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My name is Claire Marino, and I am currently a Junior Elementary (PreK—4) and Special Education (PreK—8) major at Messiah College. I am also minoring in TESOL Education. This guide has been completed for fulfillment of departmental and college senior honors.

Since my first year at Messiah College, I have been a part of an on-campus organization called the Collaboratory. The organization aims to partner students with faculty to use what they are learning in their major to serve others. The team that I have been a member of, and now lead, called “Harrisburg Science Camps,” was a source of inspiration for the topic of this guide. The team partners with an Elementary School in the Harrisburg City School District, specifically an after-school program. The team plans science instruction and activities for the 3rd and 4th grade students who attend, which is implemented by the team on Tuesdays. Being apart of this team has been so impactful for my development as a teacher, and in building my philosophy of education.

Working with Harrisburg Science Camps has given me opportunities to explore inquiry-based learning in science. I decided to dive deeper into the pedagogical research that has been done on the subject of inquiry, and share the compilation of that research in a way that is accessible for educators. I incorporated my own experiences, experiences of other preservice teachers, field tested strategies from my work with Harrisburg Science Camps, and an index of inquiry-based elementary science lessons that align with state and Next Generation Science standards. It is my hope that this guide demystifies the challenges that hold teachers back from teaching through inquiry in their science classrooms.
PART ONE

What is Inquiry?
What Does it Mean for Learning to be Based in Inquiry?
INTRODUCTION TO INQUIRY

There is no shortage of professional discussions, case studies, and experimental research published with the intent to prove that students learn best when they are questioning and curious. Whether it is called “discovery-based,” “inquiry-focused,” “inquiry-based,” or other terms specific to a study, the roots of these ideas have been a subject of discussion among educators. The tenets of inquiry-based instruction are widely accepted in schools around the country, and can be seen through the use of inquiry-based instruction in national education standards. Throughout these research studies and resources, almost each one contains a different definition for the word “inquiry.” What seems like a simple idea at first glance, actually has much more complex details when it is framed as a strategy for teaching science. The following are definitions of inquiry that summarize the general overview of current studies and resources.

“an approach to learning that involves exploring the world and that leads to asking questions, testing ideas, and making discoveries in the search for understanding.” ¹

“the dynamic process of being open to wonder and puzzlements and coming to know and understand the world” ²

“where students have the opportunity to have first-hand experience of getting in contact with something that bears some resemblance with what real scientists and researchers do and thus actively participate in producing knowledge.” ³

“[Inquiry] can be considered a way of engaging in science practices (and, more recently, engineering-related practices) to learn scientific concepts and the nature of science.” ⁴
“a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze and interpret data; proposing answers, explanations, and predictions; and communicating the results.”

Even further, there are many characterizations of the concept of “inquiry-based learning.” Some of these definitions are as follows:

“the creation of a classroom where students are engaged in essentially open-ended, student-centered, hands-on activities.”

“used to describe both teaching and doing science.”

“an ongoing investigation in which children are introduced to materials through hands-on experiences and, with teacher guidance, begin to investigate a question that they can answer through their own actions, observations, and with teacher-assisted research.”

Although there are many variations to the phrasing of these definitions, the principle ideas are the same. For this guide, we will define inquiry-based learning as:

**An approach to gaining knowledge about the world that is sparked by the learner’s own curiosities and desire to solve relevant problems**

By engaging in this type of learning, students can make their own learning more meaningful in the context it is being taught, and teachers can foster learning that goes far beyond traditional memorization of required content.
While many teachers are finding ways to incorporate inquiry-based learning into their classrooms, the idea is far from new. From the works of Vygotsky, Dewey, and Piaget, the ideas of incorporating discovery and student inquiry were present. Each of these researchers have a common belief that is presented: that true learning begins with something that interests the student and a question that prompts further pursuit of knowledge. Through this, students can engage with learning in a reflective, interesting way.

The true origins of this paradigm are in constructivism, which theorizes that all people use their experiences to shape their perception of the world. This contributes to educational theory by arguing that teaching information to students should happen in a way that is relevant to their shaping of the world. This suggests that students are more likely to engage with information when they feel it is relevant to their understanding of a concept. When something sparks the curiosity of a learner, the learner can make the information meaningful. This allows them to construct meaning of what they have learned. Since there is no certain way that a person constructs meaning, students will interpret information in different ways. An approach that is based in student inquiry helps students to make connections and construct in ways that are meaningful to them personally. At the heart of inquiry-based learning is that students will make information meaningful to them personally, which will then increase true comprehension of the material. And creating opportunities for meaningful learning and deep understanding of content are two prevalent goals of effective education, aren’t they? Teachers are taught to aim to make learning meaningful and to make sure students remember information and can apply it. This spurs another question: How can teachers facilitate this kind of learning?
For teachers, a certain degree of reevaluation is necessary to effectively implement this strategy. This is because this model of learning clashes with traditional teaching styles, especially any models that are considered teacher-centered. When the teacher’s role is redefined and the teacher is removed from the position of director of learning, changes will inevitably take place. Students are now in more control over aspects of their learning that once belonged to the teacher. Trevor Mackenzie aptly describes this process as a shift of control from “me to us,” in terms of the individuals in the class. A teacher in this process may be more focused on questioning and probing good discussion among students, rather than providing direct instruction on a concept. Compared to the model of gradual release that is used to sequence instruction, guided practice, and independent practice, inquiry-based learning is characterized by students independently exploring first. This way students can make connections about learning on their own and produce learning in this way.

Colburn points out that, for instruction that is based in inquiry to be successful, the teacher leading it must believe in its effectiveness. There has been an abundance of research published that points to experiential learning as an effective tool for retention in long term memory. The experiences that students engage in during inquiry, often characterized by a sparking of curiosity about phenomena, help them to retain information. Even though research has been done in favor of this kind of teaching, adjusting the role of the teacher is often met with some opposition. The difficulties that come with teaching in this way must be combated with the belief that it will help students learn in a more meaningful way. Colburn’s research explores further the teacher behaviors that are most conducive to this learning.

• Asking open ended questions that point students in the direction of learning the concept.
• Giving students wait time between questions and answering, which gives them the opportunity to think deeply and produce their own answers.
• Rephrasing student responses to validate what they have said and make their ideas more concrete.
• Avoiding telling students their response or results are completely wrong, but rather redirecting thinking.
• Employing effective classroom management techniques that create an environment for learning.
The term “inquiry” is vague in its relation to tangible teaching practices. Because of this, researchers and educators explain the different ways inquiry can be used in the classroom. Each form presents a different way of implementing inquiry in the classroom based on the goal of that lesson. The goal of instruction should determine which method is used. The methods are organized in order of decreasing scaffolding.¹⁰

Some researchers suggest moving through these each of these methods as a progression through a unit, so that students become more involved in the learning as they become more familiar with the topic.

**Confirmation Inquiry:**

This form is characterized by the main goal of confirming results that are already known to the students. The teacher gives students the question to investigate, the procedure by which it should be investigated, and the expected end results.

When should this be used?
- When your goal is to reinforce a previously learned idea.
- When your goal is to practice or emphasize a certain skill related to conducting experiments or research.
- When your goal is to develop students’ inquiry skills (See Appendix C) in a strongly scaffolded way.

**Structured Inquiry:**

Structured inquiry, the next step away from teacher guidance and support, gives students the opportunity to generate an explanation throughout their learning. Students are given a question to investigate and the procedure to complete, but are given the task to determine the results and decide why they found those results. This gives them the opportunity to make sense of results found and produce generalizations about the topic based on these results. This is a very
common practice in elementary classrooms as a means to build the foundational skills needed for more open inquiry.

This is an approach that fits easily within structured curriculum and specific learning standards. When the teacher can control the pace and direction of the inquiry, it can be ensured that the students are learning specific goals. When should this be used?

- When your goal is to foster motivation in students through finding the results.
- When your goal is to build inquiry skills (See Appendix C) like conducting experiments.

**Guided Inquiry:**

This method involves less scaffolding than the previous two types, but still retains some structure. The teacher gives the question to investigate, but nothing else. Students are tasked with designing and carrying out a procedure, collecting data, and producing results. Guided inquiry should be used with students who have had practice designing and implementing procedures many times before. When should this be used?

- When your goal is to give students an opportunity to practice designing procedures and other inquiry related skills.
- When students have practiced investigating a question with teacher guidance and are ready to do so independently.
- When your goal is to encourage critical thinking.

**Open Inquiry:**

When students engage in this type of learning, they are given little support from the teacher. This is often the type of inquiry referred to in research which measures the effectiveness of allowing students near full control over their learning in this context. Students are given no guiding question, procedure, or results, allowing for maximum input into the learning in the hands of the students. It is important to note that students must have repeated practice in designing inquiry before they can be successful at this level.
This is proven to motivate students and increase their interest in learning. However, this can be difficult for teachers to implement within the mandates given in a specific curriculum.  

When should this be used?

- When your goal is to give students opportunities using skills related to science inquiry.
- When your goal is to motivate students with a question that really interests them.
- When your students have questions about a topic learned in class, or the world around them.
When looking at these different aspects of inquiry, the process can seem too complex for young students. Even when faced with standards and initiatives that encourage inquiry-based science, elementary teachers are often left asking, “Can inquiry be done in a way that is appropriate and productive?”

Many classrooms do not implement science that utilizes independent inquiry skills until around third grade. The main reason for this is the skills that students possess developmentally in the early elementary grades. Abstract reasoning and other skills necessary for forming and investigating inquiry are not fully developed at this age. Ashbrook points out, however, that early elementary students do possess the curiosities that produce good inquiry. In order to turn this curiosity into science learning, teachers must focus on student interest and be ready with prompting questions and resources to support them in investigating their questions. Another great way to draw on inquiry in the early elementary grades is through ongoing inquiry. An extended amount of time over the course of several days or weeks can be a more appropriate alternative to short activities. By following an inquiry over this period of time, such as watching seed growth or butterflies develop through their life cycle, students have adequate time to formulate questions and process findings, all with strong guidance from teachers. Introducing inquiry skills at this young age lays the foundation for a life of inquiry—one that is not limited to the science classroom.
PART TWO

What are the Results of Teaching Through Inquiry?
As indicated in the National Science Education Standards, it is important for elementary age students to be proficient in using questioning in science. Several studies have been conducted to evaluate the effectiveness of teaching inquiry-based science and its impact on their ability to use these skills and overall achievement in science.

**Inquiry in Science Interventions**

A recent study examines the use of an inquiry-based science intervention program, in which students throughout elementary grades are given the tools to investigate grade-level appropriate problems using questioning to draw conclusions about the topic. These interventions consisted of instructional units, teacher workshops, and classroom whole group instruction. Researchers analyzed the results of students overall academic performance in science, in comparison to different subgroups, and their abilities in inquiry skills. This study’s results concluded that students who participated in this inquiry-based instruction made significant gains in their ability to perform inquiry related skills. It indicated that students’ ability to ask questions during learning improved in this environment. According to this study, presenting inquiry in an intervention setting can be beneficial for elementary age students.\(^\text{12}\)

**Inquiry Through Modeling**

Another study explored the use of physical models to teach science alongside inquiry. Specifically, they used models with FOSS (Full Option Science System) kits to lead inquiry. After leading students in an exploration of particle models, students were better able to explain phase changes of matter. The success achieved in this particular topic gives insight to the effectiveness of models on abstract concepts. Students, when given guidance to explore models of these abstract concept, were able to learn and show their learning.\(^\text{11}\)

**Inquiry for Literacy and Vocabulary Skills**

A shift in viewpoint in education has led to the interdisciplinary content integration. In this holistic view, students rarely learn just one subject in isolation,
but have an opportunity to develop content area skills to develop as well. A second study looks at this practice in the context of the development of literacy skills that occurs during inquiry-based science education. The results of the study confirm the theory made by the author: joining literacy and science through inquiry can be increasingly motivating for students and can encourage academic language development. Students were able to better articulate questions throughout the inquiry process, in both oral and written forms.5

**Research about scripted inquiry-based science**

This type of inquiry is characterized by learning through a series of steps that the teacher prepares ahead of time, usually guiding students to a specific learning goal. This is more common in science curriculum today in activities, demonstrations, and labs that are used to teach specific standards. Current research, however, recommends a more intentional way of teaching through scripted inquiry. Even when the instructional goal for the day is planned and steps are set to achieve it, it is important to find ways for students to take on some responsibility in the learning process, beyond just doing what the teacher says. Creating opportunities for students to make decisions about how to solve a problem, what problem to solve, or why that problem is important to the world, in turn creates meaningful engagement. When students are given more responsibility in their learning in this way, they become more engaged with the material. Active engagement is essential to the comprehension and retention of content, in any subject area.10

**Research about open inquiry-based science**

In contrast to scripted inquiry, decision making and the transfer of responsibility to students is integral to the practice of open inquiry. By teaching through open inquiry, students are tasked with a variety of responsibilities that they are not typically given. Examples include, deciding what subjects to study, how to investigate them, what materials to use, and how to share their results. Although this may seem like a hands-off approach for teachers, research suggests that teachers play an active role in ensuring success with this environment. By asking questions, based on the teacher’s own content knowledge, students are led to investigations and experiments that align with learning outcomes. Teachers have the opportunity to make meaning from whatever results students find, and therefore solidify the learning.10
Research about Inquiry-based learning for ELs

The current population of English learners and culturally diverse students is growing rapidly in the United States. With this growth has come a critical outlook on the cultural sensitivity of the material we teach and the methods in which we teach it. This type of awareness has been refined into a method of teaching, otherwise known as culturally responsive teaching. It can be defined as “using the cultural knowledge, prior experiences, frames of reference, and performance styles of ethnically diverse students to make learning encounters more relevant to and effective for them.” Much of this important research discusses the importance of inclusive literature and unbiased general education practices, as well as the teaching of history in a way that does not bias one group of people. Fewer research, however, has been done to identify ways that science, especially in the primary grades, can be taught in a culturally responsive way. Though this research applies to all culturally diverse students, it can be especially prominent for some English learners, who identify with a vast variety of cultures. Another research study presents the idea that inquiry-based learning can be beneficial for these students, because of the way it is prone to this kind of cultural sensitivity. When students are given the opportunity to explore scientific subjects on their own, they are able to bring their own background knowledge to the learning. In this type of student-centered environment, it is much less likely for a teacher’s own biases to be taught outright. Questions can be raised concerning what different groups of people believe about certain specific phenomenon, and students may explore answers to these questions free from restraint of what is considered “correct” by the dominant culture.

One of the most distinct challenges for English learners is developing academic language. While social language, that is language that is used in students’ everyday lives, is given abundant opportunities for practice, academic language is much harder to develop. Academic language refers to the words and phrases that have a meaning in certain academic disciplines, or words and phrases that take on a new meaning when used in academic disciplines. A common way to facilitate academic language development is by pre-teaching vocabulary words that are used in a certain lesson or unit. While this certainly can be beneficial for students, inquiry can also be used. If all students, not just English Leaners, are using
inquiry to find out the meanings of concepts before pairing it with terms, students can also learn this academic language. This inductive approach allows students to discover the meanings of academic language on their own first, rather than just memorizing it. This approach can be more inclusive of English Learners, since they are included in the experience of learning concepts with their peers.

**Research about inquiry-based learning for students with disabilities**

The inclusivity of inquiry-based learning for English Learners, in many cases, applies to students with disabilities. When inquiry is used, students can use the skills that they possess to figure out answers to problems. In theory, there is no specific set of skills needed, physically or intellectually, of an individual to become successful. Students are able to contribute what they can to the investigation, and are likely to feel successful in the task.

Depending on the disability that a student has, varying levels and types of support are needed from the teacher. Generally, the same accommodations given to students during traditional instruction can be used during inquiry as well. It is a very individualized process to decide how to assist students, but the experiential learning that takes place in inquiry has been shown in many studies to increase learning and improve attitude about science in students with disabilities. For many students, following inquiry-based activities with direct instruction and reinforcement of concepts is effective. By doing this, we create an inclusive and exciting learning environment that supports meaningful learning of science concepts for students with disabilities.\(^{14}\)
PART THREE

What are Some Challenges Educators Face when Teaching with Inquiry?
How Can Those Challenges be Resolved?
In researching about the use of inquiry in the classroom and listening to the accounts of teachers, several patterns of challenges seem to arise. As a part of teaching through inquiry, we must confront these challenges. By doing this, we can assure that students are getting the most out of the experience and are truly learning in the most valuable way possible.
The following headings are a list of challenges that are common to current research. Following each heading is a proposed solution to prevent each challenge from discouraging the use of inquiry in the classroom.

**Challenge: Inquiry Requires a High Level of Teacher Expertise in Science**

One of the key aspects of inquiry is pushing students to wonder and express their wonderings through questions. Although some of the answers to these questions will be found through experimentation and discovery, many of them will be answered, or at least guided, by teachers. This requires having a background knowledge of science that spans beyond what is traditionally expected. Students may, as is a goal of inquiry, have unexpected questions that stem from natural curiosity. If teachers do not have sufficient content knowledge to answer and guide students’ questions, the inquiry process can be stunted. A recent study about teacher experience in science showed that 34% of elementary teachers had taken at least one class in each of earth, life, and physical science. The remaining 66% of these teachers had taken classes in two of the three areas, one of the three, or no science classes at all. If teachers are not familiar with the content of one area of science, their ability to lead students through inquiry will be limited. It is through this logic that we claim that teaching science through inquiry requires a certain content expertise that is not required to use most traditional teaching methods.\(^{17}\)

**Solution: Expect Yourself, as an Educator, to be a Learner Too**

While this challenge is certainly present for many teachers currently, I believe a change of mindset is what is needed for success with inquiry. If a teacher feels unconfident about their abilities in science, they may be hesitant to put themselves in a position, like what often happens during inquiry, where they are unsure of how to answer a question. Being willing to step outside of this expectation that the teacher will always have the answers is the key to overcoming this challenge. When students see that their teachers are still learning as well, they will often feel more empowered to voice their own theories and questions, free from fear of being “wrong.” While a lack of formal science education in teacher education problems is a prominent challenge to teaching science deeply in elementary school, I believe that this should not stop teachers from encouraging inquiries in the classroom.
Challenge: Inquiry Does Not Fit with Traditional Assessments

On the topic of using inquiry, one of the most prevalent challenges to implementing inquiry in the classroom is its apparent juxtaposition with current trends in assessment. School accountability through standardized testing is a high priority. These assessments, as teachers can attest to, can be largely generic and surface level. Although there has been a shift towards the importance of expressing critical thinking, most assessments place value on remembering, rather than higher order forms of learning like understanding and applying. How does an education system such as this mix with a method of teaching that values deep understanding through exploration? While many voices in education argue that the two are incompatible, and thus inquiry for deep understanding is not worthwhile to teach in this current state, some others have argued that this may not be true.

Solution: Intentionally Foster Transferrable Inquiry Skills

When students learn through inquiry, many skills have the opportunity to be refined through the learning. Collaboration, critical thinking, and self-directed work are skills that most educators would agree are needed for academic success. These are not directly assessed by most standardized tests, but the skills are transferrable to the continuation of learning. These include being able to explain thinking and show work, as well as working with a group.  

While these skills, alongside content knowledge, are transferrable to other areas of learning, there is a necessity to evaluate the effectiveness of inquiry programs through the use of assessment. In order to accurately assess how well teaching through inquiry has improved these skills, creative assessments must be used. One example of these kinds of assessments is performance assessments. One study suggests that we should measure students’ learning by paying attention to their questions, specifically their complexity. When students ask higher order thinking questions and ones that go beyond one definitive answer, they show improvement in behaviors necessary for inquiry.  

Many classroom teachers have implemented inquiry that results in a project to show what students learned. This can be a helpful way to assess students since it doesn’t constrain the assessment to one format. Students can present their work, write something to show what they learned, or use other mediums that may apply to their learning. Anecdotally, some teachers have chosen to simply observe the presence of inquiry-like behaviors throughout the process. These include, again, asking more complex questions, beginning challenging problems with a positive outlook, creating an argument from evidence, and defining problems. Other research suggests authentic assessments of inquiry can include portfolios, holistic grading ru-
brics, and self-evaluations. The room for creating different assessments based on the students in a class and the inquiry completed seems endless. One unique example is assessing students through the task of creating a concept map on the subject that they learned. By doing this, students can be reflective about the conclusions of their inquiry and organize it in a succinct way.\textsuperscript{19}

\textit{Challenge: Inquiry Makes Classroom Management More Difficult}

One study brings about an important concern for teachers when it comes to implementing inquiry. To quote his article about the challenges of inquiry: “One of the greatest concerns for teachers in implementing inquiry-based instruction is the fear of losing control—control of instruction, control of students, control of the class.”\textsuperscript{20} When the learning process is more student-centered and student-directed, there may not be a concrete plan for how the day will progress. This can be daunting to educators who value planning and organization. The challenge continues when it is necessary to make sure that all students are meeting the learning objectives for the day.

\textit{Solution: Prioritize a Safe and Respectful Space}

Although this is understandable based on the more free nature of the learning in inquiry, the same solutions to any issues with classroom management are the solution here. Having a preemptive attitude about classroom management, creating an environment where expectations are set initially and are kept and one where respect is central, can help prepare students for learning through inquiry. Strong relationships with students and high expectations also promote an environment where learning can take place without hindrance.\textsuperscript{20}

\textit{Challenge: Inquiry Places More Responsibility on Students}

When inquiry is implemented in the classroom, the roles of the teacher and the students shift to give students more responsibility in their learning. As drawn out in the figure below, from a study about the responsibility levels in inquiry-based learning, the level of responsibility given to students changes based on the openness of the inquiry. If teachers chose to instruct based on any level of inquiry, there are some new expectations for students that they may not normally have. In example 3 in the chart, the most open versions of inquiry give students the task of designing the experiment, performing the experiment, and compiling results.\textsuperscript{10} Even if students do just one of these things independently, they are required to
use organizational skills, their knowledge of materials, keeping records of results, and looking at results objectively to come to a conclusion. This can be intimidating to teachers and students, and there may be reasonable doubt about how successful students would be with these tasks.

**Solution: Empower Students to Take on Responsibility Slowly**

One way to combat this challenge is to follow the model where it is suggested to move from structured inquiry, gradually releasing responsibility to open inquiry as a progression, students can be better prepared to handle this responsibility. This follows the natural progression of developing skills, as teachers remove scaffolding as students learn.10 In addition, the amount of responsibility that students have is largely up to the discretion of the teacher. Knowing your students is important when it comes to making decisions like these. Powerful inquiry can still occur with maximum guidance and scaffolding from the teacher, if needed.

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**Challenge: Inquiry Requires a Large Time Commitment**

When the theory and practice of inquiry is studied, many models such as the one below appear very thorough and, thus, time consuming. This model of the cycle of inquiry almost seems to suggest that six different periods of learning must occur to complete one investigation. With strict mandates put on classrooms to get through certain objectives each day, this kind of time commitment appears unrealistic.15

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Solution: Be Prepared to Integrate the “Steps” to Inquiry

The author of the book that proposes this model discusses how most of these steps actually happen concurrently, and are deeply interconnected. By this explanation, this process should not take much longer than other methods of teaching science. It is also helpful to note that, like any new routine, students become more comfortable with the system as time goes on and will be able to get into inquiry more quickly.

One of the most valuable ways to interact with a model of teaching such as inquiry is to hear the stories of professionals who know, hands on, the challenges and successes of its use. To do this, this section provides anecdotal experiences of preservice teachers with inquiry-based science, as well as first-hand experience from a group of undergraduate students who implemented inquiry in an after-school program for third and fourth grade students.

**Messiah College Preservice Teachers**

*Experiences with Science Instruction*

In the process of interviewing preservice teachers about their experiences with inquiry-based science, I asked them what inquiry-based science they had seen in the classroom. Responses ranged from true admiration of the process to maintained skepticism, but all provided an insight into the next generation of teachers’ perception.

In reference to a unit about simple machines that her class was doing, Teacher A* said,

“It has been a lot of fun watching my students engage in the productive struggle of trial and error in getting all the pieces of their course to work in unison. Most students are fully engaged in the process and are excited to work on it each day. There are some points in which the students have been at a standstill because they have exhausted their thought processes on how to solve an issue they're experiencing.”

The language of “productive struggle” is appropriate in describing the process that students often engage in during inquiry-based learning. It is this struggle, in fact, that makes the learning so meaningful. Using perseverance is a skill that is very transferrable areas of life, both inside and outside of the classroom.

Teacher B* recalled a time when, in one of her field placements, a substitute teacher veered from the science lesson plans left for her. Instead of giving students a vocabulary list of words related to physical changes, she decided to engage the class with a concrete event. She led students in manipulating pieces of paper in different ways, like crumpling or ripping them. Students were then encouraged to formulate their own questions related to what happened. This preservice teacher was in awe of how effective letting students create their own questions was.
Teacher C* an elementary and special education major, reflected on a teacher who prioritized time spent outdoors intended for free exploration. Students had frequent opportunities to make observations and wonder about things that they saw. This was encouraged and became the source of discussion many days.

I also asked where preservice teachers had seen science instruction that was not based in inquiry.

Teacher D* described her experiences, which were in early elementary settings, as teacher-focused and simplistic. Rather than trying to develop a science skill or knowledge of a topic related to science, the instruction was made to fit a “theme” of a unit, such as fall. Students were taught about leaves, the different colors they were, and how they fell. Although this instruction served the purpose of the unit, students were not engaged. To use her exact words, students were “bored out of their minds,” during this part of the day.

Teacher A* commented that in her experience observing this, “Student engagement decreases rapidly and firm understandings on concepts are not fostered.”

A worksheet with vocabulary related to the subject was brought to mind by Teacher E*. She said that students were assigned to define the words by looking in their textbooks. Most students just skimmed the pages until they came to the vocabulary word. Copying definitions without a real understanding of their meaning or context for their use, she explained, was not helpful.

Teacher B* reflected on negative memories from her experiences as a teacher and as a student. In both of these settings, “popcorn” reading, where each student takes turn reading a section of a textbook aloud, occurred as a means of science instruction. She remembered not only dreading reading, but also not paying attention when others were reading.

While this is certainly not the case for all science instruction that is not based in inquiry, teachers’ experiences do seem to share the common thread of decreased student engagement.

Perceptions and Personal Philosophies

It is interesting to survey the opinions of this emerging population of teachers on how they think that inquiry-based learning will impact their own practice. I asked how, keeping in mind their field experiences with inquiry-based
learning and experiences in science content classes, they personally see themselves teaching science. All who were interviewed said that they see them teaching science in a way that is primarily inquiry-based, but each shared some obstacles to making this belief a reality.

Teacher A* expressed her uncertainty that her desire to teach in this way will be supported by administration, due to the coordination and planning required, as well as the priority that is placed on literacy and math instruction in the primary grades. The challenges that are associated with inquiry-based instruction are acknowledged when she said, “Although it may be easier and more time effective to teach from a textbook, students will be missing out on so many rich experiences.... I see myself teaching science from an inquiry-based approach because I can see the benefits of it.”

Teacher D* shared that while she sees the benefits to implementing inquiry-based learning in science, she has not seen it done well in early elementary school settings. She expressed skepticism about using this model in Kindergarten, for example, since requirements of students to have responsibility for their own learning seem developmentally inappropriate for students at this age. I have found that others expressed the same caution.

Teacher B*, an elementary education major with a TESOL minor, expressed her desire to teach science using inquiry. She said that she has seen its effect on student engagement and wants to replicate this practice in her own classroom one day. Her concern, however, was the lack of resources that many schools have. In order to best support students in their inquiries, materials used to conduct experiments should be accessible. She worries that working in an underfunded school may pose challenges to facilitating inquiry.

Harrisburg Science Camps Team

A group of students from Messiah College volunteer to prepare and implement science activities for 3rd and 4th grade students at a local elementary school’s after school program. Inquiry is a prevalent focus when planning, and the participants have become familiar with implementing inquiry-based learning.

Inquiry in this Setting

In my own experience in the after-school program, I have had the unique opportunity of facilitating inquiry outside of the traditional classroom setting. Although our lessons are standards-based and driven by the core science content
that students are required to know, we have more freedom to let students explore frequently and without restriction. Creativity, authentic engagement, and meaningful discussion are essential to the learning that occurs.

Each week that we visit the school, we plan a lesson that is situated within a unit of study. These standard-based units have focused on the water cycle, simple machines, body systems, the senses, habitats, and scientific method skills. In this experience I have found that some of the richest learning occurs when students are able to explore and draw their own conclusions. I believe the climate that has been created for that time also impacts this. As the students get to know the volunteers and the program, I believe they realize that their wonderings and explorations are valued, whether or not they are correct. This classroom climate contributes to their willingness to become active participants in their learning.

One experience that most evidently exemplified successful inquiry was a recent exploration of weather. To introduce the subject, activate prior knowledge, and engage students in critical thinking, purposeful questions were developed. Students first were tasked with writing down and/or drawing whatever comes to mind when they think of weather. After, we compared and dove into questions in small groups. Questions such as, “what have you heard causes weather?”, “why would someone want to study weather?” and “how does weather affect you?” prompted some inspired responses. The picture below shows just some of the discussions that took place during this time. Discussions about how weather impacts different people and animals ensued among students, complete with evidence to back up their arguments.

The following dialogue occurred as students discussed the negative impacts of weather on humans:

“Weather affects us because it gets us out of school!”

“They cancel school because it’s dangerous to come to school”

“Yeah, weather can be dangerous, even deadly! Like those fires that happened”

“Deadly?!”

“Or hurricanes. Or tornadoes too!”

“Those fires looked scary. I don’t know why that happens”
The thing about this dialogue that is so striking to me is how comfortable students were sharing their experiences and perceptions about weather. The conversation flowed as naturally as hallway chats would, with students interjecting to share their surprise, agreement, or disagreement. I think this is largely because of their ability to share and explore through sharing in a way that does not expect them to land at a correct answer. It is made clear that our goal is quite the opposite: to identify what we want to learn more about in the world.

This example of inquiring by students through simple discussions gave way to meaningful science lessons in the weeks to follow. Especially in the “engage” stage of the inquiry process, I believe that fostering a classroom climate for risk-taking and authentic wondering is essential to producing this kind of response. The team that works with students in this program has intentionally prioritized valuing students’ questions and comments, so that they feel confident in participating.

I asked the members of this team to comment on their experiences using inquiry in this setting and how they think that teaching in this way impacted students’ learning.

Teacher F*, a student majoring in biology, discussed how this approach differed from more traditional science instruction she had in her own education. She believed that the structure of the instruction was more child centered, more flexible to foster exploration, and gave students opportunities that traditional instruction often does not. An example of this was the kinds of observations that students were able to make. Since we did not direct students to a “correct” answer, students had room to discover phenomena on their own. This produced some astute observations, which students may not have shared otherwise.

Teacher G* explained the way students were able to make meaning of the learning in an especially meaningful way. When students observed things on their own, they used them to draw conclusions authentically. One day when this happened, she pointed out, involved a group of students an acid-base reaction that, when done in a water bottle covered by a balloon, caused the balloon
to inflate. Some students instinctively noted that gas caused the balloon to inflate, but other students had different ideas. They were able to freely discuss these ideas, without an understanding of who was “right.” This gave each student an opportunity to think more deeply about why they had that idea, which may not have happened if students were told the correct answer as soon as it was said. I believe moments like this create opportunities for cultivating confidence, which can be challenging for quieter students to achieve in traditional settings.

**Inquiry Behaviors**

I asked the members of this team to be aware of the inquiry behaviors to look to recognize in students (See Appendix B). At the end of the semester, all agreed that they saw an increase in these behaviors during our inquiry-based lessons. Some stories shared about the times they observed these behaviors are written below.

**Hypothesized independently:** Teacher G*, as well as other members of the team, witnessed this behavior frequently. In one case, students verbalized wonderings during an exploration and turned them into hypotheses. During our chemistry unit, in which students were exploring acid-base reactions, students wondered what would happen differently if they mixed water and vinegar together, and then added baking soda. Students predicted if more, less, or the same amount of gas would be produced.

**Communicated Ideas with Others:** Many times, attendance in our program is inconsistent. Because of this, students had the opportunity to explain to their peers, who had missed the previous week’s instruction, about what we had learned. Students freely shared their ideas from the previous weeks in a way that showed they understood the content.

**Made Meaning of Content:** On the same day mentioned previously, in which we explored acid-base reactions, students observed the balloon inflating as a result of the reaction. Simply through their observations and teacher questioning, they were able to make meaning of what they saw. The simple question of “Why do you think that happened?” sparked a meaningful discussion that produced accurate conclusions about the content, which students arrived at on their own.
Challenges with Implementing Inquiry

In addition, I asked the members of our team to consider the challenges they encountered when teaching in this way.

One challenge that was common among several members was the difficulty of “letting go of control.” Teacher H* discussed how they have a vision in their mind of how they feel the lesson should go and veering from that feels like they are disregarding the plan. This was challenging at first because it involves letting go of an expectation for how we want the learning to take place. An important part of making inquiry-based learning successful is letting students set the tone for how learning takes place, so that it can be the most meaningful to them. After a discussion with the team about this issue, we were able to articulate our thoughts in this way: When students engage in inquiry, teachers must let go of the fear of losing control in favor of accepting that they will need to control in a different kind of way.

Teacher I* brought up that another challenge was maintaining an interactive environment with students who took advantage of the situation. Since our space for learning allowed for more expression and less structure, some students were more prone to behave inappropriately, talk with peers about things outside of science, and other behaviors of the like. This was more prevalent at the beginning of the school year when students were getting to know our team and our program. We believe that through intentional rapport building, this issue was resolved in many students. Creating a classroom where expectations are known is important to the success of inquiry.
PART FOUR

Inquiry-Based Lessons and Resources for Classroom Use
Throughout my time volunteering in the after-school program and participating in undergraduate field experiences, I have created several lessons that follow the model of inquiry-based learning and the 5 E’s. Each lesson falls into a unit of study that is focused on a topic. Much of the content of the lessons was inspired by other sources, and is cited as such. Each lesson can be easily adapted to meet the needs of an individual classroom, as well as adjusted for time constraints. For some, pictures from their use in the classroom are included. In addition, almost all of the lessons require low-cost, accessible materials. The goal of including these lessons in this guide is to provide examples of what teaching based in inquiry can look like. I hope that these lessons are useful and practical for the classroom, and can facilitate the growth of inquiry-based learning for all students.
What Will the Weather Be Today?
Exploring weather instruments and the reasons why we use them

**Engage**
- Introduce students to meteorologists and what they do. Show videos and pictures of real meteorologists.
- **To Ask Students:** Why do you think someone would want to measure weather?

**Explore**
- Split students into groups and let them explore a barometer, rain gauge, or thermometer without telling them what it is called or what it does.
- Instruct students to think about what the instruments might measure in terms of weather, and write down their ideas.
- **To Ask Students:** What do you notice about these tools? How do you think they could be used? What do you think these tools measure?

**Explain**
- Explain what each of the weather instruments measures, and instruct students to look at their instruments again. They should look for the different parts, and how they are used to measure weather.
- **To Ask Students:** What are the main parts of a barometer (or whatever instrument they are exploring)?

**Elaborate**
- **To Ask Students:** How could we use these main parts to construct our own rain gauge?
- Guide students in creating their own rain gauge using plastic cups and markers.

**Evaluate**
- Allow students to take the rain gauges home, or leave them outside of a classroom window. Students should record the rain that occurs over a period of time.
- **To Ask Students:** Why should we measure our weather? How can we use this to help others? What do you think about the job of a meteorologist?
- Students should record their observations in science journals, which can be evaluated for their understanding.

**PA Core Academic Standard:** 3.3.4.A6 Identify appropriate instruments (i.e., thermometer, rain gauge, weather vane, anemometer, and barometer) to study weather and what they measure.

**Materials Needed:**
Barometer
Thermometer,
Rain gauge
Plastic cups (one per student)
Markers

Description: This lesson creates opportunities for students to inquire about one of the most important aspects of earth science: weather! Specifically, students will explore weather instruments used by meteorologists. Questions will help students understand the importance of measuring weather and students will create their own weather-tracking instrument.
Acids and Bases
Discovering chemistry through acids and bases.

Engage:
- **To Ask Students:** Have you heard the words “acid” or “base” before?
- Explain that we classify substances, as acidic or basic. Being an acid, a base, or neutral, is a characteristic that substances have. It helps us categorize things.
- Students will look at a picture of the pH scale and its relation to acids and bases.
- Show the class the “indicator,” which is made of red cabbage juice, and explain how we will be testing different substances to see if they are an acid or a base.

Explore:
- Demonstrate adding a common acid to the indicator and students will watch for what happens. Repeat with a base.
- Students will record what happens when an acid and a base is added.
- Students will be given a list of substances and will predict if they are acidic, basic, or neutral.
- Students will test and record their data.
- **To Ask Students:** What makes you think this substance is acidic/basic?

Explain:
- As a group, students will make a list of which substances are acids and bases. They will discuss commonalities between them.
- **To Ask Students:** Can you think of things that make the substances similar? Why do you think all of these substances are classified as acids/bases?
- Ask students, based on the commonalities they came up with, think of other substances to try that may be acids or bases.

**Description:** Students will be introduced to acidic and basic substances, the pH scale, and acid-base chemical reactions. By using cabbage juice as an indicator, students will test common acids and bases and design their own procedure to test other substances. Students will observe an acid-base reaction and the gas that it produces.

**PA Core Academic Standard:** 3.2.3.A4 Use basic reactions to demonstrate observable changes in properties of matter (e.g., burning, cooking).

**Materials Needed:**
- 1 Red Cabbage
- Rubbing Alcohol
- Vinegar
- Baking Soda
- Test Tubes (5 per group)
- Pipettes (5 per group)
- Water Bottle (2 per group)
- Balloon (2 per group)
- Other Acids/Bases (self-selected by students)
Elaborate:
- Ask students to remember what we have already learned about acids and bases
- **To Ask Students:** What do you think will happen when we mix an acid and a base together?
- Demonstrate a reaction between baking soda (a base) and vinegar (an acid) by mixing them together with a balloon covering them. Students will discuss what they believed happened.
- **To Ask Students:** What do you think would happen if we mixed them in a container that was not stretchy, like the balloon? Where would the gas that is produced go?
- Demonstrate this by putting baking soda and vinegar in a film canister together.
- Students will discuss how many times, when an acid and base are combined, a gas is produced.

Evaluate:
- Students will formulate their own procedure for testing their new substances for acidity.
- **To Ask Students:** How should we test these materials to see if they are an acid or a base? Should we just put them all in at once? One after another in the same container? How should we record our findings? How will we know if it is an acid or a base?
- Assess students’ knowledge of this skill by observing behaviors during the experiment.

References
Cookie Erosion
Modeling the erosion of the Earth’s surface

Engage:
• To Ask Students: How have you seen the earth change? Have you ever heard of the word “erosion” before?
• Students will discuss as a group how the earth changes and prior knowledge about erosion. Teacher should write down all ideas on the board.
• Explain that erosion is the process of bits of land being moved by different forces, and that many different things can cause erosion.

Explore:
• Students will each be given a cookie on a paper plate. Teacher will tell students that their goal is to break up the cookie, or “erode” it, as much as possible.
• Students will be given a toothpick, with which they can poke at the cookie, a straw, with which they can blow air onto the cookie, and water, to pour onto the cookie.
• To Ask Students: What do you see happening? How is the cookie changing as we try to erode it?
• Students will draw what happens to the cookie when they attempt to erode it with each method.

Explain:
• Students will gather in a group to discuss their observations and the experience. Guide the discussion towards identifying what each of these actions represented in nature.

Description: This lesson engages students with a sweet model of erosion. Students will explore cookies as a model of the earth’s surface, and different agents of erosion. By using a tangible model of erosion, students will better understand how erosion occurs in slow processes or a rapid processes.

PA Core Academic Standard: 3.3.4.A1 Recognize that the surface of the earth changes due to slow processes and rapid processes.

Materials Needed:
Cookies (2 per group)
Straws (1 per student)
Toothpicks (1 per student)
Water
Paper plates,
Science journals for recording findings

Optional Materials:
Cookies (for consumption after the activity)
• **To Ask Students:** What happened when you blew on the cookie with the straw (and all other actions)?, what do you think would happen if we continued these actions for a long period of time? Since we said our cookie represented the land that was being eroded, what do you think our actions represent?

**Elaborate:**

• **To Ask Students:** What actions erode land the fastest?

• In small groups, students will make a plan for how to create the most erosion of a cookie using any combination of methods. These should be tested and timed.

**Evaluate:**

• **To Ask Students:** If we wanted to tell someone else how to erode land the fastest, how would we? Would this be true for every type of land, like sand, rocks, or grass?

• Students will write or draw pictures of their plan for how to erode a cookie the fastest. Plans should include different agents of erosion that demonstrate their understanding.
Engage:
- Students will gather together for a discussion about their knowledge of birds. Teacher will ask students to write down one bird that they know of on a post-it note. Students will add them to an anchor chart for the class to see.
- **To Ask Students:** Are all of these birds the same? What makes them different? Why do you think all birds are not the same?
- Write student responses on the chart.

Explore:
- Students will work in partners to find the differences between pictures of birds. Pictures should be in page protectors so that students can write on them using dry-erase markers.
- **To Ask Students:** What parts of the birds are different?

Explain:
- **To Ask Students:** I noticed that a lot of you pointed out that birds’ beaks are different. Why do you think they have different beaks?
- Students will attempt to pick up different “food” using different “beaks.” Students will first try to pick up mini marshmallows using clothespins, then tweezers, then spoons, then pipettes. Allow 30 seconds per kind of beak for students to pick up as much food as possible and move it to another bowl. Students will record data.
- Repeat this process with beans in water and water itself as the food source.

Description: Students will explore how the difference in birds’ beaks gives them the ability to eat certain foods. This is an introduction to the theme of animal adaptations and how they help animals survive. Students will contrast the features of birds, make conclusions based on explorations of models, and use their knowledge of this adaptation to create their own bird beak.

PA Core Academic Standard: 3.1.4.C2 Describe plant and animal adaptations that are important to survival.

Materials Needed:
- Post-it Notes
- Anchor Chart
- Photos of Birds
- Page Protectors
- 20 Mini Marshmallows (per group of 4-5 students)
- 20 beans (per group of 4-5 students)
- A small container of water (per group of 4-5 students)
- 4-5 Tweezers (per group of 4-5 students)
- 4-5 clothespins (per group of 4-5 students)
- 4-5 spoons (per group of 4-5 students)
- 4-5 pipettes (per group of 4-5 students)
- 5 containers to hold materials in (per group of 4-5 students)
Elaborate:
- Students will bring their group’s data to put on the board. Teacher will lead a discussion about what beaks were best for picking up which food source.
- **To Ask Students:** Which beak was best for picking up marshmallows? Beans in water? Water? What does this tell you about why birds have certain beaks?
- Guide students in realizing that certain beaks are required to eat specific foods successfully. Differentiated beaks are an adaptation that helps birds eat the food that is available to them, and survive.

Evaluate:
- Students will design a beak for an imaginary bird, based on what they have learned about bird beaks. This imaginary bird needs to eat the student’s favorite food, so their beak should reflect their ability to do this. For example, if a student’s favorite food is spaghetti, then their beak might be long and thin in order to enable them to eat it. Students will write underneath their drawing, explaining their rationale.
- **To Ask Students:** What adaptation does your bird’s beak have? How will this help them eat their food? Would it be difficult for the bird to get the correct food if they had the same beak as your neighbor’s bird?

**References**

Designing for Weather: Part 1
Using engineering principles to construct a tornado shelter

Engage:
- **To Ask Students:** What do you know about tornadoes? Do you have any experiences with tornadoes or know anyone who has?
- Students will watch a video about the powerful nature of tornadoes and their impact on humans.
- Students will discuss key points in the video and compare them to their own perceptions and experiences with tornadoes.

Explore:
- Demonstrate what happens when a single paper towel tube (the “building”) is placed in front of a fan (the “tornado”) and explain the need for a structure that will not fall over in the wind.
- **To Ask Students:** How can we change this “building” so that it can withstand the “wind” of a tornado? [With every plan that students make] How will this change the structure of the “building”?
- Students will work in small groups with a selection of materials to make the structure more resistant to the wind. Students will plan their structures before building them on large pieces of paper.

Explain:
- Students will present their plans and finished products to the class. Groups will explain their rationale for how they built certain aspects of the structure.
- Then, each group will test their structure to see if it stands up to the wind powered by the fan.
- **To Ask Students:** Why did you create this part of the structure? What makes you think your structure will stand up during the wind?

**Description:** Students will learn about the power of tornadoes and how that affects groups of people all over the world. In response to this, they will think critically about creating safe housing. Students will use engineering concepts to create a small model of a tornado-resistant building of a paper towel tube.

**PA Core Academic Standard:** 3.4.4.C2 Describe the engineering design process: Define a problem. Generate ideas. Select a solution and test it. Make the item. Evaluate the item. Communicate the solution with others. Present the results.

3.3.4.A5 Describe basic weather elements.

**Materials Needed:** Paper towel tubes (one per group)
Popsicle sticks (20 per group)
Masking Tape (one roll per group)
Construction Paper (10 sheets per group)
Table Fan
Elaborate:
- Students will return to their small groups and debrief from the results of the test.
- **To Ask Students:** Why do you think our structure stood up to the wind/did not stand up to the wind? What parts of the structure do you think helped? What parts of the structure do you think could be improved? What have you seen in the other groups’ structures that you think is a good idea?
- Students will write down what they think are the most productive aspects of their structures.
- Students will present these aspects to the whole group, and the teacher will facilitate creating a plan for a structure that incorporates all of these aspects.

Extend:
- Students will do a think-pair-share activity to discuss and share extending questions about the activity.
- **To Ask Students:** How do the design ideas we came up with in our final plan apply to designing real buildings? How would this challenge have been different if we had limited materials? Do you think this happens when engineers design buildings? Why is it important for buildings to be protective against tornadoes? How can we tell if a building is protective against tornadoes?
- Formatively assess students’ learning by listening to responses as they share.

References
Designing for Weather: Part 2  
Using engineering principles to construct a tornado shelter

Engage:
- **To Ask Students:** Did you know that many people make real structures like the ones we built for their careers? What do you know about jobs like these?
- Write down students’ responses.
- Explain that people who build structures do not have unlimited materials, and that they need to decide what kinds of materials to buy. Then, they will explain that the class will be trying that today.

Explore:
- Students will make a plan in small groups about what materials to buy given $200 of Monopoly money.
- Students will buy their materials from the front of the class, optionally set up as a storefront (see pictured on the next page)
- **To Ask Students:** What was most helpful when we first made the structures?
- Students will build their structures according to their plans and with the materials that they purchased.

Explain:
- Students will present their plans and finished products to the class. Groups will explain their rationale for how they built certain aspects of the structure.
- Then, each group will test their structure to see if it stands up to the wind powered by the fan.
- **To Ask Students:** What materials did you choose to buy? What was most important to you when building this structure?

Description: After completing the first part of this activity, students will create a tornado-resistant structure using limited resources. Students will be given a specific amount of “money” to “purchase” their building materials. Students will learn about the importance of considering weather when constructing buildings.

**PA Core Academic Standard:** 3.4.4.C2 Describe the engineering design process: Define a problem. Generate ideas. Select a solution and test it. Make the item. Evaluate the item. Communicate the solution with others. Present the results.

3.3.4.A5 Describe basic weather elements.

**Materials Needed:**
- Paper towel tubes (one per group)
- Popsicle sticks
- Masking Tape
- Construction Paper
- Table Fan
- Monopoly Money ($200 per group)
Elaborate:
- Students will return to their small groups to discuss how this exercise applies to the science of building real structures.
- **To Ask Students:** What things did we prioritize when building this structure? What items did we know were most important to buy, even if they were expensive?
- Students will discuss how our activity represents the work that some engineers do.
- **To Ask Students:** How do you think engineers make decisions about what materials to use to build? What kind of materials do you think are used to construct buildings?

Evaluate:
- Students will gather as a large group again to think about the connection to weather as a whole. Students will write the answers to the following questions as an assessment.
- **To Ask Students:** Do you think all buildings need to be built to withstand a tornado? What kinds of other weather may need to be considered when constructing buildings? What kinds of weather do we have in our area that affects us? How do you think buildings are made with this weather in mind?
- Students will return to the idea of weather and engineering as they explore other types of weather.

References
Appendix A: Connections to Standards

The following table displays important information about the standards that each of these lessons are connected to. In addition to the Pennsylvania State Education Standards, connections to the Next Generation Science Standards are provided. As more and more states shift towards using the NGSS model, it is important to consider these. The different science disciplines are included as well, with at least one lesson from each category.
### Lesson Connections to Next Generation Science Standards

<table>
<thead>
<tr>
<th>Lesson</th>
<th>NGSS Disciplinary Core Ideas</th>
<th>NGSS Cross-Cutting Concepts</th>
<th>NGSS Science and Engineering Practices</th>
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</thead>
<tbody>
<tr>
<td>Designing for Weather</td>
<td>Designs can be conveyed through sketches, drawings, or physical models</td>
<td>Cause and Effect scale, proportion, and quantity structure and function</td>
<td>Asking Questions and Defining Problems</td>
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<td></td>
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<td>Developing and Using Models</td>
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<td>Constructing Explanations</td>
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<td></td>
<td>and Designing Solutions</td>
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<td></td>
<td></td>
<td></td>
<td>Obtaining, Evaluating, and Communicating Information</td>
</tr>
<tr>
<td>Designing for Weather Part 2</td>
<td>Possible solutions to a problem are limited by available materials and resources (constraints).</td>
<td>Cause and Effect scale, proportion, and quantity structure and function</td>
<td>Asking Questions and Defining Problems</td>
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<td>Developing and Using Models</td>
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<td>and Designing Solutions</td>
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<td></td>
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<td></td>
<td>Obtaining, Evaluating, and Communicating Information</td>
</tr>
<tr>
<td>Chemistry</td>
<td>When two or more different substances are mixed, a new substance with different properties may be formed.</td>
<td>Patterns systems and system models stability and change</td>
<td>Asking Questions and Defining Problems</td>
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<td></td>
<td>Planning and Carrying Out Investigation</td>
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<td></td>
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<td></td>
<td>Obtaining, Evaluating, and Communicating Information</td>
</tr>
<tr>
<td>Best Beaks</td>
<td>Organisms have both internal and external macroscopic structures that allow for growth, survival, behavior, and reproduction.</td>
<td>energy and matter structure and function</td>
<td>Developing and Using Models</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Planning and Carrying Out Investigation</td>
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<td></td>
<td>Analyzing and Interpreting Data</td>
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<tr>
<td>Weather Instruments</td>
<td>Weather is the combination of sunlight, wind, snow or rain, and temperature in a particular region and time. People record weather patterns over time.</td>
<td>structure and function stability and change</td>
<td>Asking Questions and Defining Problems</td>
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<td>and Designing Solutions</td>
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<tr>
<td>Erosion</td>
<td>Wind and water can change the shape of the land.</td>
<td>Patterns Cause and Effect systems and system models stability and change</td>
<td>Asking Questions and Defining Problems</td>
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<td></td>
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<td>Developing and Using Models</td>
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</tbody>
</table>

*Note: The table above lists the connections between the lessons and the Next Generation Science Standards, categorizing them under Disciplinary Core Ideas, Cross-Cutting Concepts, and Science and Engineering Practices.*
A Note About Grade Level Assignments:
Since many of the DCIs span grade levels, lessons can be adapted for a range of grade levels. The indicated grade level is the recommended range for the specific questions and activities given.

<table>
<thead>
<tr>
<th>PA Core Standard</th>
<th>Science Discipline</th>
<th>Grade Level</th>
<th>References</th>
</tr>
</thead>
</table>
Appendix B: Basic Inquiry Behaviors

Many research studies are conducted by observing behaviors that are characteristic of students doing inquiry. After students have had sufficient opportunity to participate in inquiry-based learning these behaviors begin to emerge. The commonalities of these studies served as a model for behaviors that we aimed to cultivate in the after-school program. The main behaviors that we consider indicative of successful inquiry are not exhaustive, but representative of the primary goals of inquiry.
Basic Inquiry Behaviors

The list below contains “Basic Inquiry Behaviors” that are referred to throughout this guide. Each of these are skills that students complete while engaging in inquiry. The goal of progressing in inquiry-based learning is to develop these behaviors in students, so that they are able to complete them independently.16

1. Used multiple/alternative approaches
2. Attempted to solve a problem
3. Hypothesized independently
4. Communicated their ideas to others
5. Made meaning of results

Students must grow in these behaviors in order to progress to more complex inquiry, in which students are designing their own questions and procedures. It is helpful to watch and note these Basic Inquiry Behaviors in students anecdotally as a formative assessment to indicate their readiness for more open inquiry. As students progressed through units in the after-school program these behaviors were present more consistently. Most of these inquiry behaviors are skills that are transferrable to other subject areas and, more broadly, other situations in life. Facilitating inquiry-based learning in science is just one way to develop these skills as a benefit to the student in the long term.
Appendix C: Field Tested Strategies

Throughout my classroom experiences and experience in the after-school program, I have developed a list of strategies that we have found to work best when teaching inquiry-based lessons. Each helps students to develop the inquiry behaviors written previously.
Make a Concept Map of Prior Knowledge

One way to set up students for a successful inquiry experience is to make connections to their own prior knowledge. A strategy to facilitate this is to create concept maps that reflect what students already know about the topic. I have found that this is a safe, engaging way to get students thinking about a topic. Depending on the grade level and other factors like personality, students may feel more inclined to draw pictures when brainstorming about the topic. Varied vocabulary and complexity of ideas will depend on the amount of prior knowledge students have and the experience they have in articulating these ideas. The picture below shows a concept map made by a third grade student about weather.

Making these concept maps often sparks questions for students. When they realize they have a gap in their knowledge base, or do not understand why something happens, they are likely to inquire about it. Teachers can assist in this by asking guiding questions about their thoughts. It is also helpful to write questions where students can see them to validate their wonderings. I find that students take more ownership and pride in their questions when they are written exactly as they verbalized them, with no editing by the teacher. Pictured below is an example of a list of questions that came up when students completed concept maps. These questions served to inform the goals of the inquiry going forward.
Discrepant Events

This strategy is a way to spark questions in students. By demonstrating an event that defies what they expect to happen, students are likely to wonder about the cause of that event. It can be challenging to motivate students to come up with strong inquiries that are related to science, especially specific, grade-appropriate topics. In my experience, this strategy helps students to formulate ideas and can lead to productive discussions.

Presenting a “Real-Life” Problem

Similar to the previous strategy, presenting real world problems to students can help them to create questions and develop inquiries from those. Informing students of a real problem related to science makes the learning meaningful. If students are invested in the reasons behind the work they are doing, it will become more meaningful to them. This was evident in the use of the “Designing for Weather” lesson in the after-school program. Students discussed how important tornado shelters were, and how important it is to have building that are resistant
One of the most important aspects of facilitating inquiry-based learning in students is asking the right questions. Questions asked by the teacher have the power to guide students into deeply understanding science concepts, and possibly even more importantly, feeling competent in their own abilities in science. When planning for an inquiry-based lesson or unit, it is important to intentionally plan questions to ask as well, and anticipate answers students might provide. To come up with questions to accompany a lesson, I have found it helpful to start with thinking about two things.

1) Who are your students and how do they respond in this setting?
2) What is the learning goal for this lesson?

By considering each of these points, questions can be developed that will help guide students. By first considering the typical needs of your students and anticipating the areas where they may need guidance, questions can be used to fill gaps in necessary understanding. By keeping in mind what you hope students will take away from the lesson, questions can be used to redirect focus to common learning.

Each section of the lessons provided has a list of intentional questions to ask students during their explorations. They are based on teaching experience with those lessons as well as anticipated student needs.
CONCLUSION

This guide was created with the hope of encouraging current and future educators to embrace their students inquiries whenever possible. Researching the focus of inquiry-based learning in elementary settings gave me the opportunity to try what I had found in the classroom. I hope that this research and compilation of personal experiences create a convincing argument for this model. Although not without challenges, I believe that inquiry-based learning is a model that is inclusive and engaging for students, and well worth consideration from educators.
References


