

# Twig Science Evidence Portfolio: A Literature Review on Foundational Research

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## Introduction

This evidence portfolio summarizes the foundational research literature that serves as the empirical basis for the Twig Science program. Twig Science is a comprehensive science curriculum for grades pre-kindergarten – eighth that is fully aligned with the Next Generation Science Standards (NGSS). The program employs a blended learning design centered on “phenomenon-based” instruction. Through this approach, students engage in inquiry- and problem-solving based activities in service of examining specific real-world science phenomena in areas such as climate change, zoology, biodiversity, astronomy, and atmospheric science, as well as a host of others. Each curricular unit orients around these anchor phenomena and investigative problems, which in turn act as the launch point in examining content that spans three dimensions of science learning — ensuring all students have an interwoven understanding of: 1) Science and Engineering Practices (SEPs), 2) Disciplinary Core Ideas (DCIs), and 3) Crosscutting Concepts (CCCs). As highlighted by the program’s developers, this specific approach to science instruction is thought to have a host of benefits:

“Phenomena are important to science education because they give students *tangible, interesting examples of science in the real world*. They are also good opportunities for encouraging student inquiry: students can observe a phenomenon and subsequently ask questions and do research to find out more about how it works...Throughout Twig Science, explicit connections are made between phenomena in the context of 3-D science standards. Twig Science materials consistently elicit and leverage students’ prior knowledge and experience related to the phenomena and problems present. In fact, *phenomena and problems drive learning and use of the three dimensions of science learning at all levels*.” (Twig Science, 2022)

Within this overarching pedagogical framework, Twig Science seeks to leverage a variety of instructional strategies aimed at enhancing student learning and engagement in science. Most notably, across the program’s lesson plans, student activities, and digital interface and tools, Twig aims to:

- Facilitate student-centered learning through creative and coherent storylines, effective routines, and authentic learning experiences
- Facilitate science discourse through research-based language routines that support equitable access to science for all students
- Integrate multiple forms of three-dimensional assessment to monitor, evaluate, and act on data about student progress and achievement
- Provide differentiated supports to ensure learning is accessible and inclusive
- Integrate the three dimensions of science instruction to support student sensemaking, problem-solving, and knowledge building from grade band to grade band

- Provide teacher supports for effective planning, implementation, and professional learning

In the context of these overarching features, this evidence portfolio seeks to summarize the research that forms the foundation of the Twig Science theory of action and documents the research support for the primary components embedded within this program. This research was conducted by Johns Hopkins University's Center for Research and Reform in Education after consulting with Twig Science senior leadership and reviewing the program's instructional materials.

## Program Logic Model and Theory of Action

As an overarching theory of action, Twig Science seeks to improve learning outcomes for elementary and middle school science students by serving as a comprehensive curricular resource for adopting schools. The program features a research-based set of unit plans, lesson plans, and student activities that are designed to address three-dimensional science standards as well as the full content covered in the NGSS. Emphasizing an inquiry-based and phenomenon-based instructional approach aimed at helping students develop scientific reasoning and real-world problem-solving skills, the program aims to provide for a highly engaging and authentic learning experience for students. Other program components, including robust supports and professional development for teachers and program features that enable users to differentiate instruction, provide targeted scaffolding and student support, and assess student learning through three-dimensional assessment, serve to support schools in delivering more individualized and equitable science instruction to students.

Ultimately, Twig Science intends for each of these program components to work cohesively and, in combination, serve as a comprehensive point of science instruction for adopting schools. As a byproduct of schools implementing the program and leveraging these features with fidelity, Twig's developers aim for the program to serve as an efficient and effective way of enhancing learning outcomes in science for elementary and middle school students. Figure 1, below, presents a logic model for how Twig Science theoretically facilitates these intended impacts:

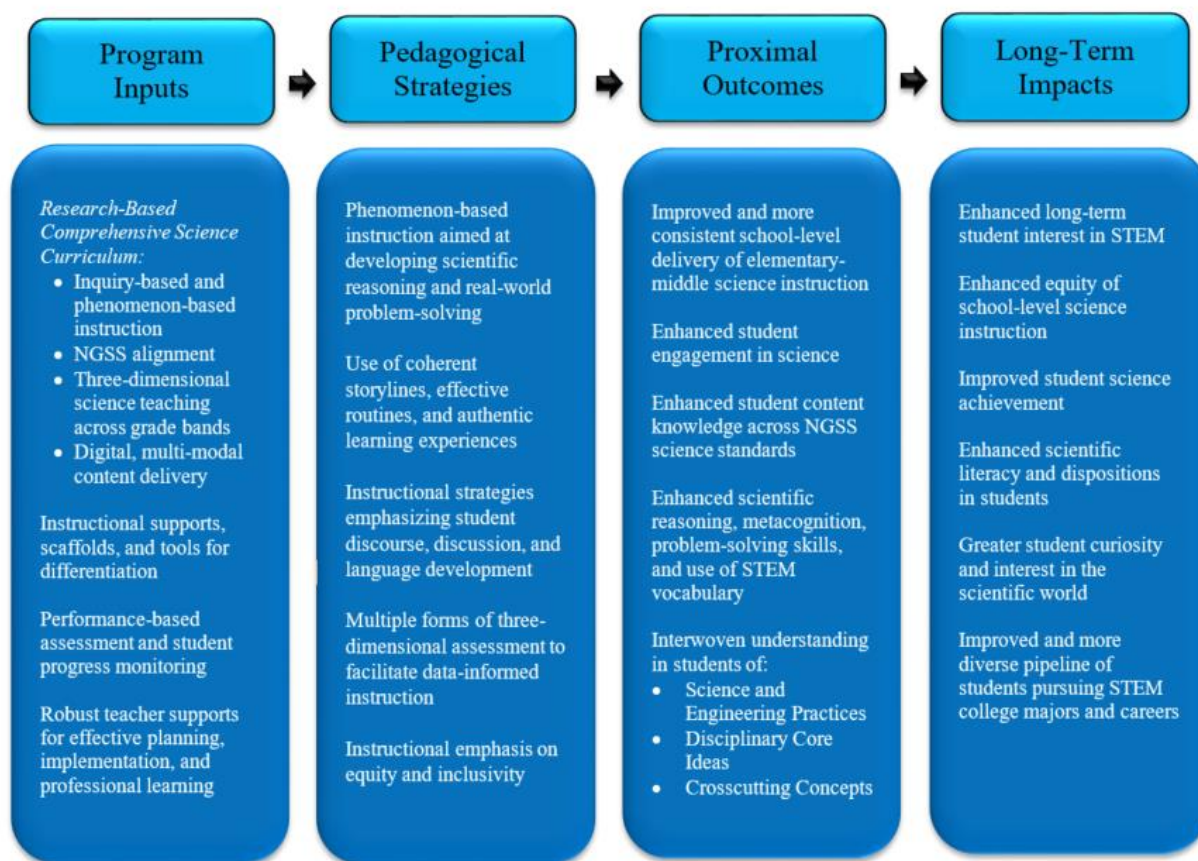


Figure 1. Twig Science Logic Model

In reviewing the intended outcomes and instructional objectives within Twig Science’s programming and situating these facets within the broader research literature on K-12 science instruction, the JHU CRRE research team created the logic model above. This model serves as an illustration of the relationships between Twig Science’s program components and these intended outcomes and can be thought of as a form of conceptual roadmap outlining how the program may function to enhance student learning in science. The program’s primary inputs and activities, including its NGSS-aligned curriculum, instructional resources, assessment regimen, and teacher professional development options, work in tandem with the unique pedagogical strategies and techniques the program incorporates. These include the program’s use of phenomenon-based teaching and science discourse, use of multimedia, storytelling, and authentic learning experiences, and use of three-dimensional assessment components and instructional features aimed at promoting equity. When implemented with fidelity, these program inputs and pedagogical strategies serve to facilitate proximal outcomes for students. These short-term outcomes are those that schools can, in theory, experience relatively quickly as they utilize the Twig Science curriculum. These potential outcomes include:

- Improved and more consistent school-level delivery of science instruction across the elementary and middle school grade spans

- Enhanced student engagement in science
- Enhanced student content knowledge across NGSS
- Enhanced scientific reasoning, metacognition, problem-solving skills, and use of STEM vocabulary among students
- Improved student skills and knowledge related to three-dimensional science learning, including improved understanding of science and engineering practices, disciplinary core ideas, and crosscutting concepts

In turn, as schools use the program over a sustained period of time, the accumulated benefits derived from these proximal outcomes may then lead to longer-term impacts. Among others, these may include:

- Enhanced long-term student interest in STEM among program users
- Enhanced equity of science instruction across adopting schools
- Improved student science achievement as measured by standardized assessments
- Enhanced scientific literacy and dispositions in students
- Greater student curiosity and interest in the scientific world
- The development of an expanded and more diverse pipeline of students pursuing STEM college majors and, potentially, STEM careers

As Twig Science continues its development and engages in summative forms of evaluation exploring its efficacy, this model can serve as a guide for examining proximal, intermediate, and long-term outcomes. In the following sections, we examine the underlying research connecting these program inputs with these intended impacts.

## Literature Review: Foundational Research Underlying Twig Science

Building on this theory of action, the following section summarizes the foundational research that serves as the empirical basis for the Twig Science program. Broadly, this section seeks to provide an overview of the research germane to the primary instructional components of Twig Science: phenomenon-based teaching, authentic student-centered learning and differentiated instruction, science discourse, and three dimensional science instruction and assessment. Conclusions and recommendations for future research directions are provided at the close of these sections.

### *Instruction through Real-World Phenomena and Problems*

As a key area of emphasis, Twig Science seeks to promote student learning with instruction centered on engaging students with real-world phenomena and problems. This approach is thought by many in the field to be particularly valuable as a means of potentially enhancing student interest STEM, as well as the likelihood that they consider pursuing STEM-oriented careers as adults, and is currently promoted as such by a variety of professional science organizations, including the National Research Council as well as the National Oceanic and Atmospheric Administration (NGSS, 2022; NOAA, 2022). In phenomenon-based instruction, students are presented with an engaging scientific phenomenon, often through a demonstration, video, or simulation, and then engage in instructional activities in the form of inquiry- and problem-solving tasks that anchor around what they observe (NOAA, 2022). Typically, the phenomena that are presented are visually interesting and not easily understood at first glance. The goal being that the natural curiosity and engagement that these tasks elicit will help fuel students' motivation as they wrestle with complex ideas, ask questions, and draw upon multiple areas of science to investigate the phenomena at hand (NOAA, 2022).

A bevy of research on K-12 science instruction, as well as constructivist forms of pedagogy more broadly, have demonstrated support for instructional approaches of this type (Brandwein, 1995; Cotabish, Dailey, Robinson, & Hughes, 2013; Isabelle, 2017; Johnson, Mohr-Schroeder, & English, 2020; Nesmith & Cooper, 2020;). Particularly as it relates to science instruction in the early elementary grades, research points to the value of instruction that generates curiosity around scientific phenomena and stimulates idea-enactive, inquiry-oriented behavior (Brandwein, 1995; Johnson Mohr-Schroeder, & English, 2020). As Nesmith and Cooper (2020) summarize:

“Critical thinking, problem solving, and working collaboratively can be effectively nurtured through STEM learning. STEM learning experiences support the development of independent, critical thinkers who are capable of making good decisions while working collaboratively with others and provide opportunities for students to grow into responsible citizens... Proponents argue that STEM learning experiences provide students with these 21st-century skills, all necessary to become the next generation of innovative STEM professionals”

Within the phenomena-based approach to teaching science, a variety of key strategies have been identified through research that appear particularly useful. Utilizing scaffolding tools that

help students organize their thinking around *claims*, *supportive evidence*, and *reasoning* (Davis et al., 2019) appear useful in helping students develop skills with constructing explanations (Berland & Reiser, 2009; Davis et al., 2019; National Research Council (NRC), 2012; NGSS Lead States, 2013). Other approaches, such as the “Engage-Experience-Explain+Argue” framework (Davis et al., 2019) and the “5E” model (Bybee et al., 2006; Davis et al., 2019) have been shown to be useful in decomposing phenomenon-based instruction into structured steps. Across phenomenon-based teaching frameworks such as these and others, students work to identify questions and elicit ideas about the phenomenon they are studying, formulate ways of collecting data to carry out an investigation, analyze their findings and look for patterns, and then construct evidence-based claims and extend their learning to new situations (Cianca, 2020; Davis et al., 2019). A variety of recommendations from the National Research Council (NRC) (2012) support these approaches as well. In fact, these strategies have been cited as being a particularly important part of K-12 science instruction for the specific reason that they are reflective of the actual ways that scientists and other STEM professionals engage in their work (Cianca, 2020; NRC, 2012). As it relates to this area, the NRC (2012) outlines eight overarching science and engineering practices that should be taught in K-12 schools as a means of fostering students’ real-world STEM skills and exposing them to the thinking processes they may need to engage in if they pursue STEM-based careers.

“Students’ opportunities to immerse themselves in (certain) practices and to explore why they are central to science and engineering are critical to appreciating the skill of the expert and the nature of his or her enterprise. We consider eight practices to be essential elements of the K-12 science and engineering curriculum: 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” (NRC, 2012).

As it pertains to phenomenon-based instruction, several of these key practices can be employed with advantageous effect. Asking questions and defining problems is viewed as central to the work of scientists and lends itself well to children generating and testing theories on the phenomena they observe. Planning and carrying out systematic investigations and experiments and utilizing data generated through these activities to answer questions and formulate theories are practices that should be embedded within phenomena-based instruction as well (NRC, 2012).

Research has also pointed to other strategies that can be effectively integrated into this form of pedagogy. Perhaps most notably, problem- and project-based approaches to instruction (Guzey, Caskurlu, & Kozan, 2020; Johnson, Mohr-Schroeder, & English, 2020), as well as approaches that involve elements of Design-thinking (Chin et al., 2019) have been shown to be particularly advantageous in this area. As Guzey, Caskurlu, and Kozan (2020) note: “Both problem- and project-based learning approaches focus on providing hands-on experiences and can be considered as variations of teaching science as inquiry.” In problem-based learning, students engage in a form of cognitive apprenticeship where they utilize problem-solving experiences as a means of promoting the simultaneous development of content knowledge and problem-solving skills (Guzey, Caskurlu, & Kozan; 2020; Kolodner, 2003). Project-based learning in science involves

student-designed inquiry that is organized by investigations to answer driving questions, and often includes collaboration among learners, the use of new technology, and the creation of authentic artifacts that display student understanding” (Guzey, Caskurlu, & Kozan, 2020; Marx et al., 1994). Inquiry-based approaches such as these have been shown to provide a valuable outlet for STEM teachers to deliver student-centered science instruction (Marshall & Smart, 2013) where students can uncover assumptions and leverage critical thinking skills to construct a better understanding of the concepts at hand (Barron & Darling-Hammond, 2008; NRC, 1996). Across both of these areas, research has consistently demonstrated that these forms of instruction can be a valuable means of exposing students to authentic, rich, real-world problems and allowing them to learn and apply science concepts in authentic situations (Chin et al., 2019; Gijbels, Dochy, Van den Bossche, & Segers, 2005; Guzey, Caskurlu, & Kozan, 2020; Huerta-Wong & Schoech, 2010). Of perhaps particular importance, a growing body of research has demonstrated the ways that phenomenon-based approaches to learning, including those which adopt problem- and project-based techniques, can be enhanced by the inclusion of Design Thinking concepts (Chin et al., 2019; English, Adams, & King, 2020). As a pedagogical approach, Design Thinking, provides students a means to learn theoretical concepts while engaging in rich problem-solving grounded in authentic, integrated, learning (English, Adams, & King, 2020; Gómez Puente, van Eijck, & Jochems, 2011; Grubbs & Strimel, 2015; Mehalik, Doppelt, & Schunn, 2008). Perhaps not surprisingly, Design Thinking has been demonstrated to be a powerful tool that teachers can employ for integrating STEM-based pedagogical approaches (Bartholomew & Strimel, 2018; English, 2018) and has been shown to have a lasting impact on students’ learning and problem-solving skills, even into adulthood (Chin et al., 2019). Taken in combination, these techniques, coupled with the robust research supporting them, point to the advantageous effects phenomenon-based instruction can have for science students.

### **Twig Science in Action: Providing Opportunities for Phenomenon-based Learning**

As discussed throughout this section, Twig Science is designed to incorporate phenomenon-based learning as a means of promoting inquiry, scientific reasoning, and real-world problem-solving skills. The instructional design of each module centers around an anchor phenomenon (observable event) or problem that students make sense of and/or solve by the end of the module. For example, in Grade 1, Module 3 Shadow Town, students take on the role of STEM detectives to explain why the town of Rjukan, Norway, remains in darkness half of the year, even during daytime, and in Grade 7, the Volcano Hunters Module, students join a team of volcanologists to figure out why some mountainous areas have volcanoes and others do not by analyzing real-life data from active volcanoes, assessing threat levels, and devising a plan to protect people from the dangers of eruptions.

In elementary, when students first engage with the Anchor Phenomenon at the start of each module, they work as a class to generate and record the questions they want to investigate to make sense of the Anchor Phenomenon. These questions are used to drive their sensemaking as students return to the questions at regular touchpoints in the module and use their learning to construct their own explanations of the phenomenon. Anchor Phenomenon touchpoints are found throughout each module. Students follow the same sequence of steps in every module: Engage with the Anchor Phenomenon and Generate Questions About the Anchor Phenomenon, Investigate the Anchor

Phenomenon, Evaluate the Anchor Phenomenon, Explain the Anchor Phenomenon, and Resolve the Anchor Phenomenon.

In middle school, at the start of each module, students engage with the Anchor Phenomenon or Engineering Design Challenge and generate Wonder Questions. Lessons focus on using student questions to drive instruction and support sensemaking as they complete investigations to generate, refine, organize, prioritize, and answer their questions. At multiple points during a lesson, students document the evidence they gathered and explain what they figured out to help craft their final explanation of the Anchor Phenomenon or their final solution to the Engineering Design Challenge at the end of the module.

### *Student-Centered Learning and Authentic Learning Experiences*

Within the broader context of this phenomenon-based teaching model, Twig Science incorporates a variety of instructional components aimed at facilitating student-centered learning through creative and coherent storylines, instructional routines, and authentic learning experiences. A variety of research has explored the ways that instructional strategies related to authentic learning, including those situated around these key features, can enhance student engagement and learning. Authentic learning typically refers to learning experiences and practices that are based on real-world problems and simulations tied closely with the field of study, and in the field of science education, emphasizes scientific inquiry and discovery (Nicaise et al., 2000). In practice, authentic learning often includes complex hands-on experiential activities that provide students with various levels of control and real-world application. It also includes student discourse and social learning in which science teachers engage students in addressing “real-world problems encountered by scientists, allowing (them) to investigate problems in their own lives and communities” (Rule, 2006). Not surprisingly, authentic learning methods overlap a great deal with numerous research-based instructional models, including problem-based learning, project-based learning, and open-inquiry (Quigley, 2013; Herrington & Oliver, 2007). In examining the impact of authentic learning programs in science education, researchers have highlighted the impact such programs may have on students’ views of the relevance of science to their lives, improve learning overall, and develop students’ awareness of and ability to use scientific evidence to draw conclusions and make scientific arguments (Murphy et al., 2006). As importantly, researchers have highlighted several critical characteristics that can be employed by teachers to optimize the ways this approach can impact learning (Herrington & Oliver, 2007; NRC, 2012). These include:

- Using authentic contexts that reflect the ways knowledge is used in real life
- Using instructional activities that have a high degree of real-world relevance
- Emphasizing complex learning tasks that are completed over a sustained period of time
- Providing students with concrete models of processes
- Providing students access to professional experts in the area they are studying
- Introducing students to multiple and varied perspectives on a topic
- Helping students collaboratively construct knowledge to solve problems
- Having students complete reflection activities
- Providing opportunities for students to articulate and/or publicly present an argument
- Providing outlets for students to use informal language and familiar modes of interaction while developing science vocabulary

- Providing coaching and scaffolding
- Using authentic forms of assessment

In the context of these methods, one related method that has been shown to be particularly promising as it relates to offering authentic learning experiences to students is the use of storytelling (Davidhizar & Lonser, 2003; Gahkar & Thompson, 2007; Karakoyun & Yapici, 2016; Miley, 2009; Roney, 1996). A long-standing and robust field of research has demonstrated support for the use of storytelling as an effective method for teaching across a host of subject areas and disciplines (Davidhizar & Lonser, 2003; Dirksen, 2012; Gahkar & Thompson, 2007; Karakoyun & Yapici, 2016; Miley, 2009; Roney, 1996). Moreover, digital forms of curricula are increasingly incorporating storytelling elements as a central feature (Davidhizar & Lonser, 2003; Gahkar & Thompson, 2007). Researchers have also highlighted the particular benefits of culturally-based storytelling in engaging students in argumentation and science inquiry, as well as promoting educational equity (NRC, 2012). Instructionally speaking, effective use of storytelling helps learners connect new concepts with pre-existing knowledge, provides for a logical flow of information that aids in knowledge retrieval, and can build greater engagement in learners relative to more explicit forms of instruction (Dirksen, 2012).

“Stories usually involve sequenced events, and frequently follow a chronological flow. You are more likely to remember the sequence of crawl > walk > run than you are to remember the sequence of walk > run > crawl, because there is a logical flow. Part of the promise of stories is that they will also have a logical flow, and when you are recalling them, you can use that logic to recall what the events are” (Dirksen, 2012)

### **Twig Science in Action: Authentic Learning Experiences**

As outlined above, the Twig Science program aims at facilitating student-centered learning through creative and coherent storylines, effective instructional routines, and authentic learning experiences. Each module within the curriculum aims to weave a captivating narrative mirroring what scientists and engineers experience in the real world that guides students through a progressive sequence of discovery-based learning and problem-solving. This learning progression is explicitly designed with the intention of empowering students to expand their understanding of scientific concepts, layer complexity onto their existing knowledge, and refine their schematic understanding of phenomena based on the evidence they uncover through the program’s inquiry-based learning features.

Each module is instructionally centered on a different science-based storyline, which is intentionally scaffolded to inspire student curiosity and drive active learning. This process begins in the elementary grades with the Anchor Phenomenon instructional routine, a thoroughly-choreographed routine that aims to nurture independent thinking and collaborative learning. During this routine, students are immersed in a structured series of steps. When they Engage with the Anchor Phenomenon, students are encouraged to activate prior knowledge to use as a starting point to ask questions and develop their noticings and wonderings as a means of exploring and defining the phenomena at hand. Investigating the Anchor Phenomenon becomes an interactive process, drawing students into smaller investigations that foster deeper understanding. These

Investigative Phenomena are driven by the science and engineering practices, mirroring what scientists and engineers do in the real world. The routine continues with the Evaluate and Explain steps, which encourage independent and collaborative synthesis of knowledge. Here, students are tasked with demonstrating their newfound insights through multiple mediums with the aim of displaying a three-dimensional picture of their learning. During the module's final instructional activity, Resolve the Anchor Phenomenon, students are tasked with forming connections between the tangible and intangible concepts taught, as well as the specific and conceptual. Students Resolve the Anchor Phenomenon through activities, such as collaborative class discussions, developing presentations and/or models, and independent activities in which they reflect on how they explored and explained the Anchor Phenomenon.

At the middle school level, instruction is guided by the Think Talk—Co-Craft Questions and Phenomena Tracker and Engineering Design Tracker routines. The process begins with the Think Talk—Co-Craft Questions language routine, which allows students to experience and express curiosity when they encounter a novel phenomenon or problem without feeling the pressure to produce correct answers. It creates space for students to generate scientific questions in their own language. The routine is used in the first lesson to capture students' Wonder Questions about the Anchor Phenomenon, and at the start of each subsequent lesson to generate further questions based on related smaller Investigative Phenomena. Students follow the Phenomena Tracker or Engineering Design Tracker routine to record and refine their Wonder Questions, explanations or solutions, and highlight the interplay between the phenomena or problems they investigate and their understanding. During the routine, students typically work with a partner to explain the phenomena or provide a solution to the problem they have been exploring and record how they have used specific science and engineering practices and crosscutting concepts. They also make claims in response to their Wonder Questions and consider if they have new Wonder Questions. Through generating questions that connect their previous knowledge with what they observe, this routine aims to position students to actively shape their learning trajectory. Students revisit their trackers every few classes until they record their final explanation of the Module Anchor Phenomenon or solution to the Module Engineering Design Challenge.

### *Science Discourse and Discussion as an Instructional Approach*

Within the program's phenomenon-based teaching framework, Twig Science places a significant emphasis on providing teachers with opportunities to facilitate science discourse through research-based language routines that aim to support equitable access to science for all students. As it relates to this area, a bevy of research supports the effectiveness of collaborative and cooperative learning strategies (Gillies, 2016; Slavin, 2009). Strategies that involve students discussing and sharing ideas, working together toward a common goal, or strategically socializing in ways that enhance learning are well-supported in the research literature on how people learn (Dirksen, 2012; Means et al., 2010; O'Connor, 1998; Okita, Bailenson, & Schwartz, 2008; Robertson & Riggs, 2018; Saloman & Perkins, 1998; Slavin, Hurley, & Chamberlain, 2003).

As it specifically relates to the subject of science -- discourse, argumentation, and discussion have been identified repeatedly in research as central features of quality instruction (Davis et al., 2019; Driver et al., 2000; Johnson Mohr-Schroeder, Moore, & English, 2020; Naylor & Keogh, 2001; Rebello, Asunda, & Wang, 2020). Prominently featured as part of the Next

Generation Science Standards (NGSS Lead States, 2013), developing student skills with regard to evidence-based reasoning, communication, and argumentation are widely viewed as among the top priorities of K-12 science learning (Davis et al., 2019; NRC, 2012). As Rebello, Asunda, and Wang (2020) highlight: “Argumentation plays a crucial role in scientific inquiry and can facilitate an arguing-to-learn process in which students construct scientific understandings through justifying, evaluating, and confronting varying scientific views.” Indeed, research has shown that facilitating opportunities for discourse and argumentation among students can enhance science learning, deepen conceptual understanding, and enhance students’ subject-specific critical thinking skills (Johnson, Mohr-Schroeder, Moore, & English, 2020; Rebello, Asunda, & Wang, 2020; Walker & Sampson, 2013). Other research points to the ways that investigation-based discussion can help foster sense-making and can provide opportunities for more inclusive and equitable science teaching (Davis et al., 2019).

Research has demonstrated support for the use of whole class discussion, in which the teacher serves as a moderator (Gunter, Estes, & Schwab, 2003; Slavin, 2009), and even more so, small-group discussion, where students engage in structured discussions with small groups of peers (Johnson & Johnson, 1999; Sharen et al., 1984; Slavin, 2009). Research has found that discussing complex concepts and issues can increase students’ knowledge of the topics at hand and can deepen their understanding of the nuances within these topics (Johnson & Johnson, 1999; Slavin, 2009). This is particularly the case in instances where students are encouraged to engage in controversy and debate, as opposed to simple consensus building (Johnson & Johnson, 1999; Slavin, 2009).

### **Twig Science in Action: Student Discourse and Collaborative Learning**

In light of these findings, Twig Science centers a variety of programming on fostering scientific discourse, and aims to employ a series of research-based language routines with the goal of supporting equitable access to science for all students. In specific, Twig Science has collaborated with SCALE Science at WestEd, to develop a series of innovative language routines that aim to champion equitable access to science education. These methodologies are centered on the following five research-based concepts:

- Teachers, peers, and texts serve as language resources for learning (Vygotsky, 1978).
- Deep learning of disciplinary content and skills is gained through language, as it is the primary medium of school instruction (Halliday, 1993).
- Through successive and supportive experiences with disciplinary ideas, learners make sense of disciplinary content with their existing language toolkit (Moschkovich, 2012).
- Language is an inseparable part of all human action, so when students are engaged in meaningful activities (projects, presentations, investigations), language develops through perception, interaction, planning, research, and discussion (Van Lier & Walqui, 2012).
- Language routines help focus attention on student language that support in-the-moment teacher, peer, and self assessment (Cazden, 2001).

These language routines aim to serve as a bridge to empower students in their learning journey and involve a combination of authentic learning activities and sequenced-activities involving discussion and research. Through these iterative experiences, students gradually assimilate complex ideas into their existing linguistic repertoire, aiding the assimilation of disciplinary content.

At the elementary level, the Stronger and Clearer Each Time language routine aims to foster dynamic growth by inviting students to repeatedly engage in paired conversations. The routine is designed to provide a structured opportunity for students to revise and refine both their ideas and verbal and written output. The main steps of the routine include students working individually to look at a problem or prompt, giving students time to think about what they will say to their first partner to explain what they are doing (or did) to solve it, and then implementing a successive pairing structure. In pairs, students listen to and understand each other's ideas or explain their ideas as a scientist would, strengthening and clarifying their ideas each time they talk to a new partner. Finally, students write or draw their final explanations to see the impact that talking about a problem or an idea can have on their ability to explain it. These “Final Explanations” are a key formative assessment activity within the program. Moreover, the Collect and Display language routine aims to capture students' everyday language, offering a scaffold for scientific language development while instilling confidence by bridging familiar vocabulary with academic terms. The main steps of the routine include recording words that are familiar to students where every student can see them, such as a word wall. The words that are collected can be organized, revisited, and explicitly connected to formal scientific terms. This gives all students the opportunity to refer to, build on, or make connections with them during future discussions or writing. Throughout a module, the collection of words can be referenced as a model, and updated and revised as students' language changes.

At the middle school level, in addition to the Think Talk—Co-Craft Questions language routine described previously, the Think Talk—Productive Discussion language routine facilitates rich and inclusive discussions (Zwiers & Hamerla, 2017) that develop students' reasoning skills and deepen their understanding of phenomena (Michaels & O'Connor, 2012), Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts. It provides feedback for students in a way that increases sense-making while simultaneously supporting meta-awareness of language. It also honors the language students are using and developing. The main steps of the Productive Discussion language routine include identifying learning goals, selecting a good prompt to start the discussion, and facilitating the discussion using talk moves. Talk moves include supporting students to expand and clarify their thinking, helping students articulate their reasons and evidence and explain the relationship between the two, and encouraging students to listen and respond to the ideas of their peers. This routine is coupled with the Collect and Display language routine, where students visually showcase key vocabulary while engaging in meta-cognition and reflection of language nuances.

### *Three-Dimensional Science Instruction*

The Twig Science phenomenon-based teaching approach is informed greatly by the Next Generation Science Standards (NGSS) and A Framework for K-12 Science Education (National

Research Council, 2012) – and aims to position the NGSS three-Dimensional standards of 1) Science and Engineering Practices (SEPs), 2) Disciplinary Core Ideas (DCIs), and 3) Crosscutting Concepts (CCCs), at the core of pedagogical and curricular planning. Ultimately, the program aims to encourage an interwoven understanding of these three dimensions and an appreciation of science in the real world by emphasizing student sensemaking, problem-solving, and knowledge building across and between grade bands.

As an overarching pedagogy, this integrated approach to science instruction is well-situated within what research shows about best practices for K-12 science teaching (Consortium for Policy Research in Education, 2009; NRC, 1999; 2007; 2012). As outlined by the NRC(2012):

“In order for students to experience and engage in the opportunities needed for understanding the three dimensions of scientific and engineering practices, crosscutting concepts, and disciplinary core ideas described in the framework, many other players and components of the system will need to change, often in dramatic ways.... Curriculum developers will need to design K-12 science curricula based on research and on learning progressions across grade levels that incorporate the framework’s three dimensions.”

Grounded in over 20 years of research on science education, each of the 3-D concepts from NGSS is designed to operate at a nexus with one another (NRC, 2012), with their own practices that are deemed essential to supporting science learning. The science and engineering practices dimension emphasizes asking questions and defining problems, developing and using models, and analyzing and interpreting data, and emphasizes the importance of engaging in the *practices* of science as a means of developing content knowledge as well as metacognitive skills. The cross-cutting concepts dimension includes seven discipline-bridging concepts (patterns, cause and effect, scale and proportion, systems and system models, energy and matter, structure and function, and stability and change). Finally, the disciplinary core ideas dimension is rooted in the concept that learning is a developmental progression, with the goal of guiding student knowledge and understanding within and across science and engineering disciplines. The dimension also is based on the concept that science and engineering learning requires integration of knowledge and practices.

Taken together, these interwoven areas of emphasis serve as the pedagogical foundation of the NGSS, and are aimed at reflecting the interconnected nature of science as it is practiced in the real world (NGSS, 2013). Thus, these standards are explicitly defined by NGSS as “Performance Standards” *not* as prescribed curriculum in and of themselves – allowing for a high-degree of creativity on behalf of science teachers delivering content through the framework. The thinking behind this approach is that by interweaving SEPs, DCIs, and CCCs, students will be exposed to more thorough, nuanced forms of science instruction that allow for the development of practical expertise where they can apply core principles and theoretical constructs to make sense of new information (NGSS, 2013; NRC, 1999). As summarized by NGSS (2013):

“To develop a thorough understanding of scientific explanations of the world, students need sustained opportunities to work with and develop the underlying ideas and to appreciate those ideas’ interconnections over a period of years rather

than weeks or months. This sense of development has been conceptualized in the idea of learning progressions. If mastery of a core idea in a science discipline is the ultimate educational destination, then well-designed learning progressions provide a map of the routes that can be taken to reach that destination. Such progressions describe both how students' understanding of the idea matures over time and the instructional supports and experiences that are needed for them to make progress.” (Consortium for Policy Research in Education, 2009; NGSS, 2013; NRC, 2007; 2009; Smith, Wiser, Anderson, & Krajcik, 2006)

As it relates to science education, there is a bevy of research supporting the integration of scientific *ideas* and *concepts* with the *practice of science* itself. Strategies that involve the development of student sensemaking and problem-solving with knowledge building are well-supported by the research literature on effective science teaching (NRC, 2012). As discussed in other sections of this evidence portfolio, project-based learning (PBL) may be seen as one of the best possible means of integrating these different dimensions, and there is a great deal of research centering on the efficacy of the PBL model for science specifically (Krajcik et al., 2021). Other researchers have pointed to the use of practical scientific models (Park et al., 2019) to help students visualize the complex concepts aligned with the NGSS dimensions. Doing so requires that teachers take time to provide opportunities for students to understand what models are, how models can be developed, and how symbols and other model features can inform reasoning. Other studies have focused specifically on the impact sense-making practices – with many results suggesting the potential benefits of these approaches if teachers receive appropriate training and coaching with how to facilitate sensemaking conversations with their students (Carotenuto et al., 2020; Davis et al., 2017; Haverly et al., 2018). Taken in combination, approaches such as these can be woven as part of an integrated approach to science pedagogy emphasizing the three core dimensions. In the following section, the specific approaches and features employed by Twig Science as it pertains to these areas are discussed in greater depth.

### **Twig Science in Action: Integrating the Three Dimensions**

As outlined above, the Twig Science program engages students at both elementary and middle school grade bands in integrating the three dimensions of Science and Engineering Practices (SEPs), Disciplinary Core Ideas (DCIs), and Crosscutting Concepts through sensemaking, problem solving, and knowledge building.

As an overarching pedagogy, the program aims to integrate the NGSS three dimensions of science education throughout its curriculum, catering to students across grade bands. The program's focus on student-facing three-dimensional learning objectives, lessons, activities, and assessments is explicitly designed to comprehensively approach learning. Through using the program, students are encouraged to utilize the three dimensions - DCIs, SEPs, and CCCs - in a synergistic manner to make sense of complex phenomena and solve intricate problems. This integrated approach seeks to provide students with a deeper understanding of scientific concepts while nurturing their problem-solving skills.

For elementary students, the Twig Science Science Tools Poster serves as a visible and structured tool to scaffold their use of SEPs. These posters, initiated by teachers during the first

module of each grade, remain an ongoing reference point throughout the year. By the end of a grade, the Science Tools Poster serves to showcase the incorporation of all eight SEPs, tracking the students' progress and growth. In the middle school grades, the program introduces the Phenomena Tracker or Engineering Design Tracker to guide students in their engagement with SEPs and CCCs. This tool encourages students to document their evolving comprehension of phenomena and problems, while highlighting their application of specific SEPs and CCCs – the goal being to enhance their ability to articulate and reflect upon their learning across the targeted dimensions.

Ultimately, the integral goal of the program is for students to master NGSS Performance Expectations (PEs) within a specific grade or grade band. These three-dimensional goals delineate the knowledge and skills students should possess by the end of a given period. By progressively building on Performance Expectations across grades and grade bands, the program aims to position students to transition and progress smoothly between the elementary, middle, and high school grade spans as their science content knowledge and skill sets expand. The Twig Science Performance Expectations Progressions documents provide a clear and detailed overview of the performance expectations students are advancing from and those they are striving toward in each module and grade level. Through the comprehensive integration of the three dimensions, Twig Science ultimately aims to provide a cohesive framework for goal-oriented learning that facilitates student's development as problem solvers and proficient scientists.

### *Three-Dimensional Assessment and Progress Monitoring for K-12 Science*

As another key component of the Twig Science theory of action, the program aims to integrate multiple forms of three-dimensional assessment to monitor, evaluate, and act on data concerning student progress and achievement. As described in detail above, three-dimensional assessments stem from the NGSS three-dimensional standards of 1) Science and Engineering Practices (SEPs), 2) Disciplinary Core Ideas (DCIs), and 3) Crosscutting Concepts (CCCs) (NRC, 2012). Three-dimensional assessments typically align an assessment task and rubric design with course performance statements (McElhaney et al., 2019), and can include formative assessments, summative assessments, and program evaluation measures. Designing assessments consistent with the three-dimensional format requires that assessments target the full range of skills and knowledge included in the NGSS guidance. This includes assessing students' science comprehension as a content domain *and* as a process. Moreover, it includes positioning assessments so that they provide evidence of a student's ability to apply knowledge as appropriate to real world scenarios and build on existing knowledge and skills so as to lead to deeper understanding of science concepts (NRC, 2012).

Until recently, the K-12 STEM field has predominantly relied on utilizing traditional assessments that target isolated knowledge of facts and procedures, as opposed to a more authentic assessment option that integrates assessments into the curriculum and prioritizes practical competencies and understanding (NRC, 2012). In general, these traditional assessments have been only able to provide a narrow range of data on student learning, and are not capable of providing as much information for teachers, school leaders, or policymakers as to how students may actually perform as scientists (NRC, 2012). Recently, however, researchers have pointed to a shift in philosophy towards assessments, moving more toward an emphasis on three-dimensional,

performance-based assessments that help examine students' evidentiary thinking skills (NRC, 2012; McColskey & O'Sullivan, 2000; Jotson & Mohr-Schroeder, 2020). The Next Generation Science Standards encapsulate this sentiment (Mark et al., 2020), prioritizing reflexivity and practical learning. Science learning is multifaceted and practical, intended to cultivate creative thinkers and able communicators. As such, assessments must be multifaceted and must serve to assess the skills and competencies STEM educators hope to instill in students. Here, several test frameworks are useful references. The PISA science test framework distinguishes between competencies, identifying scientific issues, explaining phenomena scientifically, and using scientific evidence (NRC, 2012). The TIMSS Science Assessment Framework features three cognitive levels for assessment questions: knowing, applying, and reasoning (al-Balushi et al., 2022). This differentiates between recalling facts, concepts and procedures, comparing and contrasting groups of objects and relating conceptual knowledge, and the use of evidence and scientific understanding to analyze, synthesize, and generalize. Taken in combination, approaches such as these provide insights into the ways that three-dimensional science assessments can better position educators to understand student's ongoing knowledge and skill development in STEM.

### **Twig Science in Action: Three-Dimensional Assessment**

With these trends in mind, Twig Science integrates multiple forms of assessments at the elementary level, including pre-exploration assessments of prior knowledge, progress tracking tools, formative assessments, summative performance tasks and rubrics, multiple-choice assessments, and benchmark assessments. These assessments and tools are designed to evaluate progress and provide data for teachers to adapt and revise their classroom activities with the goal of addressing individual student needs.

Pre-Explorations set teacher understanding of student knowledge and misconceptions related to the module's Performance Expectations. Progress Trackers are provided in each module to help teachers track student misconceptions and progress toward mastering the assessed standards. Formative assessments support this effort, quickly allowing teachers to gauge student understanding and adapting instruction as necessary. These take the form of class discussions, written and drawn responses, self- and peer assessments, and teacher observation.

In each module, summative performance tasks, based on clear teacher rubrics, motivate students in demonstrating their knowledge and skills. Another form of summative assessments available for all elementary grades at the end of modules are multiple-choice assessments. These are aimed at assessing students' scientific concept knowledge in relation to specific key elements of the performance expectations.

Finally, benchmark assessments, developed in collaboration with SCALE for elementary grades 3-6, are also available to summatively assess students in each module. These assessments provide teachers with further evidence of student learning connected to the NGSS, integrate the three dimensions of the performance expectations, and offer open-ended problems to challenge students to apply learning. Taken in combination, these integrated assessment tools provide Twig Science teachers with a deep and varied set of options for monitoring student progress and addressing diverse learning needs.

Similar assessment features are available to teachers at the middle school level. Pre-assessments, informal assessments provided at the end of day-to-day lessons, formative and summative assessments, and benchmark assessments, are all available for program teachers to leverage. Pre-assessments at the beginning of each module consist of multiple choice items and short response items aimed at helping teachers identify strengths and gaps in students' understanding of concepts related to the module's performance expectations. Rubrics and sample student responses are provided for scoring and to inform instruction. Informal assessments are also available for teachers to utilize at the end of most day-to-day lessons to aid with gauging student learning incrementally.

Lastly, the program's formative and summative assessments provide different means of measuring student learning. Embedded formative performance tasks with accompanying student and teacher rubrics include an unscored collaborative component and a scored individual task. Embedded summative performance tasks with accompanying student and teacher rubrics at the end of a collection of day-to-day lessons, include a scored individual task. Summative multiple choice and short performance task benchmark assessments, developed in collaboration with SCALE, are delivered at the close of each curricular module. These assessments are used to provide teachers with an understanding of the totality of student learning that has occurred during a block of study. As part of Twig Science's suite of assessment options in these areas, students are asked to complete multiple-choice items, engage in written tasks, and deliver presentations.

### *Differentiated Supports – Focus on Equity and Inclusivity*

Twig Science aims to provide differentiated supports to ensure that learning is accessible and inclusive. As outlined by the program's developers, more so than a single set of program components, these scaffolds aim to act as part of the program's overarching instructional philosophy – and, as such, are embedded throughout each of the core program strategies discussed throughout this evidence portfolio.

A bevy of research supports this overarching approach. In fact, one facet that differentiates blended learning, such as that presented through Twig Science, from traditional forms of instruction is the flexibility that digital modes have with regard to providing supports, scaffolds, and differentiated forms of media to students. A key advantage here is that digital forms of curricula are not bound by some of the inherent limitations of print-based materials, as digitized versions can offer options for interactive presentations, videos, audio, and other multi-modal means of teaching (Clark, 2002; Sankey, Birch, & Gardiner, 2010). Much research points to the value of teachers leveraging features such as these. Research on pedagogical approaches such as differentiated instruction (Tomlinson et al., 2003) and Universal Design for Learning (Rappolt-Schlichtmann, Daley, & Rose, 2012; Rose, Meyer, & Hitchcock, 2005) have demonstrated the utility of using strategic, multi-modal types of teaching. The positive impact of differentiated instruction on student learning is well-established in education science (Chamberlin & Power, 2010; Firmender, Reis, & Sweeny, 2013; Johnsen, 2003; Tomlinson et al., 2003; Tulbure, 2011). Students benefit, in terms of both engagement and achievement, from receiving content that is tailored to their skills, interests, and needs. Moreover, a growing body of literature has found support for Universal Design for Learning, an instructional approach whereby teachers differentiate modes of instructional presentation, provide multiple entry points for students to

engage with content, and provide flexible options in terms of how students demonstrate their learning (Rappolt-Schlichtmann, Daley, & Rose, 2012; Rose, Meyer, & Hitchcock, 2005). The use of non-linguistic representations of information, whether they be through images, graphic organizers, or videos, have long been found to be an effective means of helping students to form a deeper understanding of concepts as well (Beesley & Apthorp, 2010; Dean, Hubbell, Pitler, & Stone, 2012; Marzano, 2007; Medina, 2008). Importantly, the affordances of instructional technology facilitated through programs like Twig Science appear to make flexible, multi-modal forms of teaching such as these easier and more robust (Dean, Hubbell, Pitler, & Stone, 2012; Sankey, Birch, & Gardiner, 2010) thus saving teachers valuable time that can instead be spent on other instructional behaviors (Hunter, Jordanna, Sonneman, & Joiner, 2022). In addition to enabling content to better adapt to students' individual needs, digitized instructional features can help teachers distribute differentiated content quickly and discreetly to students. This may include differentiated instructional activities, as well as opportunities for small group instruction and individualized tutoring.

For a variety of reasons, both ethical and instructional, inclusive practices such as these are justifiably viewed as an essential feature of quality science programs across the full K-12 grade span. One of the most consistent findings from research in this area is that instructional strategies aimed at improving equity and inclusivity wind up not only being advantageous for marginalized groups of students but also are regularly shown to benefit *all* learners. Inquiry-based and phenomenon-based approaches to instruction, for instance, have been shown to be particularly impactful in enhancing engagement and learning outcomes for special education students (Basham, Marino, Hunt, & Han, 2020; Johnson, Mohr-Schroeder, Moore, & English, 2020), and have also been shown to be consistently impactful for general populations of students as well (Brandwein, 1995; Cotabish, Dailey, Robinson, & Hughes, 2013; Isabelle, 2017; Johnson, Mohr-Schroeder, & English, 2020; Nesmith & Cooper, 2020; NGSS, 2022; NOAA, 2022). Culturally and linguistically responsive teaching (CLR teaching), though frequently thought of as an instructional framework more often used in schools serving ethnically and linguistically diverse student populations, has been consistently shown to be an effective and highly useful approach to instruction for students regardless of the demographic composition of their school (Bancroft & Nyirenda, 2020; Hollie, 2018; Loucks-Horsley et al., 2010; Sleeter, 2011). Indeed, constructivist approaches within this umbrella, such as place-based learning (Lee & Buxton, 2010; Sobel, 2005), culturally relevant pedagogy (Ladson-Billings, 1995), and culturally responsive pedagogy (McKinley & Gan, 2014; Sleeter, 2011) that allow for teachers to connect students' community contexts, culture, and native language into science teaching, can enhance engagement and learning for any student by providing for a more personalized, and authentically rooted instructional experience (Bancroft & Nyirenda, 2020; Hollie, 2018). Training programs that seek to challenge teachers to examine their instructional practices for bias (Loucks-Horsley et al., 2010; Sleeter, 2011), as well as programs that provide students with examples of scientists and other accomplished STEM professionals representing a range of genders, ethnicities, nationalities, and backgrounds, have also been shown to be beneficial at enhancing inclusivity (Estrada et al., 2016; Hurtado, Newman, Tran, & Chang, 2010; Phalen, Harding, & Harper-Leatherman, 2017; Skolnik, 2015; Stearns, Bottia, Davalos, Mickelson, Moller, & Valentino, 2016).

As it relates to inclusivity, in much the same way that CLR-type instruction can benefit *all* learners, so too can many instructional strategies aimed at enhancing equity for students learning

English (ELLs) (Basham, Marino, Hunt, & Han, 2020; Johnson, Mohr-Schroeder, Moore, & English, 2020). For instance, strategies aimed at emphasizing language-rich science instruction that provides students with ample explicit teaching of science vocabulary, as well as opportunities for discussion and application, have been found to be effective with ELLs (Buxton & Alleksaht-Snider, 2016) and non-ELLs alike (Buxton & Alleksaht-Snider, 2016; Buxton, Cardozo Gaibisso, Xia, & Li, 2017). Many other strategies have been identified that appear particularly beneficial for ELL science students while clearly having application with non-ELL populations as well. Scholars on this topic, Buxton and Alleksaht-Snider (2016), highlight many of these, including:

- Creating opportunities for students to meaningfully interact using science language and ensuring that all students' participation is valued
- Supporting students in understanding and reflecting on each other's ideas
- Using visual representations to contextualize science vocabulary and language
- Using "successive approximations" towards more complex conceptual knowledge and linguistic abilities
- Using high-interest and linguistically accessible topical reading material
- Providing writing opportunities that have an authentic purpose and audience
- Utilizing paired reading/discussion/writing activities and structuring these activities so that students engage in conversations where they construct, share, and debate ideas
- Encouraging students to use all the language and linguistic resources they have access to in order to make meaning
- Using the student's first language to support and develop skills in the second language and vice versa (i.e., maintenance of the first language is beneficial for driving content learning in the second language)
- Valuing everyday conversational language for explaining science ideas rather than immediately utilizing jargon and academic language

While considering these strategies for building more inclusive and equitable instruction for English language learners, a variety of strategies aimed at addressing the needs of exceptional learners, including those receiving special education services, are also important for science teachers to incorporate within their practice. Consistent with so much of the research discussed in this section, the vast majority of these strategies have been shown to not only be beneficial for students with special needs but have also been consistently shown to improve learning outcomes for other students as well. Providing scaffolds and instructional supports to students, for example, as they encounter new science content and engage in inquiry-based learning has been shown to improve learning outcomes for both special education and general education students alike (Basham, Marino, Hunt, & Han, 2020; Marino, 2009; Mastropieri & Scruggs, 2007). Graphic

organizers, process charts, glossaries, visual aids, and many other scaffolds can be provided to beneficial effect to help support student learning. Much research has pointed to the benefits these tools can yield for students in the upper elementary and middle school age ranges (Marino, 2009; Mastropieri & Scruggs, 2007). Other scaffolds, such as coached elaborations (i.e., the teacher asking a series of leading questions during class discussions) and use of mnemonics, have also been identified as particularly beneficial scaffolds in this area (Basham, Marino, Hunt, & Han, 2020; Mastropieri & Scruggs, 2007).

As it relates to digital curriculum, as well as programs that utilize forms of blended learning, research has highlighted the benefit of certain design features aimed at enhancing the impact of scaffolds and program components. Captioning second-language videos, presenting key points one at a time (as opposed to multiple points at once), removing distracting details from visual presentations, and communicating new vocabulary terms both visually and aurally, can all be beneficial design functions embedded within digital programs (Noetal et al., 2022). As can the use of signaling principles (i.e., directing learners to know where to focus their attention in the digital interface) and segmenting virtual lessons and videos into small, meaningful chunks (Noetal et al., 2022). As it relates to the teaching of abstract concepts, such as those often found when addressing more advanced content in STEM, application of these design features appears to be especially important (Noetal et al., 2022; Reilly & Storey, 2022).

Ultimately, when embedded as part of an instructional framework aimed at designing instruction that proactively addresses the needs of all learners, the strategies listed throughout this section can serve to significantly benefit general and special education populations alike (CAST, 2018; Meyer & Rose, 2000). Indeed, by anticipating the needs of students individually and emphasizing the use of strategies aimed at providing authentic, engaging forms of learning while applying common-sense scaffolds and instructional supports, equity and inclusivity can be enhanced in K-12 science.

### **Twig Science in Action: Promoting Equity and Inclusive Science Teaching**

In order to promote equity in science instruction and ensure that learning is accessible, inclusive, and contributes to the development of confident learners, Twig Science incorporates a number of key differentiated supports across each grade level. Broadly, the overarching design of Twig Science is rooted explicitly in the principles of Universal Design for Learning (UDL). In the program's effort to provide an equal opportunity for every student to explore and succeed in science, the program incorporates a variety of innovative teaching methods to accommodate different learning needs, and aims to create an immersive and enriching learning experience that goes beyond that of traditional approaches.

The UDL principles at the core of Twig Science aim to provide equitable access to learning opportunities. The program emphasizes multiple pathways for presenting scientific concepts. It uses videos, interactive labs, simulations, authentic texts, and even songs for younger students, to provide diverse visual and auditory experiences. Additionally, all Twig Science videos include closed captions and a printable transcript. Text-to-speech, or read-aloud technology, is available for all student- and teacher-facing digital texts as well. Print materials are available in the NIMAC (National Instructional Materials Access Center) repository and can be ordered by users in braille

and large print. Customized accessibility options are also available to ensure a tailored learning experience for various user profiles.

Throughout both elementary and middle school, students are provided a variety of opportunities to demonstrate their learning in different ways – including through completing sketches, constructing models, and through written responses. Moreover, the Twig Science digital platform offers various question types and response options, including drawing tools, multiple-choice prompts, and open-response/narrative response prompts. Through structured supports, including guided response scaffolds, graphic organizers, and the Claims, Evidence, and Reasoning (CER) framework, the program aims to progressively nurture students’ understanding.

In addition, a range of resources are employed to support students' language development and vocabulary acquisition. Instructional videos are designed to help students understand academic vocabulary with visual aids and grade-appropriate definitions. Text features like glossaries, word walls, and vocabulary lists are provided to enhance the understanding of scientific articles and texts, with the ultimate goal of promoting language proficiency while maintaining a strong connection to the core content at hand.

Teacher supports, such as Access for All sidebars, provide guidance for adapting instruction and the modality of assessments that is in line with UDL principles. Other teacher supports include a wide range of suggested instructional scaffolds and modifications to address the needs of English Language Learners, students with varying academic skills, as well as students with specific physical or situational needs to ensure all students have access to equitable learning opportunities.

Twig Science also worked closely with experts in culturally and linguistically responsive teaching to develop a suite of materials to support teachers who choose to adopt a culturally and linguistically responsive approach to science instruction. The suite of materials includes in-depth background, rationale, guidance, and suggestions at point-of-use for activities to validate and affirm students’ cultural behaviors, as well as a framework for evaluating the cultural authenticity of classroom materials.

### *Teacher Supports and Professional Learning*

Building on the Twig Science Theory of Action and Logic Model (see Figure 1), it is important for teachers to have the support they need to engage in effective planning, implementation, and professional learning. Supporting teachers in these practices is vital to improving teacher delivery of science instruction, and ultimately, for enhancing student engagement and learning in this often-overlooked subject matter.

As it pertains to providing teacher support for delivering core curricula, research points to the central importance of robust teacher training and professional development (Bayar, 2014; Darling-Hammond et al., 2017; DeMonte, 2013; Guskey, 1994; Penuel et al., 2007). Substantive professional development that is conducted regularly and sustained over time, as opposed to single session onboardings and workshops, has been shown to play a key role in enhancing the abilities and confidence of teachers (Darling-Hammond et al., 2005; 2017; Garrison, 2019; Guha et al.,

2016). Perhaps more importantly, *content-specific* professional development (Darling-Hammond et al., 2017; DeMonte, 2013; Desimone et al., 2002; Guskey, 2003; Hixon & Buckenmeyer, 2009; Klein & Riordan, 2011; Penuel et al., 2007), as well as that which explicitly targets developing teachers' skills and aptitude with the delivery of the specific programs their schools are using, is of utmost importance (Bayar, 2014; DeMonte, 2013; Guskey, 1994; 2003; Hixon & Buckenmeyer, 2009; Penuel et al., 2007). Closely job-embedded PD that maintains a high-level of instructional coherence and is aligned to specific programs has been shown to be of particular importance (Penuel et al., 2007).

As it relates specifically to the professional development of *science* teachers, supports and trainings that are targeted to the unique instructional aspects of this content area, particularly that aimed at the elementary-level where science often takes up a substantially smaller portion of teachers available planning and instructional time, appears to be of special importance as well (Boakye & Ampiah, 2017; NRC, 2012; Van Driel et al., 2012). Indeed, science teaching often comes with specific challenges, including those related to instructional time management, and the need for instruction that addresses many abstract concepts and higher order thinking skills in students (Boakye & Ampiah, 2017; Van Driel et al., 2012). Given that many science curricula employed in schools across the United States still rely heavily on teaching surface-level content as opposed to a deeper understanding of *the practice* of science (Osborne & Dillon, 2008), many teachers may lack the practical experience of delivering more advanced instruction in this area. Science teaching in the K-12 space has been highlighted by researchers as being a particularly complex instructional endeavor that requires teachers to integrate an extremely broad array of content (Davis et al., 2006) – often much more so than other core subject areas. Understandably, given the breadth of content encompassed through the NGSS, including that related to biology, Earth science, physics, and chemistry, among others, significant planning time and expertise are required of teachers if they are to deliver science instruction effectively. Thus, supports and professional development aimed *explicitly at the needs of science educators* can play an important role in helping address these unique challenges, and ultimately, improve the quality of the instruction they deliver.

With regard to helping teachers develop the skills needed for effectively addressing three-dimensional science learning, the NRC (2012) highlights the importance of professional development that is “not only rich in scientific and engineering practices, crosscutting concepts, and disciplinary core ideas, but (that is) also closely linked to teachers' classroom practices and needs” (NRC, 2012; Howes, Lim, & Campos, 2009; Smith & Neale, 1991). Trainings that help teachers develop a conceptual understanding of three-dimensional science content (Kokkotas, Vlachos, & Koulaidis, 1998; Krall, Lott, & Wymer, 2009; NRC, 2012) as well as the key techniques needed to facilitate this form of integrated pedagogy, are also key (NRC, 2012; Taylor & Dana, 2003; Wee, Shepardson, Fast, & Habor, 2007).

In the context of these approaches, research has found that the specific instructional strategies used by trainers can have a substantial impact on teachers' learning. Use of active learning strategies (Bayar, 2014; Darling-Hammond et al., 2017; DeMonte, 2013; Desimone et al., 2002; Hixon & Buckenmeyer, 2009), incorporating instruction that addresses adult learning theories (Darling-Hammond et al., 2017), using collaborative and cooperative learning techniques (Darling-Hammond et al., 2017; DeMonte, 2013; Guskey, 2003; 2009), and providing clear

modeling and illustrative examples (Darling-Hammond et al., 2017; DeMonte, 2013) have all been shown to noticeably enhance the impact that PD has on teacher learning and behavior. Research shows that ideally, trainings should strive to recognize and leverage teachers' prior knowledge and experiences, provide teachers with choices based on specific interests and needs, include ongoing opportunities for reflection and inquiry (Darling-Hammond et al., 2017) and provide opportunities for cooperative learning and teacher-to-teacher collaboration (Darling-Hammond et al., 2017; DeMonte, 2013; Ertmer, 2005; Guskey, 2003; 2009; Hixon & Buckenmeyer, 2009). Providing clear modeling and examples of the instructional techniques that are being taught, whether it be in the form of videos of accomplished teaching, demonstration lessons, sample lesson plans, unit plans, or exemplar student work can also be highly valuable (Darling-Hammond et al., 2017; DeMonte, 2013; Penuel et al., 2011). Coaching, particularly that which provides a structured opportunity for teachers to receive feedback and engage in reflection, also appears particularly beneficial with regard to teacher support (Carver-Thomas, 2018; Carver-Thomas & Darling-Hammond, 2017b; Garrison, 2019; Kraft et al., 2018). Lastly, providing teachers with materials and procedures that help address the unique challenges they may be facing, whether they be materials aimed at communicating with parents (Boakye & Ampiah, 2017), those aimed at helping develop literacy skills in the context of science teaching (Boakye & Ampiah, 2017; Goldschmidt & Jung, 2011; McDonald, 2018; Pearson et al., 2010; Rutt & Mumba, 2020), or those aimed at providing scaffolds (U.S. Department of Education, n.d.) or lesson planning support (Meyers et al., 2016; U.S. Department of Education, n.d.), can also be of key value as well.

Ultimately, research suggests that strategies such as these form the foundation of much of what is empirically known about supporting science teachers through professional development. In the following section, we discuss the key strategies embedded as part of the Twig Science program in this area.

### **Twig Science in Action: Supporting Teachers**

As it pertains to supporting teachers to engage in effective planning, implementation, and professional learning – Twig Science offers comprehensive teacher supports across both the elementary and middle school levels. At the elementary level, access to various resources is provided to assist teachers in instructional planning and delivery. These resources include a Framework Alignment document, which offers guidance on curriculum alignment with established educational frameworks. Insights into the progression of topics are provided by the Scope and Sequence, while resources providing guidance on effective classroom management and language instruction strategies are offered by the Guide to Scientific Discourse, Language, and Classroom Routines.

In each elementary module, Teacher Introduction videos can be utilized by program users to gain an overview of the content at hand. Model Lesson videos, which aim to showcase exemplary teaching practices while using the program are also provided. A Teacher Background Knowledge document is provided for each of the module's "driving questions" to provide teachers with an overall content review. Comprehensive overviews, preparation details, and day-to-day teacher instructions are made available in both print and digital formats. Progress Trackers are made available to help monitor student progress, and presentation slides are provided as an additional digital resource.

Similar supports are provided at the middle school level. These include Framework Alignment and Scope and Sequence documents as well as a Guide to Scientific Discourse, Language Routines, and Vocabulary, and a Teaching and Research Aids document. Other lesson planning documents include the Guides for Making Sense of Phenomena and the Teaching the Engineering Design Process resource. The program's hands-on guide for practical implementation is also made available to teachers. Similar to the elementary level, Teacher Background Knowledge documents are available on a per-lesson basis, as are the comprehensive overviews, preparation information, presentation slides, and day-to-day teacher instructions (made available in both print and digital formats).

A variety of professional learning is also provided to accompany the program's adoption and implementation. "Getting Started" sessions are provided to teachers and are designed to familiarize teachers with the instructional shifts required to teach the NGSS – and highlight the key features of phenomena/problem-based learning and three-dimensional science instruction. Ongoing professional learning, including teacher coaching, is provided that focuses on grade-level specific program implementation and work within the context of a user's specific school or school district. Customizable informal Q&A sessions are available through Twig Science Office Hours and Administrator Reports and Observation resources are provided to help school leaders understand what to observe during classroom visits.

Additional, specialized professional learning sessions, such Twig Science & English Language Arts, are also made available where teachers can explore the informational text integrated into the program and utilize it cross-circularly with English Language Arts (ELA) classrooms. The Twig Science & English Language Development professional learning provides differentiated resources aimed at supporting English learners. Finally, the Twig Science & Supporting Students with Disabilities in the Problem-Based Classroom professional learning aims to provide an overview of best practices for accommodating students with disabilities through dashboard tools and accessibility adjustments.

## Conclusion

In light of these findings, Twig Science appears to be a potentially highly efficacious science curriculum with distinct potential to enhance the development of students' skill acquisition and overall knowledge base in this subject area across the full elementary and middle school grade spans. The program's comprehensive instructional offerings and alignment with the Next Generation Science Standards, along with its inquiry-centered pedagogical approach, appear to position the program to help students develop an interwoven understanding of science and engineering practices, as well as disciplinary and interdisciplinary core ideas in STEM. As importantly, the instructional materials and resources made available to Twig Science users, as well as the overarching design and structure of the Twig pedagogical framework, incorporate a variety of prominent instructional features that appear well-supported in contemporary research on best teaching practices for elementary and middle school science.

As discussed throughout this evidence portfolio, the research literature related to the program's core components – phenomenon-based learning, science discourse, differentiated instruction, and three-dimensional science instruction and assessment -- is quite supportive and is suggestive of the potential benefits this overarching approach may yield. Importantly, program components across each of these areas appear embedded with key instructional strategies aligned with research-based best practices. Rooted in an overarching pedagogical framework that emphasizes a combination of inquiry-facing phenomenon-based instruction and student discussion, Twig Science lessons appear well-designed to bolster student engagement in authentic STEM learning (NGSS, 2022; NOAA, 2022; Murphy et al., 2006) and appear well-positioned to develop students' critical thinking skills, scientific literacy, and overall knowledge base in science (Brandwein, 1995; Cotabish, Dailey, Robinson, & Hughes, 2013; Isabelle, 2017; Johnson, Mohr-Schroeder, & English, 2020; Nesmith & Cooper, 2020). As students participate in these forms of instruction over time, research indeed suggests that long-term engagement in STEM can be enhanced, and students may begin to internalize the curiosity-laden dispositions of burgeoning scientists (Brandwein, 1995; Johnson, Mohr-Schroeder, & English, 2020; Nesmith & Cooper, 2020; NGSS, 2022; NOAA, 2002). Instructional strategies embedded within this overarching framework, most notably, features aimed at developing students' metacognitive skills (Alexander, Graha, & Harris, 1998; Hattie et al., 1996; Marzano, Pickering, & Pollack, 2001; Slavin, 2009; Wang, Haertel, & Walberg, 1993) and features aimed at providing opportunities for student discussion (Davis et al., 2019; Driver et al., 2000; Johnson, Mohr-Schroeder, Moore, & English, 2020; Naylor & Keogh, 2001; Rebello, Asunda, & Wang, 2020), appear well-positioned to enhance learning outcomes as well. The incorporation of resources aimed at providing differentiated instruction, whether it be through multi-modal features, coherent storytelling, or differentiated supports, also appear to be well-grounded in instructional best-practices research, particularly as it relates to enhancing student engagement (Budhai & Skipwith, 2017; Connelly et al., 2012; Hamari et al., 2016; Rappolt-Schlichtmann, Daley, & Rose, 2012; Rose, Meyer, & Hitchcock, 2005; Tomlinson et al., 2003). As importantly, program features aimed at promoting inclusion and enhancing the equity of STEM learning (Johnson, Mohr-Schroeder, Moore, & English, 2020; Nesmith & Cooper, 2020; NRC, 2012), as well as those aimed at providing opportunities for three-dimensional assessment and feedback, serve to potentially provide for a data-informed and personalized learning experience for students. These features have also been highlighted in the contemporary literature as serving a central role in enhancing the quality and

authenticity of student learning experiences (Bellon, Bellon, & Blank, 1997; Lee, 2014; Mark et al., 2020; McColskey & O’Sullivan, 2000; Saphier, Haley-Speca, & Gower, 2008).

In the context of this research base, Twig Science appears well-positioned to positively influence school-based science instruction and potentially enhance STEM learning outcomes for students. As the program continues its ongoing development and expansion, evaluation research that examines schools’, teachers’ and students’ experiences with the program, as well as its impact on explicitly fostering improved science learning, is warranted. Indeed, given the breadth of foundational research supporting the program’s overarching approach and instructional methods, Twig Science represents a potentially highly efficacious core science program, as well as a distinctly promising target for future research.

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