives. For example, this is a part of the early childhood edTPA, which preservice teacher candidates must pass as a part of acquiring a state teaching license. So, it is important to understand integration more broadly, and it is also a benefit of building competence in teaching in an integrated way.

### Maximize Instructional Time During the School Day

Second, we can meet two or more learning objectives within one or more planned experiences when we pay attention to how the domains are integrated. This may save time when done well, for school days that are increasingly packed with demands. For example, first grade reading experiences that require practice reading informational texts, students must read about something. The content could be science! An Earth science standard related to, "Earth's Place in the Universe, 1-ESS1-1. Use observations of the sun, moon, and stars to describe patterns that can be predicted" and an ELA standard "1RL.KID.2 Retell stories, including key details and demonstrate understanding of the message or lesson" could be addressed in an experience that involves researching the phases of the moon, reading an informational text or researching in others ways (e.g., Google moon), then creating a model to represent and label the phases and then describe the cause of the phases (see NASA for a lesson plan for moon phases). What other educational standards could be met here?

### Authentic Representations of the Real World

Third, the content across and between STEM disciplines, as well as with areas such as language and literacy, are actually connected to one another, naturally in our world, in everyday life, and in our minds. We may focus on one specific content area separate from others sometimes for a variety of reasons in the context of teaching, such as teaching and assessing a specific skill in math. For example, we may want to know if our kindergarteners understand 1-1 correspondence in math, so we do a small group activity in which we ask children to count a set of toy cars so we can assess that skill. In another example, we may want to check if students understand the meaning of vocabulary words related to density, so we ask students to take all the objects out of the water tub that are *sinking.* However, content across domains is very much intertwined. As educators, we are preparing students to solve problems in their personal and professional lives, problems which will require students to draw on their knowledge from multiple domains simultaneously.

### Promote Powerful Learning

Finally, seeing how disciplines are connected can bring them to life, help students make connections to their real lives, and enhance engagement (NRC, 2014). Consider a case in which a 3rd grade teacher identifies a real problem in the classroom: the bins for the classroom's books are old and there are now more books than they have space for in the room. Can the students come up with a solution within some given parameters or constraints, such as that the solution must be at low or no cost, fit within the limited space, be strong enough to hold the books, be easy to move around if needed, and allow specific books to be easily found? What opportunities for STEM learning might this challenge offer? How is this challenge and the resulting experience integrated? Do you think the students would be interested and motivated to engage in this? What might they learn from it?

That said, note that it is imperative that we pay attention to each domain such that students have opportunities to master content as well as abstract concepts (e.g., students have to learn the number sequence in counting, which will require memorizing the number names, in the correct order). Research suggests that it is especially powerful when students have opportunities for both.

## How should we teach integrated STEM?

The value of integrated STEM may be clear, but how do we do it? Below, we outline a number of strategies to support integrated STEM teaching and learning. They are to identify a disciplinary emphasis, making integration explicit, ensuring sufficient attention to each discipline, identifying the level of integration, and determining the scope.

### Identify a disciplinary emphasis

Identify an anchoring discipline, which may translate in practice to identifying an anchoring standard. For our integrated STEM projects, we found that science was often a strong candidate for the anchoring standard because it's a domain rich with content to connect to the other domains. We can read about and use math to understand phenomenon related to weather (Earth science), to gravity (physical science), or to hibernation (life science). However, math can also be the anchoring standard (See project example in the math chapter). The important message here is to choose one dominant standard around which the rest of the project will orbit.

### Make integration explicit

Be sure to tell students that they will be engaging in an integrated STEM experience. It is not always clear to students that what is happening is integrated. Note this warning from the NRC report:

> *"Observations in a number of STEM settings show that integration across representations and materials, as well as over the arc of multi-day units, is not spontaneously made by students and therefore cannot be assumed to take place. This highlights the importance of designing integrated experiences that provide intentional and explicit support for students to build knowledge and skill both within the disciplines and across disciplines. In many integrated STEM experiences, such supports are missing or only implicitly embedded within the classroom activities or the CAD software, measurement instruments, and computational tools used in the classroom."*
> *(p. 5: NRC, 2014)*

Say things like, "We will be doing an experience today where we will get to be mathematicians *and* scientists! We'll be *using* measurement (math) to figure out how tall our plants grew in the closet versus on the windowsill (life science experiment)."

### Ensure sufficient attention to each discipline

As noted above, students' understanding and skills in each of the individual disciplines in S.T. E., and M. – as well as other domains involved, like English Language Arts or ELA – must be supported and appreciated on their own. In early math, for example, research suggests that children benefit most when they have both experiences focused on a specific math goal, and experiences in which they find math all around them, in their play, and across the day. Young learners benefit from explicit attention paid to math, such as a small group focused on cardinality with concrete objects. Trying to integrate everything all the time does not necessarily lead to better learning (NRC, 2014).

### Identify the Level of integration

Take a look back at the levels of integration shown in Figure 2. Note that not all content lends itself to integration. If it does, consider the extent to which integration can occur. When thinking about a unit or project that will involve meaningful, deep, integrated STEM, be clear on your learning objectives, which standards you are trying to meet, and the big ideas in math or science. You might have a topic to explore that comes from a current issue in the news, state or national standards, or from your students. Once you have a big idea or theme, then, figure out how you might integrate meaningfully: how can students use a math concept in service of understanding a scientific phenomenon? See more in the Example Project below.

### Determine the Scope

Determining the scope of the integrative project is part of the planning process. As a teacher, your district or center may require you to plan in a certain way. Sometimes, that involves submitting lesson plans for each day and each week; other times, planning may involve showing that your classroom experiences align directly with the district's chosen curriculum. Whatever your requirements are, we want you to think about the science and integrated STEM experiences of your future students in terms of how they will be 1) long-term, with repeated opportunities for students to engage meaningfully with content, and 2) allowing for room for inquiry or the science practices.

Below we describe one "product," which is a Unit Plan, and that might be used to plan out integrated STEM activities in a Pre-K through 5th grade classroom. Early childhood programs in which the authors taught used a Unit Plan as the major assignment. It included 2 weeks of learning experiences that must integrate a variety of areas with the focal science standard. Pre-service teachers created a calendar, at least 10 separate learning experiences across the 10 days that have clear learning goals and that follow the 5Es lesson planning template.

Make it your own. As pre-service teachers, you may or may not have a choice for a given course or for your future classrooms. Once you are teachers in your own classrooms, we want you to have a variety of approaches at your disposal. Whatever method or "product" you choose to engage your learners in integrated STEM, we want you to see the 5Es and the other frameworks and guidance discussed here as a roadmap to guide your curriculum and planning efforts.

**Example Unit Plan Project: Kindergarteners as Clothing Designers**

Daisy Flomberg, an undergraduate student in our project, designed a two-week unit focused on the "theme" of clothing, which integrated a kindergarten math and science standard along with literacy, language, music, and art. She noticed that her students were interested in clothes, such as what they are made out of, what people wear in different parts of the world (social studies), and how they are made. She saw an opportunity to meet multiple standards by exploring clothing over time, as something of a "theme." The anchor Tennessee science standard was K.PS1.01: Plan and construct an investigation to describe and classify different kinds of materials including wood, plastic, metal, cloth, and paper by their observable properties (color, texture, hardness, and flexibility) and whether or not they are natural or human-made. She also noticed a link to the engineering standard of K.ETS.2. 1: Use appropriate tools (magnifying glass, rain gauge, basic balance scale) to make observations and answer testable scientific questions. Finally, the math standard she chose related to an early K math measurement standard: K.MD.A.1 Describe measurable attributes of objects, such as length or weight. Describe several measurable attributes of a single object.

Over 2 weeks, children read about clothing, explored different types of materials used in clothing, and then design and create their own item. They follow the 5E Framework throughout their study of clothing. Students increase their knowledge about clothing and materials by reading, discussing, singing, and interacting with samples of different materials (Literacy, Language, Music). Students also record their observations in their science journals as they worked with the samples (Science, Art). At this point, the teacher assesses students' knowledge of the materials through a comparison test. The teacher provides direct instruction on how to measure accurately, and students then practice these new skills on different materials by cutting and measuring different lengths (Math). Students began designing their item of clothing and creating it from the materials they had studied (Math, Engineering.) This project ends with the students presenting their design to their classmates, which allows teachers to evaluate their learning. This project integrates math and science as well as engineering, literacy, language, art, and music.

**Reflection Questions**

1. Read one of the examples of a Unit Plan to teach integrated STEM from our website (or another example as assigned). With a peer or in a small group, discuss what surprises you the most about the integrated learning experience described. Also, discuss what levels of integration you notice in the activities described.
    a. The Worms are Dancing! focuses on a preschool classroom's experiences over time, integrated across domains, with life science at the center. An undergraduate early childhood teacher candidate and a practicing teacher were co-authors.
    b. More examples of articles and projects can be found at the EC STEM Lab website. The articles noted above have been posted at the EC STEM Lab with permission from the publishers.
2. Interactive notebooks. Read more about interactive notebooks below, which are an example of another way of encouraging integrated STEM learning. Then, follow the instructions that follow.
    a. Interactive notebooks are an elementary student's ongoing record of their learning. Each individual student creates their own notebook and uses it to answer teacher questions, record data, draw graphs and sketches, analyze results, and more depending on how the notebook is used in the classroom. Teachers have a lot of freedom with the content of the notebooks as well as how they are utilized in the classroom. More than Data: Using Interactive Science Notebooks to Engage Students in Science and Engineering is a great resource to learn more about how to use interactive notebooks and how to include them in your classroom.
    b. Choose one example interactive notebook, like the project in 2nd grade called Sailing into Integration. This project is also described in Unit 8. An undergraduate elementary education pre-service teacher and a practicing teacher were co-authors. Discuss with peers the strengths and challenges of such an approach.

# Unit 4: Standards, Lesson Planning, & Assessment

**Standards**

We will discuss standards only briefly here because other courses in preservice teacher education programs often emphasize standards and how to use them. We find it useful to spend some time diving deeply into the science standards in our state. This is because unpacking the standards in science is critical to teaching science or integrated STEM in the early and elementary years. In addition, seeing the way in which both the knowledge (what we want students to know) and the practices (what we want students to be able to do) are both integrated into the standards in our state of TN as well as in the national NGSS standards. The crosscutting concepts are also evident in the standards. The Unpacking Standards tool that we have adapted from a local school district to support our standards unpacking activities is included in the Appendix.

When considering the role of standards in science and integrated STEM projects, we have found success in first identifying a focal or **anchoring standard** and then identifying the one or more supporting standard(s). We have most frequently first identified a science standard, then built projects around those. However, we have also successfully started with math as the focal standard, then asked our pre-service teachers to build a project integrating at least one science standard that way. An example of such a project is in the Math unit.

**Lesson Planning**

Similar to standards, we place less emphasis on lesson planning in this text because this tends to be covered in other courses and may vary by department or university and may even be guided by state testing or university or college accreditation standards. What we do want to discuss in more detail is the critical importance of a few components of lesson planning in science and integrated STEM. These components are as follows:

1) Take the long view. We must think about linking learning experiences in science over time, and not view a given lesson plan as a stand-alone science experience (e.g., we covered "weather" this year, because we did that one lesson plan on weather that one day in the fall). Rather, science explorations require in-depth exploration over time. This is especially true considering the current thinking in science education as we discussed previously, which demands that students are *doing* the science themselves, figuring out for themselves what will happen to the toy bear if we put it in the bowl of water and put it in the freezer. Making conclusions and connections, through careful facilitation from a teacher, about the connection between temperature and the movement of molecules (or toy bears!).
2) Include clear learning objectives. Science teachers have to think about learning objectives in terms of both what we want students to know and what want them to be able to do. This aligns well with the standards. But being clear on this in a particular lesson plan can be tricky.
3) Find reputable sources. Many practicing teachers report to us that they find activity ideas to do in science or STEM online, especially on websites like Pinterest. This can be a great source of inspiration, but it can also be a problem, if the science is inaccurate, or if the activities do not support the kind of learning that we have discussed so far – one that is inquiry-rich, with opportunities to explore over time, and to engage in the science practices (also supporting a constructivist theory of learning, as noted above). Finding and critically evaluating resources to support science and STEM teaching will continue to be a challenge,

so find resources to guide you in this process, such as the article, *To Pin or Not to Pin*, by Peterson et al., 2019, published by NAEYC in *Teaching Young Children.* Another tip is to look first at high-quality, well-respected sources in a given area, such as those listed in the Trusted Early and Elementary STEM Sources, in the Appendix.

**Assessment**

Assessment is a critical part of teaching. How will you know if your students learned the content you had hoped they would learn, such as the names of the moon phases? How can we assess skills, which include the science practices, and even habits of mind, like engagement or curiosity? Assessment is important to all of the areas of learning in your classroom (McAfee, Leong, & Bodrova, 2015), and science and STEM is no exception.

There are different types of assessment, which you will likely learn more about in other classes. As a quick review, there are formal assessments, like standardized tests, and informal assessments, like anecdotal notes. There are also formative assessments, which are meant to directly inform your teaching practice and may be done before, during, and after teaching. Summative assessments, on the other hand, are meant to measure whether the learning objectives have been met at the end of some time period. For example, during a unit of study focused on the moon, the anchor standard I am going to address is, 1.ESS1.1: "Use observations or models of the sun, moon, and stars to describe patterns that can be predicted." I asked my 1st grade students to diagram one of the moon phases in their science journals that we have just talked about. I review these to see if students understand the term and can explain it, and if not, I will revisit the concept on the next day (formative, informal). At the end of the unit, I give my students a fill in the blank test that I created (summative, informal) to assess whether my students all now name the phases of the moon accurately (measuring content knowledge). I also ask them to do a short presentation in pairs to explain how the phases of the moon are created, using a model they have made (measuring practices like communicating thinking, creating and using a model, and demonstrating conceptual understanding).

We can also think of assessments in terms of the methods of assessment. We might use multiple choice or fill in the blank questions when we are asking students to do simple tasks, like recall. On the other hand, we might use more complex assessment methods such as performance assessments, when we are asking students to show that they understand and can complete more complex tasks (Arter, 1999). For the 3-dimensional science teaching approach we have discussed here, performance assessments are very often appropriate. This is because we want students not only to recall facts, but also to find out about scientific phenomena, or facts, for themselves by engaging in the science practices that scientists use, such as creating models. Below are some examples of performance assessments that you might use to assess your students' learning in science or integrated STEM.

- For the standard K.LS1.2: Recognize differences between living and nonliving organisms and sort them into groups by observable physical characteristics, a kindergarten teacher asks each student to sort a set of pictures into living and nonliving things and explain how they did it. (see example rubric below)
- A 1st grade teachers asks students to select the best tools to use when observing objects in the sky. (TN 1.ESS1.2)
- A 2nd grade teacher asks students to create a list of observations and wonderings while viewing eagles on a webcam. (TN 2.LS1.1)
- A 3rd grade teacher asks students to design an experiment to test the strength of different magnets. (TN 3.PS2.2)

- A 4th grade teacher asks her students to graph the results of an experiment on speed and energy and write a Claim, Evidence, and Reasoning response. (TN 4.PS3.1)
- A 5th grade teacher asks students to work in pairs to build, test, and improve a simple catapult. (TN 5.ETS1.1)

Example Rubric

| Evaluation Criteria | Starting Out | Developing | Meets Expectations |
| --- | --- | --- | --- |
| **Sort objects into living and non-living groups.** | Less than 7 items (out of 10) sorted correctly into living and non-living groups. | 7-9 items (out of 10) sorted correctly into living and non-living groups. | Correctly sorts 10 items (out of 10) into living and non-living groups. |
| **Explain how things were sorted into living and non-living categories.** | Explanation does not relate to the differences between living and non-living things. | Explanation is partially correct or incomplete. | Explanation correctly relates to the differences between living and non-living things. |

**Reflection Question**

1. Choose one of the example assessment items noted above in this chapter and create a rubric that might be used to assess performance.

## Unit 5: Integrated STEM Through **Physical Science** Anchor Standards

A child setting up his team's light obstacle course as part of a first grade 5Es activity.
Photo credit: Ronald Campbell, 2019

**Example Projects**

*Example Project 1*

*Title*

Energy and its Interactions

*Author*

Adapted from the Unit Plan by Anna Lowe, 2018

*Grade/Grade Span*

Third Grade

*Third Grade Summary*

Students will engage in an exploration of energy over the course of several weeks, specifically focusing on the transfer of energy. They will explore this concept through activities, whole-group discussions, reflections in their science journals, and peer interactions. Throughout this unit, students will discover what different types of energy are, how energy is transferred, how energy affects interactions, and how to identify potential and kinetic energy. They will experience these phenomena through hands-on projects, including creating their own version of Newton's Cradle to understand the transfer of energy. Students will also create a ping pong launcher to experience the different types of energy.

*DCI*

- Physical Science

*Standards – TN DOE*

Physical Science
3.PS3.1 Recognize that energy is present when objects move; describe effects of energy transfer from one object to another

*5Es*

**Engage.** Day 1 will be focused on generating students' interest in energy and getting them thinking about what energy is. Teachers will provoke the interest of students by doing an energy scavenger hunt around the classroom. In the scavenger hunt, students will look for examples of different kinds of energy. This will generate excitement and enthusiasm for the upcoming unit while also connecting students' past learning. Learners will record their findings in their science journals, which will provide teachers with valuable information about the current understandings of energy.

**Explore**. Students will then begin their exploration of energy over the next few days. The teacher will read the book, *Energy Makes Things Happen* (Brubaker Bradley, 2002) to get students thinking about the transfer of energy. Then, students will explore the idea of the transfer of energy through an experiment called Newton's Cradle. The teacher should tell students that they will be creating their own version, so that they can start thinking about what theirs will look like as they experiment with the example. The teacher will provide the materials for students to create Newton's Cradle in pairs. Students will work to create a structure that is strong enough to hold the balls at the end of the string. This will allow students to experience the transfer of energy while also establishing a relationship between mass and force. The teacher will be asking students questions as they work so that students can share their ideas and examine their own thinking.

**Explain**. Students will be asked to present their cradles to their class and explain how they made them. They will discuss their process in engineering the structure and the transfer of energy that is happening between the balls. Teachers will record anecdotal notes during presentations while also extending the conversations to deepen students' content knowledge. Teachers will also ask students to record their findings in science journals as well as their peers. They will explain the differences and similarities of the cradles. This is an opportunity for students to practice discussing the transfer of energy using formal and informal language. Teachers will ask guiding questions and give learners vocabulary such as kinetic and potential energy to use in their discussions.

**Elaborate**. The next few days will present students with different activities to further their understanding of energy. Teachers will pair-up learners and give them puff balls and a ruler. They will put some puff balls on top of the ruler, then, they will flick one puff ball towards the ruler and observe what happens to the other puff balls. They will also measure how far each puff ball went with the ruler and record this on their documentation paper. Teachers will ask guiding questions to each pair and encourage them to explain what is happening in formal language. Students will use their knowledge from creating Newton's Cradle, as well as other learning from the unit, to explain what happens to the marbles.

**Evaluate**. Teachers will evaluate the learning from this unit by having students create their own ping pong launchers with balloons. First, the class will discuss the transfer of energy from one object to another (although not until 4th grade, students may be ready to discuss potential and kinetic energy). The teacher will begin evaluating the learning through this discussion as students give answers to the questions. Then, students will be given a cup and a balloon, they will also be asked to choose different materials to launch. They will make predictions about the launches and then experiment with the different objects. Students will see that when the balloon is stretched, there is a creation of potential energy and when it is released it has kinetic energy. They will also discuss what happened to their objects with peers and document their findings in their science journals. They will also reflect on their learning in their journals at the end of this activity to self-evaluate. They should be able to explain that the objects have different energy transfers and lighter objects can go further while heavier objects do not go as far. Teachers will evaluate students by observing their work with the ping pong launchers and asking open-ended questions to hear students' ability to demonstrate their understanding of energy transfer.

*Example Project 2*

*Title*

Making Waves

*Author*

Adapted from the Interactive Notebook created by Allison Frazier, 2019

*Grade/Grade Span*

Fourth Grade

*Summary*

This unit explores waves and their properties. There will be several whole-group discussions about waves that will engage students and expand their knowledge of waves. Students will experience waves through hands-on activities in stations around the classroom. These stations will involve jump ropes, water, and Slinkys. Throughout the unit, students will record their findings from their experiments in their interactive notebooks as they work with partners to discover different types of waves and explore the different properties.

*DCI*

- Physical Science
- Math

*Standards*

NGSS

Physical Science
4.PS4.1 Use a model of a simple wave to explain regular patterns of amplitude, wavelength, and direction.

Math
4.MD.A.1 Measure and estimate to determine relative sizes of measurement units within a single system of measurement involving length, liquid volume, and mass/weight of objects using customary and metric units.

*5Es*

**Engage.** This set of learning experiences will begin with the classroom discussing the different types of waves and if they have seen them in their own experience. They will also talk about the “wave” being done at sporting events and if they have been a part of that kind of wave. Teachers will play a video of the world record for the biggest wave done at a sporting event and the class will talk about what they noticed in the clip. The video and discussion will create an interest in the main idea for this unit while also demonstrating the knowledge students already have of waves. Another way to engage could be to explore the various geographic points where waves are known to be intense and dynamic – this could be a connection to social studies content in the upper elementary grades. For example, some surfing locations around the world are particularly known for their amazing waves the Pipelines in Hawaii, Supertubes in South Africa, etc. (see videos from National Geographic).

**Explore**. Students will explore waves by visiting different stations set up in the classroom, this will provide them with hands-on experiences of making different waves. There will be 3 stations for students to rotate through with a partner. The first involves creating waves with jump ropes, the second station will have a rock that students will drop into a dishpan and watch the waves the rock creates, and the third station involves putting a slinky on a yardstick and observing the movement of the slinky when one end is still and the other is moved back and forth.

As students move through the stations, they will record their observations and write which type of wave they created in their interactive science notebooks. Teachers will observe students as they create waves and ask questions as they work. This activity will allow students to experience the key concept of this unit by seeing real examples of each kind of wave.

**Explain**. For this phase, teachers will go through an article with students about the properties of waves. They will discuss properties like direction, amplitude, wavelength, crests, and more. Teachers will go through the content with the class and then students will answer questions about properties in their science notebook. This gives students formal vocabulary surrounding waves and lets them practice using it.

**Elaborate**. Students will extend their knowledge of waves by working to create waves with jump rope with a partner. Teachers will challenge students to create certain wavelengths and amplitudes with the ropes. Students will use a measuring tape to record the distances of the wave and to check the wave’s accuracy. They will record their findings and complete a CER (Claim, Evidence, Reasoning) in their interactive notebook. Students will be able to apply their new learning in this activity and communicate their understandings of the properties of waves.

**Evaluate**. Students' learning will be evaluated by answering questions in their science interactive notebook. The questions will be in two sections, math and science, and they will be in a variety of formats including multiple choice and short answer. Students will also evaluate their own learning by writing a reflection on their experience and learning throughout the unit. Teachers will assess their learning by looking at what they have recorded in their interactive notebook throughout the unit and their answers to the final questions.

**Ideas for Other Explorations**

Teachers doing a physical science activity written for 4$^{th}$ graders by a pre-service teacher, as part of a professional early childhood conference. Photo credit: Laura Robertson, 2019

Two 2$^{nd}$ graders playing tug of war as part of an early childhood education student's applied microteaching project on forces in physical sciences Photo credit: Ronald Campbell, 2019


Engineering catapults with 3rd graders. Photo credit: Alissa Lange, 2019

**Reflection Question**

1. Choose one of the example activities from the Ideas for Other Explorations section above. How could these topics be the focus of a 5Es set of learning experiences? Come up with one idea for each of the 5Es.

## Unit 6: Life Science

Photo credit: Alissa A. Lange, 2020

**What is it?**

Life science is the study of livings things, their processes and life cycles, and their needs. Life science focuses on, "…patterns, processes, and relationships of living organisms. Life is self-contained, self-sustaining, self-replicating, and evolving, operating according to laws of the physical world, as well as genetic programming" (p. 139, NGSS). There are four core ideas within life science that span the K-12 grade range, appearing in different grades at different levels. These are:

- Structures and processes in organisms
- Ecology
- Heredity
- Evolution

Explore each of these further to learn more about what they mean, to what extent they are emphasized in a given grade range in your state, and how the concepts build on one another across the grades. In this chapter, we will give you an example of a set of learning experiences with life science at the core, as the anchoring standard. In this example, areas across math, engineering and technology, social studies, and literacy are covered.

**Example Projects**

*Example Project 1*

*Title*

How Birds Protect Themselves

*Author*

Adapted from the Unit Plan created by Alyssa Hare, 2020.

*Grade/Grade Span*

Kindergarten-2nd

*Summary*

Explore how animals, in particular birds, need shelter to survive. Do hands-on and minds-on activities across STEM and other domains, following the 5Es framework, to find out

1) how birds build nests to protect themselves from different predators and from the outside elements, including using materials that blend into the surroundings (not bright colors),

2) where they tend to be found (hidden within branches, high up in a tree), and

3) the structure or form and function (crosscutting concept) of the nests that make them good for their purpose (e.g., keep eggs warm, tend to be a cup-like shape, or have just a small hole to get in and out).

Learners will apply their knowledge of measurement in math to figure out the right dimensions for a bird nest, based on the size and weight of an egg they are given. Later, students will look for patterns by finding shelters for other animals that have similar characteristics.

*DCI*

- Earth and Space Science
- Life science

*Standards*

NGSS

Life science

K.LS1.1: Use observations to describe patterns of what plants and animals (including humans) need to survive.

Earth Science

K.ESS3.1: Use a model to represent the relationship between the basic needs (shelter, food, water) of different plants and animals (including humans) and the places they live.

Engineering

K.2.ETS1.1. Ask questions, make observations, and gather information about a situation people want to change to define a simple problem that can be solved through the development of a new or improved object or tool.

*5Es*

**Engage.** Early in the experience will be the Engage phase. Students will play the Camouflage Game (adapted from multiple sources). As a group, the students will play the camouflage game in which the teacher hides objects around the room and students must find them. Some will be easier to find because they are different colors than the background. The images and objects that are hidden will be different materials that birds might use to build a nest, along with others that birds might be less likely to use, such as bright string. Students will then discuss their experiences and talk about why some objects were harder to find than others. During free play time, students will explore a sensory table with feathers, twine, small and large twigs, eggshells, and other materials. Students will observe the materials and choose one to draw and/or write about in their science journals.

**Explore**. Students will participate in an activity in which they will test different shaped containers and containers made of different materials to see which one is best to hold an egg when there is a lot of movement. The teacher will use motor or fan so that the same amount of movement happens to each condition. Students will see that the eggs roll out of the mostly flat containers, it is hard to get the eggs out of the containers that are too deep, and there should be some padding in the container to keep the eggs from breaking. Students may also notice that containers with flimsy sides do not hold the eggs well, and even containers that are the right size and shape cannot be too heavy. Students will document their findings in their science journals.

On another day, students will explore the different materials from Day 1 and a variety of eggs that will be used in the bird's nest. They will have the opportunity to their different attributes, weights, and lengths.

**Explain**. For this day we will read the book, *Robyn Boid: Architect* (Author, year) to explain specifically how birds build their nests. Students will discuss how camouflage works and how some animals camouflage their homes to keep them safe. Students will also discuss other characteristics of nests that make them suitable for a home that can keep birds alive.

**Elaborate**. This will actually cover all of day 9 and then part of day 10. That is because our final activity will be 2 parts. In Part 1 students will design their own bird's nest, and in part 2, the students will actually construct their own bird's nest using the materials they explored earlier in the week and data they retrieved from a math lesson. During this elaborate phase, students are asked to, "Construct a bird's nest using your data from the math activity and your new learned knowledge of how birds build their nest to protect their eggs and themselves."

**Evaluate**. At the end of the unit, students will reflect, in their science journal, on their experience designing and constructing their birds' nest. The teacher will assess students' learning via a presentation of the final nest creation and an explanation of why they think it will work to hold a bird's egg. Students will discuss the shape and size of the nest, and the reasons they made the size that they did. Students will also describe the colors they used and will be required to support the reasons for their creations with evidence based on what they learned about birds' needs. Students will assess their own learning and the learning of their peers as part of this phase by pairing up and answering questions about their creations and the creations of their peers.


Photo credit: Kim Lange, 2020

### *Extensions*

This activity can start with explorations of habitats and shelters of animals in general, before focusing in on birds. The set of experiences could be even more open-ended if students are the ones who identify the animal shelter that they would like to research and then try to construct.

Another extension is to incorporate animal cams, like the Eagle Cams at ETSU. There are a number of these resources that are free and allow for "virtual field trips."

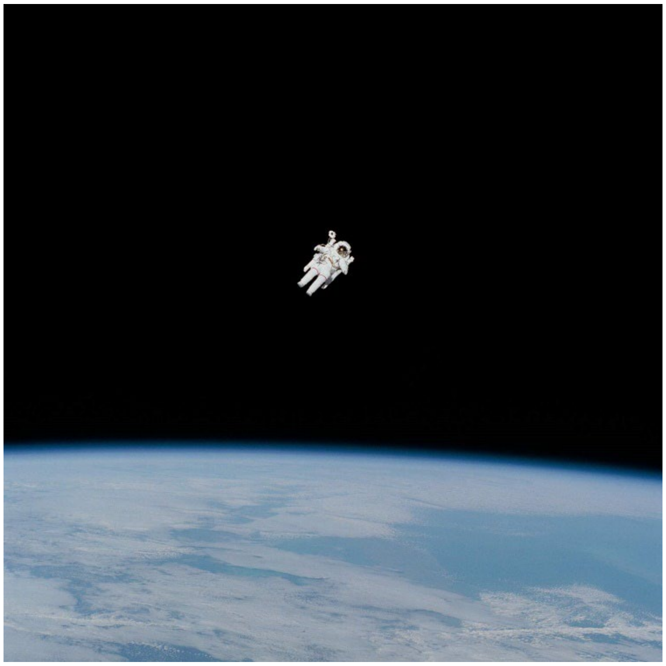
Photo credit: Ronald Campbell, 2019

**Reflection Question**

1. Choose one of the example activities from the Ideas for Other Explorations section above. How could these topics be the focus of a 5Es set of learning experiences? Come up with one idea for each of the 5Es.

## Unit 7: Earth and Space Science



Rights to photo purchased by EC STEM Lab (2019)

**What is it?**

Earth and space science is the study of earth materials and space. In grades K-12 (NGSS) it focuses on a wide range of Earth and space concepts and includes: the universe and its stars, Earth and the solar system, the history of planet Earth, Earth materials and systems, plate tectonics and large-scale system interactions, the role of water in Earth's surface processes, weather and climate, biogeology, natural resources, natural hazards, humans impact on earth systems, and global climate change (NGSS, 2013, Earth Space Science Progression). For early childhood and elementary learners, these core disciplinary ideas can include:

- Observational patterns and characteristics of the sun, moon, and stars
- Earth's orbit and rotation
- Exploring how time and events have occurred on Earth
- Wind, water, ice, rainfall, gravity, rocks, and erosion
- Earthquakes and volcanoes
- Maps that indicated water and land
- Weather and weather patterns
- Natural resources & natural hazards
- Humans impact on the environment

The Tennessee Academic Standards for Science are organized with the NGSS core ideas and component ideas in mind. Further, some concepts are expanded to include specific concepts, terminology, and processes. For example, TN Standard 3.ESS1: *Earth's Place in the Universe* includes a specific focus on the solar system and the physical properties of both inner and outer planets.

Applicable to the discussion here are the integrated STEM opportunities and links between engineering, technology, mathematics, and space science. Students can explore scientific discoveries on Earth and in space, investigate tools and machines (like microscopes, satellites, rockets, rovers on Mars, and computers) and explore the interconnected areas of spaceflight and space exploration. Students can engage in the stories and lives of diverse people represented in STEM careers, spaceflight, and space history. With a renewed focus on human spaceflight currently underway, students will likely experience in their lifetime a return to the Moon (estimated 2024) and perhaps a human landing on Mars (estimated 2040). Helpful resources for teachers and students can be easily found on the NASA.gov website and some relevant resources with excellent visual images and engagement opportunities for students are listed below.

**Example project**

*Title*

The Moon

*Author*

Adapted from the Unit Plan created by Elizabeth Schock, 2019.

*Grade/Grade Span*

First Grade

*Summary*

This unit involves a 2-week exploration of the moon and its pattern. Students will discover the pattern that is happening by observing the moon each night at home (just so they can see it clearly, but make sure that they know the moon is sometimes visible during the day too!) and recording what it looks like in their moon calendar. They will also discuss what they saw in the classroom each morning and complete several different activities that allow them to explore what is happening to the moon to cause that pattern. One activity completed will involve students working in pairs to create a life-size model of how the moon's pattern changes as the Earth revolves around the Sun by using their bodies, a Styrofoam ball, and a flashlight. By the end of the unit, students should be able to identify the pattern and correctly identify the different phases of the moon.

*DCI*

- Earth and Space Science

*Standards*

NGSS

Earth and Space Science

1.ESS1.1: "Use observations or models of the sun, moon, and stars to describe patterns that can be predicted" (Tennessee State Board of Education, 2016).

### *5Es*

**Engage.** Teachers will begin this unit by showing students Google Moon. This is an interactive model of the moon that uses satellite images and allows users to interact with the moon and displays Apollo landing sites. As the class explores the surface of the moon, teachers will ask students to describe what they are seeing and discuss NASA and their research.

Students will take home a family letter and a moon calendar journal. The letter will explain the unit as well as the calendar. Learners will observe the moon each night at home and draw what they see. Each morning at school, the class will discuss what they saw and then create a large model which they will hang in a line so they can track the changes they are seeing.

**Explore**. On another day, students will begin their exploration of the moon. First, the class will read *Max and the Tag-Along Moon*. There will also be a discussion about where the moon gets its light from. Teachers will then provide flashlights and a Styrofoam ball covered in aluminum to students so they can investigate where the light comes from. This activity allows students to discover new information about the moon while also sharing their ideas about what is happening.

**Explain**. The next day, teachers will play the Pattern song from GoNoodle. The class will discuss the pattern of the moon and if they have any predictions about what will happen over the next two weeks. Through the class discussion, students will be able to use their prior knowledge to make predictions and discuss their new understandings of the pattern the moon follows. The teacher will provide students with vocabulary for the different phases of the moon and discuss how the moon changes throughout each month.

**Elaborate**. On this day, students will experiment with what causes the pattern they see with the moon. Students will look back at their moon models they have been creating based on their home journals and then discuss the pattern that is emerging. Teachers will prompt students by asking if the moon looks the same each night and asking them to record what they think causes this in their science journal. Students will work in pairs and be given a Styrofoam attached to a wooden dowel (the Moon) and a flashlight (the Sun). One learner will be the Earth and hold the moon and the other will be the sun. They will take turns and investigate what causes the pattern they are seeing each night. They will record their findings in science journals and then they will discuss their findings as a group. Through this activity, students will discover new information about the pattern in the moon which extends their current understanding of the moon.

**Evaluate**. The teacher will assess students' learning in two different ways. First, students will create a model of the pattern they have seen in the moon over the last two weeks using Oreos and use correct vocabulary when labeling the different phases. The next day, the class will create an anchor chart depicting all the different phases. They will also discuss what they think will happen over the next 14 days. Teachers will present students with 8 flashcards of the moon and ask them to put the cards in the correct order. Teachers will photograph the students' work and then complete a checklist to see if students were able to order the cards sequentially. These activities provide teachers with multiple ways to see if students can demonstrate what they have learned through the unit.

**Ideas for Other Explorations**

- For more space science ideas, see the OER on Astronomy for Educators, by Daniel Barth
- Engineering a shade for sand box, melted chocolate, earth materials?
- Clouds and telling time – 3rd
- Flower pictographs,
- Weather/climate and graphing (CUAI), grade 3rd or 5th

**Reflection Question**

1. Choose one of the example activities from the Ideas for Other Explorations section above. How could these topics be the focus of a 5Es set of learning experiences? Come up with one idea for each of the 5Es.

## Unit 8: Technology and Engineering

Preschool child drawing her sail car design plan and using open-ended materials in her structure. Photo credit: Alissa A. Lange, 2018

Early childhood teachers use the engineering design cycle to plan, create, test, revise, and retest their own sail cars in front of a fan. Photo credit: Tim Altonen, 2018

**What are they?**

Technology and engineering are separate but related areas. As noted above,

"Technology involves the application of scientific knowledge for practical purposes, such as to improve productivity, make things, or provide services. It includes all human-made objects—basic and advanced, non-digital and digital— that support us in work and in our daily lives.

Engineering is the process of designing to meet human needs and wants under various constraints such as time, money, available materials, and the laws of nature. Engineering has strong connections to many other disciplines, particularly mathematics, science, and technology." (Sarama et al., 2018; p. 1)

Below, we describe example projects that incorporate the engineering design cycle, while students use technology, and as a part of the process, they create new technology.

**Example project**

*Title*

Sail Cars

*Author*

Adapted from *Sailing into Integration* by Laura Robertson, Eric Dunlap, Ryan Nivens, and Kelli Barnett

*Grade/Grade Span*

Second Grade

*Summary*

This unit involves an exploration of sail cars and what makes them travel the greatest distances. Students will explore this concept by engaging in the engineering design cycle by designing, creating, and testing their own sail cars against "wind" created by fans. Learners will measure the distances travelled by the cars and compare and contrast the features that allowed them to travel the furthest. Students will then go through the process of redesigning the cars based on their discoveries through comparisons. They will retest their cars and see how their changes impacted distances travelled.

*DCI*

- Technology and Engineering

*Standards*

NGSS

2.ETS1: Engineering Design
2) Develop a simple sketch, drawing, or physical model that communicates solutions to others.
4) Compare and contrast solutions to a design problem by using evidence to point out strengths and weaknesses of the design.

2.ETS2: Links Among Engineering, Technology, Science, and Society
1) Use appropriate tools to make observations, record data, and refine design ideas.

*5Es*

**Engage.** To begin this unit, the class will watch a video of a land sailing competition followed by a discussion about what they just saw. The teachers will ask open-ended questions about the video that encourage children to reflect on what they saw, share their ideas for how they think the sail cars are able to move, and what features enable them to move the longest possible distance. This video and discussion will generate interest in the sail cars and frame the idea as the unit moves forward.

**Explore**. To test their thinking about the sail cars, students will move into a large area (cafeteria, hallway, etc.) so they can construct and test their cars. Teachers will put students in pairs to create a sketch of their sail car design before beginning construction. Once they have their design, learners will use the provided materials to make their design come to life. Students will build their sail car and then test them against a fan. They will measure the distance the cars travel and repeat the test two more times, writing the distance travelled on a sticky note to plot on a graph. This activity allows students to experience the key concept in this unit and examine how their thinking translated into the real world.

**Explain**. During this phase of the unit, students come together for a whole-group discussion. Teachers and students discuss the distances seen on their graph. Teachers will provide information about the graph, teaching them the name of the graph and asking them to make their own line plot in their notebooks. Students will also compare and contrast the cars that were able to travel furthest and discuss the strengths and weaknesses of the different sail cars. They will then go back and re-evaluate their design based on the new information they gained from the whole-group discussion.

**Elaborate**. Students will be given the same materials they had access to during the Explore phase to redesign and retest their sail cars. Once they have made the changes they want, students will test their sail cars again and record their data in a table. They will also create another graph showing the changes in the distances travelled from their original and second attempt, allowing them to compare how the changes they made affected how far the sail car could travel. Students can apply their new learning and communicate what is happening with formal language.

**Evaluate**. To assess learning, students will complete a Claim, Evidence, and Reasoning response individually. They will answer questions about the sail cars, describe what made the cars travel the greatest distances. Students will also reflect on their own learning and the designs they created in their science journals. Teachers can look at students' responses as well as their designs from their sail cars to assess their learning throughout the unit.

Sail Cars with Preschool Children

This project can also be adapted to work with preschool-aged children. The process will be to follow a more basic cycle of inquiry since the work is with younger children. The phases in the cycle will be shorter and more simplified. These phases will be Explore, Create, and Improve. During the Explore phase, the problem will be presented to students to create a sail car that will travel the farthest possible and to build the tallest structure possible to withstand the wind. Once they understand the problem, students will begin the process of designing. They will observe the materials available, draw representations of their thinking, and talk about what they want to create.

During the Create phase, children will bring their ideas to life and test them against the wind from a box fan. Once they have tested their creation, they will go back and improve their designs based on what happens. Teachers will work with them through this process and scaffold their learning as they make adaptations to their creations. Students will also work with their peers, and they work through the rebuilding process. Children will retest their new sail cars and structures and share their findings with their whole class.

**Ideas for Other Explorations**

- Solving a problem in the garden: the hose doesn't work for our classroom garden; how can we water our plants? Check out our article on preschool engineering.
- Engineering a shade for the playground
- Exploring simple machines (technology)
- Using media (another kind of technology) to document change and transformation over the school year, related to seasonal changes

**Reflection Question**

1. Choose one of the example activities from the Ideas for Other Explorations section above. How could these topics be the focus of a 5Es set of learning experiences? Come up with one idea for each of the 5Es.

## Unit 9: Math


Photo credit: Ronald Campbell, 2019

**What is it?**

Math does not have one clear definition. In fact, Farrell and Farmer (1980) argue that mathematics is a verb, as well as a noun. Sarama, et.al (2018) consider mathematics as a noun as they note:

> *"Mathematics is the study of quantity, structure, shape, and change. It provides a foundation for many aspects of daily life, including for much of science, technology, and engineering. The mathematical sciences include more than numbers and arithmetic—they also deal with such topics as geometrical figures and structures, measurement, and logical argumentation. Mathematicians and children doing math use the practices of mathematics to identify crosscutting patterns and structures and to understand and explain phenomena."*
> - p.1, CADRE report, by Sarama et al., 2018

Recent efforts in mathematics education, including the introduction of the Common Core State Standards for Mathematics, focus on mathematics as a verb as they call for students to be involved in "doing mathematics" in the classroom. This raises the question: What does it mean to "do mathematics"? Doing mathematics involves giving students opportunities to make sense of mathematics through exploration. It involves engaging students in solving rich problems and asking them to justify and defend their reasoning. For more on how to support students in doing mathematics, see https://www.oerafrica.org/system/files/8230/unit-1-pdf_0.pdf.

We believe that students can be given the opportunity to engage in high-level, quality math lessons when they are integrated with other subject areas, including those of the STEM field. The example projects below were a part of our STEM Collaboration project, but their development began with a math standard and used a supporting science standard, instead of the reverse. The first project, Shape Hunt and Plant Parts, is for first grade and focuses on shapes, with a science emphasis on plant parts. The second project is from fourth grade, with a math emphasis on angles, while the science standards drew from technology and engineering.

**Example projects**

*Example Project 1*

*Title*

Shape Hunt and Plant Parts

*Author*

Alissa Lange, Amie Craven, & Jamie Price

*Grade/Grade Span*

First Grade

*Summary*

This unit explores different shapes, their characteristics, and composite shapes. Students will experience these concepts in books, shape hunts, videos, and shape tiles. They will find various shapes around their classroom in a shape hunt. One activity will involve asking students to use pattern blocks and pattern block puzzles to create plants. Students will use composite shapes and discuss the various plant parts that make up the plants. Students should be able to discuss attributes of different shapes, create composite shapes, and accurately name major plant parts by the end of their shape study.

*DCI*

- Math
- Science

*Standards*

Math

1.G.A.1 Distinguish between attributes that define a shape (e.g., number of sides and vertices) versus attributes that do not define the shape (e.g., color, orientation, overall size); build and draw two-dimensional shapes to possess defining attributes.

1.G.A.2 Create a composite shape and use the composite shape to make new shapes by using two-dimensional shapes (rectangles, squares, trapezoids, triangles, half-circles, and quarter-circles) or three-dimensional shapes (cubes, rectangular prisms, cones, and cylinders).

Science

1.ETS2: Links Among Engineering, Technology, Science, and Society 1) Use appropriate tools (magnifying glass, basic balance scale) to make observations and answer testable scientific questions.

1.LS1.1 Recognize the structure of plants (roots, stems, leaves, flowers and fruits)

*5Es*

**Engage.** Students will begin this unit in a whole group as teachers read the book, *I Spy Shapes in Art* (or other shape composition book, like *The Shape of Things)*, to the class. This book asks students to find shapes in various paintings and the class will go through this book and talk about the shapes they find on the pages. Teachers will name the different shapes and discuss the shapes characteristics throughout the book. Students will be thinking about shapes, their characteristics, and how to look for them in their environment, especially looking for shapes related to growing things, like trees and flowers. This helps students link their past knowledge and creates interest for the focus of the unit.

**Explore**. Teachers will provide students with a paper showing different shapes, especially focused on quadrilaterals, which can be problematic for students (Oberdorf & Taylor-Cox, 1999). Students will be instructed to go on a shape hunt around the classroom, working to find all the shapes on the paper. Once they find the shapes, students will draw the object they found. They will also write the number of sides for each shape, and any other attributes they notice, demonstrating their understanding of attributes that distinguish shapes. Students will share their findings in a whole group discussion. Later, they will create their own shape art, inspired by the book and the shape hunt. They may first be creative with their art, then they'll be asked to focus their creations on a plant of some sort, like a flower or tree.

**Explain**. To extend learners knowledge of shapes, teachers will show the video "What are Composite Shapes" to begin talking about how some shapes are composed of other shapes. Teachers will draw composite shapes and discuss the shapes used to create them. Teachers will answer students' questions throughout the discussion and continue to point out different attributes of the basic shapes to reiterate characteristics that define the shapes. This activity will extend students' understanding of shapes and provide them with additional formal vocabulary.

**Elaborate**. On this day, teachers will give students access to a variety of pattern blocks and pattern block puzzles that are shaped like plants. Students will choose a puzzle and then use the patterns blocks to complete it. They will then be asked to label the puzzle with the plant parts and explain to a peer how they know it is that plant part. After students finish their puzzles, they will be asked if they can fill in their plant puzzle in another way – such as two trapezoids instead of one hexagon. Students will be able to apply their new learning about composite shapes by observing how shapes make up other shapes and experience changes in surface temperatures. If students need a challenge, they can create pattern block puzzles for their peers to complete.

**Evaluate**. Learning will be assessed individually with a teacher and in pairs. First, they will work in pairs to create composite shapes with a partner, and they will discuss characteristics of the shapes and describe how they are building them. Teachers will have students create composite shapes as well as other shapes from the composite shapes and ask them various questions about what the shapes were created from. Students should be able to identify different attributes of the shapes, such as the number and length of sides, perhaps starting to notice differences in angles. They should also be able to create a variety of composite shapes and identify what shapes were used to create them. Teachers will take anecdotal notes and use a checklist to assess what students learned.

*Example Project 2*

*Title*

Mirror Maze Experiment

*Author*

Adapted from the Unit Plan created by Taylor Spence, 2020

*Grade/Grade Span*

4th Grade

*Summary*

This unit explores the relationship between the angles of mirrors and the number of reflections shown. Students will be introduced to the idea of a mirror maze through a video which shows how difficult it is to complete the maze. Then, learners will conduct a hands-on experiment using an object, mirrors, and a protractor to see how changing the mirror's angle affects the number of reflections of the object. Once they have completed the experiment, students will discuss their findings with peers and graph their data using bar graphs and Venn diagrams. Students will also revisit the video they watched at the beginning of the unit in order to see if they are able to give a more accurate explanation for why the maze is so difficult. Teachers will assess students' learning through a test which involves a CER, math concepts about angles, and hypothetical changes to the experiment and what their effect could be on the number of reflections. An overview video can be found here.

*DCI*

- Math
- Science

*Standards*

Math

4.MD.C.5a: Understand that an angle is measured with reference to a circle with its center at the common endpoint of the rays, by considering the fraction of the circular arc between the points where the two rays intersect the circle.

4.MD.C.6 Measure angles in whole-number degrees using a protractor. Sketch angles of specified measure.

4.ETS2: Links Among Engineering, Technology, Science, and Society
1) Use appropriate tools and measurements to build a model.

2) Determine the effectiveness of multiple solutions to a design problem given the criteria and the constraints.

*5Es*

**Engage.** Students will begin this unit watching the Ellen Game of Games Video, called Mazed and Confused. In this video, contestants are put in a maze filled with mirrors. Their objective is to find a ball and get out of the maze. Throughout the video, contestants bump into the mirrors and find it difficult to get out. Following the video, the students will engage in a discussion about what they saw. These questions will get the students thinking about what was happening in the maze, especially why it was so difficult for them to get out. Students will also share their own experiences if they have ever been in a mirror maze. This activity generates interest in the unit while also allowing students to share prior knowledge they may have related to the topics associated with the unit.

**Explore**. Students will then perform an experiment about angles and reflection with mirrors. The teacher will have a variety of small objects for students to choose from that can be reflected in a small mirror. These objects might include a small toy car or a figurine. Students will also select 2 mirrors and a protractor to use during the experiment. Students will be instructed to set the mirrors up like they were in the video (see project overview video) they had watched. They will place the protractor underneath the mirrors and adjust the mirrors along the protractor to produce different angles. Students will create 5 angles, with the requirement that there are 2 acute and 2 obtuse angles. Then, students will place the object they chose between the mirrors and measure the number of real and reflected objects they see. They will repeat this process for each angle. Students can experience the key concept of this unit and make connections between the size of the angle and the number of reflections observed.

**Explain**. On this day, students will demonstrate their learning and discuss their findings from their experiment with mirrors conducted during the Engage phase of the unit. Students will be given questions to assess their basic knowledge of angles as well as questions asking them to express their findings from the experiment and graph them using bar graphs and Venn diagrams. Students will work with a partner for discussion and comparison of their data. They will also explain why the dimensions of their objects affected the amount of reflections they saw in the mirrors. This activity asks students to communicate their new knowledge and use formal language associated with angles

**Elaborate**. Students will revisit the mirror maze video they watched at the beginning of this unit and engage in a discussion to see if they are able to more accurately explain why the mirror maze was so difficult for the people in the video. They will also estimate what the measures of the angles of the mirrors that were in the video and identify the angles that would produce different numbers of real and reflected objects. This discussion asks students to revisit their original thinking and apply their new learning.

**Evaluate**. Students' learning will be assessed through a test that asks students to discuss math and science concepts they have explored, as well as a CER for the experiment they completed. Students will be asked to discuss what they learned through the experiment and their data, math concepts related to angles, and what might happen if there were changes to the experiment (object size, flat mirrors, tools that could work instead of mirrors, etc.). This will assess students' understanding of angles while also showing their evidence of accomplishment in the activity.

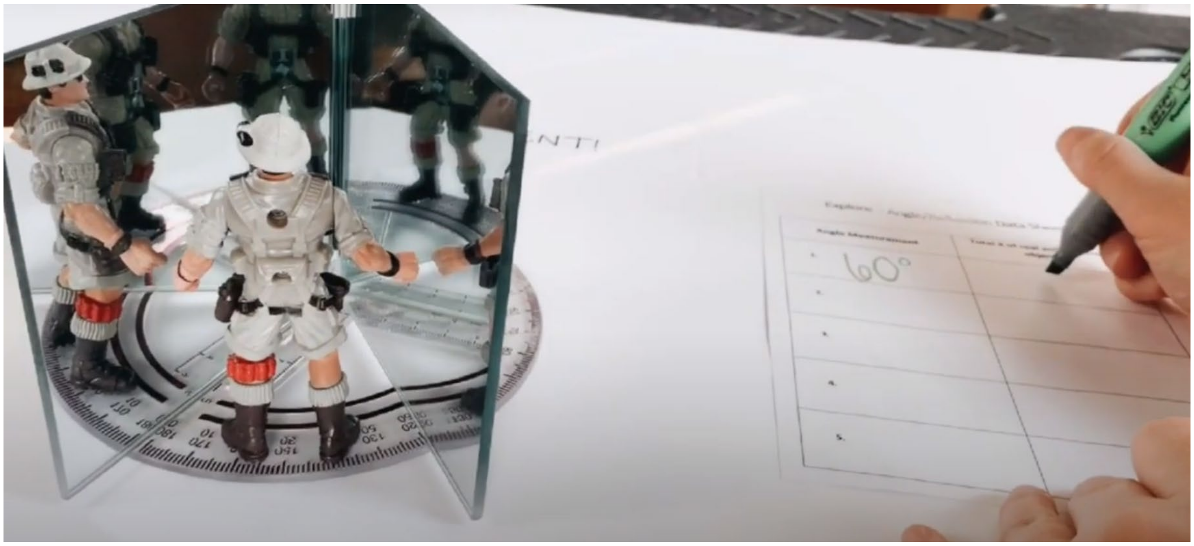


Photo credit: Taylor Spence, 2020

**Key Resources**

- *The Young Child and Mathematics (3rd edition)*, in press

**Reflection Questions**

1. What might be a challenge with doing one of these activities with students? How would you prepare?

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**Teacher author

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# Appendix

**Appendix A: Starting Your Own Early/Elementary STEM Collaboration**

Building a collaboration with classroom teachers has transformed our STEM education courses, because it provides opportunities for pre-service teachers to engage in authentic learning experiences with elementary students. We recommend that other STEM educators build collaborations of their own. One of our articles, entitled, *Making Stone Soup: A Collaborative Approach to Integrated STEM* (in press) describes our collaboration briefly and includes tips on starting new collaborations like ours. Suggestions to guide the start-up of a new collaboration, or to adapt an existing STEM education teacher education program include:

- Collaborate. Seek out partners who might bring expertise that you do not have (e.g., university faculty in mathematics department), who could bring authentic challenges to the project (e.g., a local school or teacher looking to infuse more STEM), or who connect to families or communities (e.g., the local library doing STEM nights). Some work might need to be done to bridge early childhood and elementary programs, if they come from different philosophical traditions, as is the case at our institution. Note, for example, this quote related to math teaching, "all-encompassing recommendations that instruction should be entirely 'student centered' or 'teacher directed' are not supported by research" (NMP, 2008, p. xxii).
- Be flexible. We have learned the importance of being flexible and learning from participants. Feedback from students, pre-service teachers, and teachers have made our project better each year.
- Make it yours. Make a collaborative project suit your own needs, pre-service teachers, students, teacher partners, and contexts. Partnering with schools isn't possible? What about local museums? Does your pre-service program have a different major assignment in your science or STEM class? No problem! How could your assignment connect to a real problem of practice? Could you do video calls with a classroom instead of visiting? What professional collaborative opportunities could there be?

## Components of the Approach

After experiencing the powerful transformation in our courses, we sought to identify the primary elements of our collaboration that contributed to its success. The resulting framework consists of five components shown in Figure 1.

  

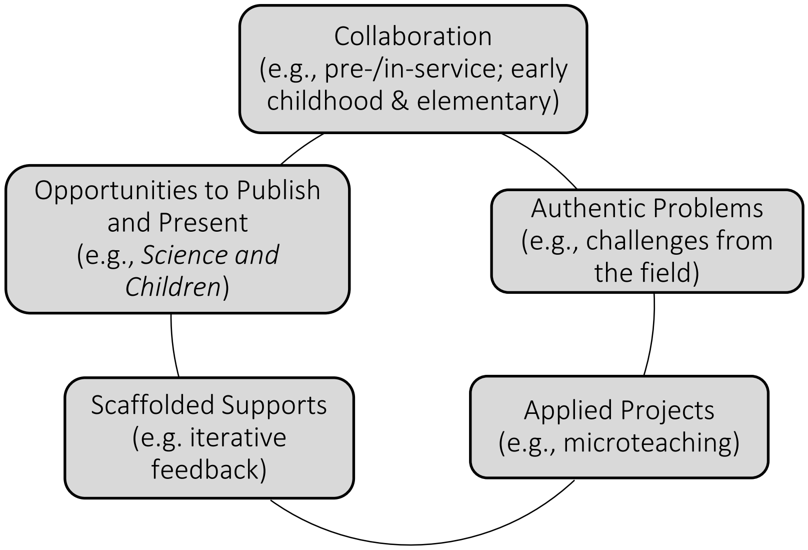


Figure 1. Components of our Early/Elementary STEM Collaboration approach.

*Collaboration*

- Defined: working together with others towards a common purpose. Our collaboration has been between stakeholders, such as practicing teachers, university faculty, preservice teacher candidates, and the community. But others could be involved, such as families. Early and elementary education have different philosophies and traditions, but teaching STEM and integrated STEM may provide space in which early childhood and elementary education teacher preparation programs can find common ground.
- Purpose: learn from each other, draw on strengths, broaden perceptions of STEM education

*Applied projects*

- Defined: applied teaching experiences (microteaching) with real early/elementary students that build on authentic problems from the field
- Purpose: increase motivation, allow for application of knowledge learned in course

*Authentic problems*

- Defined: applied teaching experiences (microteaching) with real early/elementary students that build on authentic problems from the field
- Purpose: increase motivation, allow for application of knowledge learned in course

  

### *Scaffolded Supports*

- Defined: scaffolded supports for teacher candidates as they learn, including feedback and multiple stages, and extra support as needed
- Purpose: provide support for teacher candidates as they tackle a challenging project

### *Opportunities to Publish and Present*

- Defined: professionalization opportunities for pre-service teachers and teachers in the form of co-presenting at conferences, co-authoring papers, and co-developing resources (see list of publications below)
- Purpose: pre-service teachers see their role in the field, how publications and research impact practice, support their later employment

## Publications

Below is a sample of our EC/Elementary STEM Collaboration project's publications since it started in 2016/2017. Many of the co-authors include teachers and pre-service teacher candidates. See an updated list at our website.

*Pre-service teacher co-authors
**In-service teacher co-authors

Books

- Lange, A.A., Robertson, L., Price, J., & Craven, A.* (2021). *Teaching Early & Elementary STEM.* OER Textbook. https://dc.etsu.edu/etsu-oer/8/

Practitioner Articles

- Lange, A., Rice, E.,* Howe, N.,** & Tian, Q.* (2021). A Light Challenge: First Graders Engineer an Obstacle Course with Flashlights, Jan/Feb. *Science and Children.*
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- Clevenger, C.,** Lange, A. A., & Schock, E.**(2022). Moon, Math, and Literacy: Interdisciplinary Connections through a Space Science Study in Preschool. Science and Children.
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- Phillips, E.,* Doran, E.,** Robertson, L., & Nivens, R. A. (2021). Flower Pictographs: Mathematics and Life Science. *Mathematics Teacher: Learning and Teaching PK–12.*

Journal Articles, Peer-Reviewed

- Lange, A.A., Robertson, L., Tian, Q., Nivens, R., & Price J. (2022). The effects of an early childhood-elementary teacher preparation program in STEM on pre-service teachers. *Eurasia Journal of Mathematics, Science and Technology Education.*
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Conference Presentations

- Lange, A.A., Robertson, L., & Hare, A.* (2020). Impacts of, and reflections on a collaborative approach to pre-service STEM education. Roundtable presented at the NAECTE annual fall conference, Nov 4, virtual.
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**Appendix B: Unpacking Standards Guide**

See your professor for this tool. Will be updated soon.

  

## UNPACKING STANDARDS GUIDE – Template with Example

<table>
<tr><td rowspan="3">STEP 1</td><td rowspan="3">Standard as it appears in the TN State Standards (copy/paste):<br>K.ETS1.2 Describe objects accurately by drawing and/or labeling pictures.</td><td colspan="2">DCI: Engineering Design-Developing Possible Solutions</td></tr>
<tr><td colspan="2">SEP: Developing and Using Models</td></tr>
<tr><td colspan="2">CC: Systems and System Models</td></tr>
<tr><td>STEP 2</td><td colspan="3">Initial Gist:<br>Students draw and label pictures accurately.</td></tr>
<tr><td>STEP 3</td><td>A Nouns / Noun Phrases:<br><br>Objects, pictures</td><td>A Verbs / Verb Phrases:<br><br>Describe, draw, label</td><td>B Webb's DOK levels:<br>1</td></tr>
<tr><td>STEP 4</td><td>Key Academic Vocabulary:<br><br>Describe, accurately</td><td colspan="2">Key Content Vocabulary:<br><br>Label</td></tr>
<tr><td>STEP 5</td><td colspan="3">Learning progression notes (What comes before/after this standard? Use TN Science Standards Reference):<br>2nd grade – draw sketches to communicate solutions to problems<br><br>Prior knowledge (What prior knowledge/skills are needed to master this standard?<br>Students need to know how to make drawings.<br>Students need to know how to observe key features of objects.<br><br>Common misconceptions (also check out Uncovering Student Ideas books by Page Keeley):<br>Drawings in science and art are the same.</td></tr>
<tr><td>STEP 6</td><td colspan="3">Learning Objectives:<br>Draw an object accurately.<br>Label features of a picture accurately.</td></tr>
<tr><td>STEP 7</td><td>A Instructional Implications:<br>(i.e., activities/strategies/writing)<br><br>Observe objects<br>Draw objects.<br>Label pictures and drawings.</td><td colspan="2">B Assessment Implications (formative and summative):<br><br>Formative – observation of drawings; ask students to describe what they see<br><br>Summative – accurate labels on a picture and drawing</td></tr>
<tr><td>STEP 8</td><td colspan="3">How will you differentiate to meet the needs of your students?</td></tr>
</table>

  

**Appendix C: Trusted Early and Elementary STEM Sources (examples)**

- STEM and Science
  - National Science Foundation
  - Exploratorium - https://www.exploratorium.edu/snacks
  - NSTA: Science and Children
  - Mass Audubon Society
- Space science
  - www.NASA.gov
  - NASA Science Space Place: Explore Earth and Space! For Kids & Teachers (K-5)
    - https://spaceplace.nasa.gov
  - NASA Solar System Exploration: Explore Planets in our Solar System
    - https://solarsystem.nasa.gov
  - NASA's International Observe the Moon Annual Event (typically in October)
    - https://moon.nasa.gov/observe-the-moon-night/about/overview/
    - https://moon.nasa.gov/observe-the-moon-night/participate/10-ways-to-observe-the-moon/
  - NASA Kids' Club
    - https://www.nasa.gov/kidsclub/index.html
  - NASA at Home: For Kids and Families (Loads of Activities for Kids & Families)
    - https://www.nasa.gov/nasa-at-home-for-kids-and-families
  - NASA Artemis Mission (Return Missions to the Moon)
    - https://www.nasa.gov/specials/artemis/
  - NASA Mars Exploration Program (includes a focus on recent rovers, like Perseverance landing on Mars in 2021)
    - https://mars.nasa.gov
    - https://mars.nasa.gov/mars2020/
  - NASA STEM Resources for Educators
    - https://www.nasa.gov/stem/foreducators/k-12/index.html
  - NASA Aeronautics for Pre-K
    - https://www.nasa.gov/aeroresearch/resources/k-12/aero-for-prek/

- Earth science
  - www.usgs.gov
- Life science – National Wildlife Federation (NWF)
  - https://www.nwf.org/Educational-Resources/Educator-Tools
- Physical Science
  - University of Northern Iowa's Regent's Center
- Engineering
  - National Academy of Engineering (www.nae.org)
  - Engineering is Elementary
- Early mathematics
  - DREME Network
  - Erikson Institute Early Math Collaborative
  - Learning Trajectories in Early Math
  - National Council for Teachers of Mathematics
- Early Childhood
  - National Association for the Education of Young Children
    - Teaching Young Children
    - Young Children

  