

3D Into 5E for Space Sciences Lessons Using NASA Education Resources for Elementary and Middle School Classrooms

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Abstract

Implementation of the Next Generation Science Standards (NGSS; NGSS Lead States, 2013) 3D learning that is well aligned with the performance expectations has been challenging for many science teachers. Furthermore, studies on curriculum materials for NGSS have rarely provided templates or guidelines that are straightforward for teachers to use in their science classes. This project aimed to provide professional development opportunities to middle school teachers (Grades 5–8) through a workshop designed to facilitate the integration of NASA's educational resources into science lessons aligned with the NGSS 3D learning framework. The workshop included a conceptual model (i.e., 3D Into 5E), lesson templates, and sample lessons. Specifically, the project activities were designed to improve the participating teachers' space-science content knowledge and instructional strategies, thereby enabling them to capture their students' interest and channel it toward related STEM careers. Although the BSCS 5E Instructional Model (Bybee et al., 2006) is not a new concept, this project has demonstrated its efficacy as a template for effectively integrating the three dimensions of NGSS with related phenomena in science teaching. This project has not only demonstrated the effectiveness of the 5E model as a tool for promoting a deeper understanding of scientific concepts but also innovatively incorporated hands-on space-science activities to enhance its impact. By engaging teachers in these activities, the project improved their ability to modify instructional materials using the 3D Into 5E template, ultimately leading to a more engaging and impactful learning experience for their students. The study's results showed that participating teachers experienced significant improvements in their space-science content knowledge and teaching confidence, indicating the effectiveness of this innovative approach. The teachers also reported high levels of student engagement and enjoyment during space-science activities, indicating the potential of this approach to enhance student-centered learning and improve the quality of science instruction delivered to students. Overall, this project's innovative approach has the potential to transform science education by providing teachers with practical tools and strategies to engage students in science and promote a deeper understanding of space-science concepts.

Introduction

K–12 students today have access to an incredible number of educational resources, including NASA’s offerings, that can be especially valuable in learning about space sciences and developing an interest in STEM careers (Buxner et al., 2017; Knezek & Christensen, 2020; Sheerin, 2019). However, many teachers encounter difficulty in aligning these resources with the performance expectations of the *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013) for their space-science lessons, resulting in a lack of confidence and comfort in their teaching methodologies. This is due to several challenges, including a lack of familiarity with the standards, limited availability of high-quality educational resources, and difficulties in integrating hands-on activities. To address this issue, this project provided middle school teachers (Grades 5–8) with a conceptual model (i.e., 3D Into 5E), lesson templates, and sample lessons that illustrate how to incorporate NASA’s educational resources into science lessons that are well aligned with NGSS 3D learning. With the 3D Into 5E model, the teachers effectively integrated NGSS’s (NGSS Lead States, 2013) three dimensions into the five phases of the BSCS 5E Instructional Model (Bybee et al., 2006). Although the 5E model is not a new concept, this study demonstrated its effectiveness as a tool for incorporating NASA educational resources into the NGSS 3D learning model, ultimately leading to a more engaging and impactful learning experience for their students. The study’s results showed that participating teachers demonstrated a significant improvement in their space-science content knowledge and teaching confidence. The teachers also reported high levels of student engagement and enjoyment during space-science activities, indicating the potential of the 3D Into 5E model to improve the quality of science instruction delivered to students. This project’s approach has the potential to improve science education by providing teachers with practical tools and strategies to engage students in science and facilitate a better understanding of concepts related to space sciences.

Brief Overview of NASA Education Resources

NASA operates ten major facilities across the United States, including the Armstrong Flight Research Center, the Glenn Research Center, the Goddard Space Flight Center, the Jet Propulsion Laboratory, and the Johnson Space Center. Each NASA center offers engaging and informative materials, including lesson plans, games, and activities to help students explore STEM concepts. Together, they form a diverse and interconnected network of resources that support NASA’s scientific and technological endeavors. Recently, NASA has compiled a comprehensive list of all its resources and STEM-related activities for educators and students on the A–Z List of NASA Websites for Educators (https://www.nasa.gov/audience/foreducators/Alpha_index.html). The NASA STEM Engagement homepage is a recommended starting point for K–12 teachers seeking classroom resources. This website provides resources for students categorized by grade level, including STEM activities, games, lesson materials, and engineering projects in

categories such as “Build It!,” “Play It!,” “Explore It!,” “Read It!,” and “Watch It!” The website also offers teaching materials for STEM topics, information on opportunities for educators, and resources for elementary, middle, and high school educators.

Conceptual Framework: 3D Into 5E

NGSS Three-Dimensional Learning and Inquiry-Based Learning

The *Framework for K–12 Science Education* (National Research Council [NRC], 2012) and the NGSS (NGSS Lead States, 2013) emphasize Disciplinary Core Ideas (DCIs), Crosscutting Concepts (CCs), and Science and Engineering Practices (SEPs) as three interconnected dimensions of scientific learning, which we refer to here as the 3D framework. The *Framework for K–12 Science Education* (NRC, 2012) describes how the three dimensions work together to support student making sense of phenomena through experiences in which students “actively engage in scientific and engineering practices and apply crosscutting concepts to deepen their understanding of the core ideas in these fields” (pp. 8–9). This approach is known as three-dimensional or 3D learning (NRC, 2012; NGSS Lead States, 2013). In this project, we particularly focused on the use of CCs when teachers practiced integrating NASA’s materials into the 5E model. The reason for this is that NASA’s resources, such as satellite imagery, space probes, and astronaut experiences, provide rich examples of these crosscutting concepts in action. For example, the use of satellite images can illustrate patterns in weather systems or the movement of tectonic plates, and the study of astronaut experiences can demonstrate the effects of space travel on the human body and the role of systems and system models in space exploration. Studies also showed that CCs can better engage students in generating scientific questions, building a model and explanation, and making sense of a phenomenon by prompting students to use key elements they may otherwise ignore (Anderson et al., 2019; Bybee, 2013; Fick, 2018). Furthermore, CCs can provide teachers with consistent language to guide students in making sense of phenomena. For example, consistent labeling of *patterns* and *cause-and-effect* not only aids students in developing their initial ideas for investigation but also helps them continuously extend those ideas to new phenomena by connecting them to coherent mechanisms, thereby effectively improving their understanding of the phenomena (Anderson et al., 2019; Fick, 2018). Teachers can prompt students to make sense of phenomena by asking about the *system* being investigated, *patterns* as evidence for the *causes* of a phenomenon, or *energy* added to a *system* (Anderson et al., 2019; Fick, 2018; Science SCASS States, 2018).

The BSCS 5E Instructional Model, developed by Bybee et al. (2006), has been widely recognized as an effective approach to inquiry-based instruction in science education. The 5E model provides a versatile framework that can engage students in exploring a wide range of scientific concepts and phenomena through empirical investigation, enabling them to explain and understand the underlying principles and relationships (Banchi & Bell, 2008; Burnham, 2019; Sotáková et al., 2020). The 5E model (Bybee et al., 2006) consists of five

instructional phases that follow a logical sequence: *Engage*, *Explore*, *Explain*, *Elaborate*, and *Evaluate*. Bybee (2013) argued that the 5E model can serve as an understandable and manageable application of an integrated instructional sequence even for the three dimensions of the NGSS. The 5E model provides a coherent and structured approach that can help teachers design instructional sequences that engage students in SEPs to make sense of phenomena for targeted DCIs (Bybee, 2013, 2014). Overall, the 5E model is a powerful tool for teachers to guide students through the process of exploring phenomena, constructing explanations, and applying their knowledge to new contexts while aligning with NGSS's three dimensions of scientific learning.

Conceptual Framework: 3D Into 5E

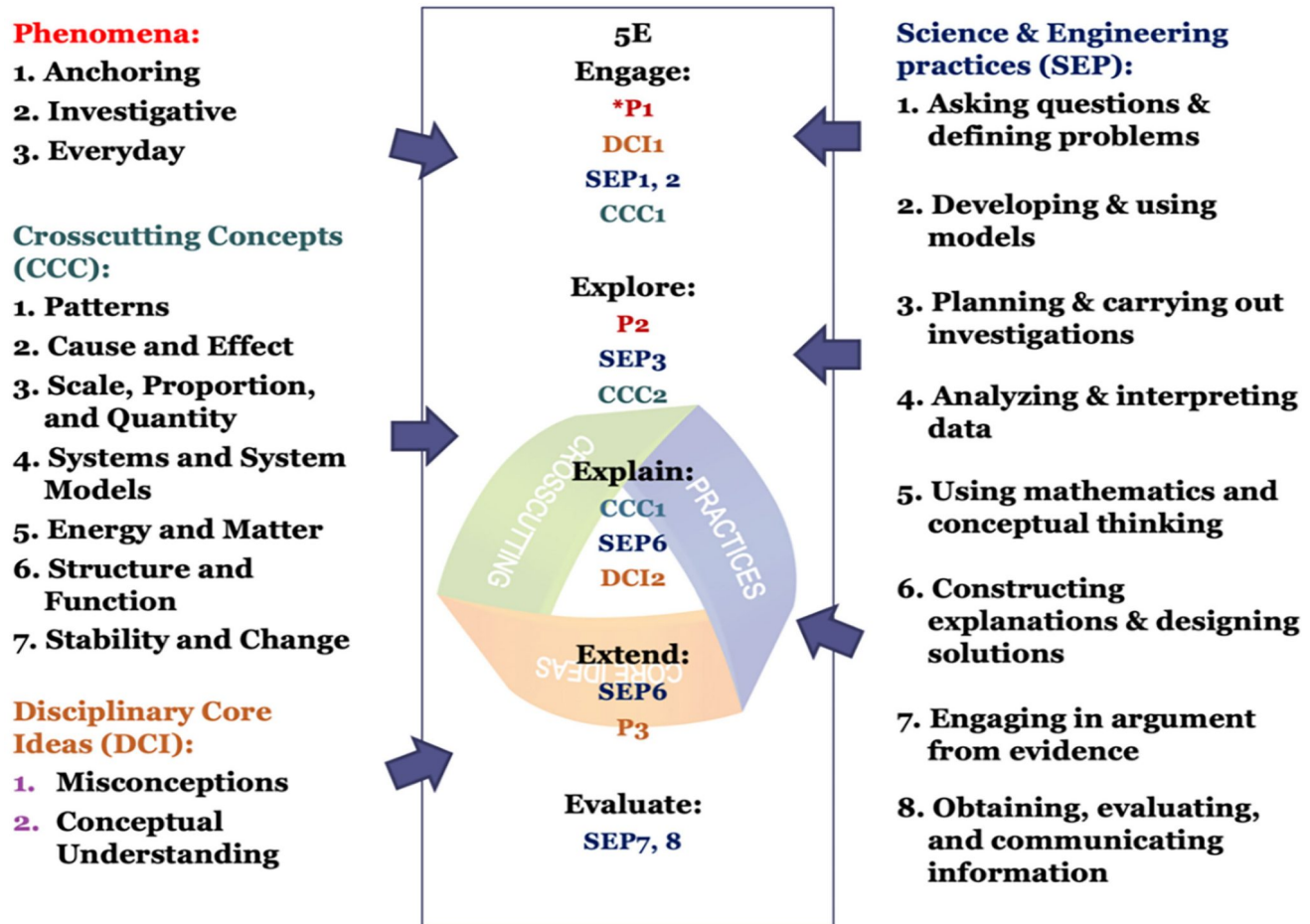
Making sense of phenomena often requires engaging students in hands-on experiences with appropriate science or engineering practices through well-designed integrated instructional sequences (Anderson et al., 2019; Bybee, 2013; Klahr et al., 2007). However, it has been a challenge for teachers to engage students in hands-on experiences to assist their understanding of space-science concepts such as moon phases, the reason for the seasons, or the scale of the solar system (Chakour et al., 2019; Petcovic et al., 2018; Wyssession, 2022; Yoon & Peate, 2015). This is due to several reasons, primarily a lack of teachers' knowledge in (a) using associated hands-on learning materials, (b) understanding space-science concepts, and (c) applying appropriate instructional strategies, such as modeling earth and space-science phenomena (Chakour et al., 2019; Gilbert & Ireton, 2003; Petcovic et al., 2018; Wyssession, 2022; Yoon & Peate, 2015). Moreover, many elementary and middle school teachers have difficulty incorporating the new pedagogical approach (i.e., 3D learning) suggested by NGSS (Petcovic et al., 2018; Wyssession, 2022). To overcome these challenges, teachers must be provided with instructional materials integrated into well-designed instructional sequences that support students in making sense of natural phenomena (Lee et al., 2018). For instance, NASA education resources can be integrated into the NGSS 3D learning or 5E model, providing opportunities for students to “engage in scientific and engineering practices and apply crosscutting concepts to deepen their understanding of the core ideas in these fields” (NRC, 2012, pp. 8–9; see also NGSS Lead States, 2013). This integration can assist teachers in designing units of science lessons that target specific DCIs and engage students in SEPs to make sense of phenomena, ultimately enhancing their students' understanding of space-science concepts (Bybee, 2013; NGSS Lead States, 2013).

Thus, we proposed a framework with a concept map that can help teachers to integrate the three NGSS dimensions into lessons structured using the 5E template (Figure 1). This concept map illustrates how the components of different types of phenomena, SEPs, CCs, and DCIs fit into the 5E phases. This framework has been developed in response to the challenges faced by teachers in incorporating the new pedagogical approach, 3D learning, suggested by the NGSS. As shown in Figure 2, the phases of the 5E model provide spaces

in which teachers can translate NGSS's performance expectations into sequences of investigations and laboratory experiences integrated with the three NGSS dimensions (Anderson et al., 2019; Bybee, 2013; Bybee et al., 2006).

Figure 1

Framework and Concept Map for Teaching Science With 3D Learning and Phenomena Into 5E Inquiry Instructional Model



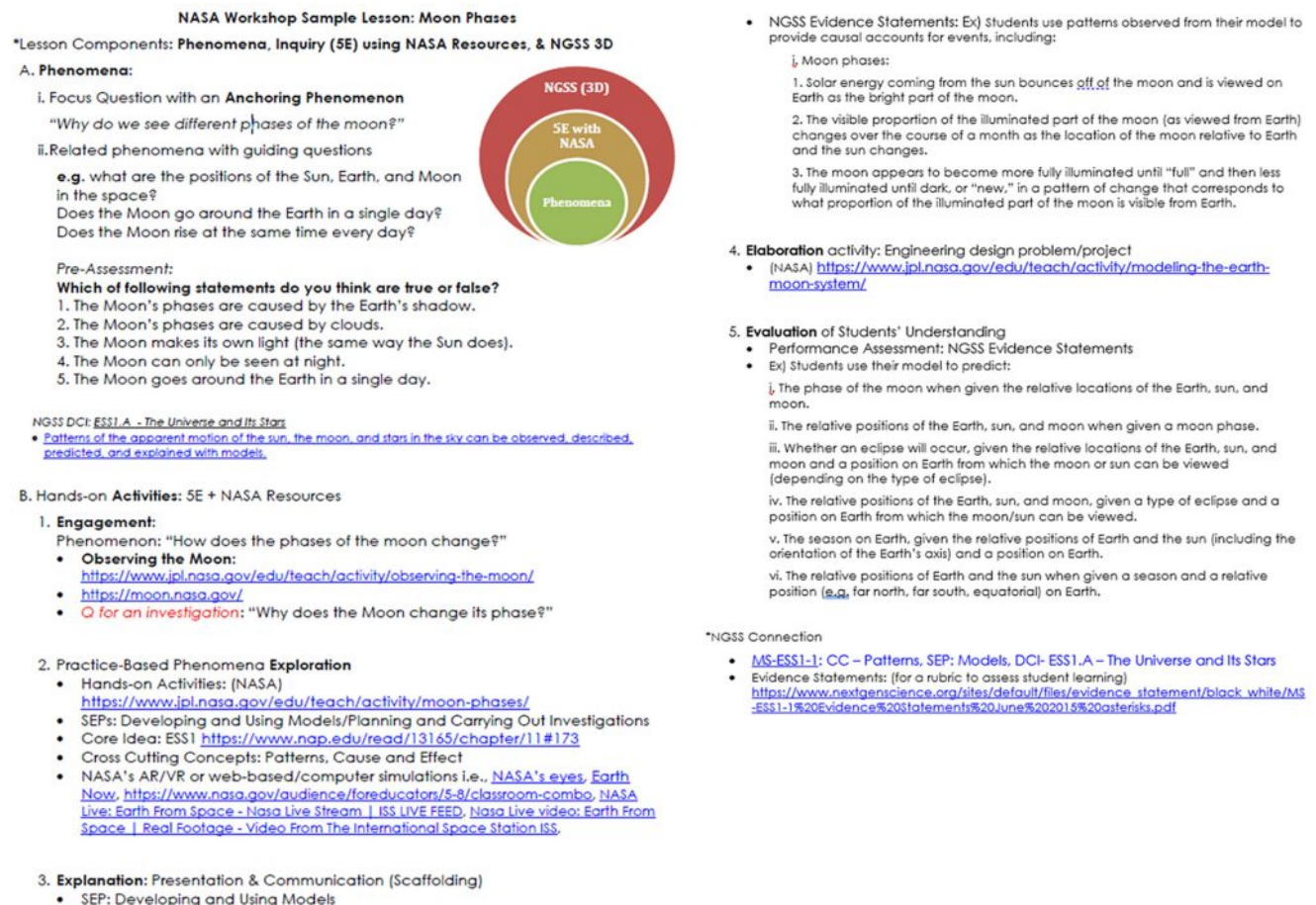
Note. The 5E template incorporates possible phenomena (P1, P2, and P3), CCs, DCIs, and SEPs selected for a science lesson.

Additionally, this framework highlights the importance of aligning the NGSS performance expectations with the 5E phases, providing teachers with a systematic approach to designing instruction that effectively engages students in science practices and processes. Although it does not directly involve NASA resources, it facilitates effective utilization of these resources by situating them within a comprehensive sequence of lessons and investigations. Stand-alone lessons based on NASA resources can be challenging to integrate into a cohesive science curriculum. The 5E Into 3D framework provides teachers with a structured strategy for effectively incorporating NASA resources into well-organized and coherent science instruction. Using the 3D Into 5E lesson template and sample lessons, we assisted the teachers in seeing where NASA's materials and activities fit into one of the 5E phases

(Figure 2). The project staff and coaches developed four sample lessons using the 3D Into 5E framework and engaged the participating teachers in them during the summer workshop (Table 1). Figure 2 is a model lesson that illustrates how space-science phenomena can be the center of the lesson with an anchoring question, guiding questions, and investigative questions leading to specific NGSS SEPs and CCs that match the selected NASA lesson materials or activities.

Figure 2

Space-Science Lesson Sample Designed With the 3D Into 5E Framework



Note. Although we did not specify any safety rules in the sample lessons, teachers were encouraged to include safety guides for the activities, even if none were listed in the NASA resources.

Table 1 describes the outlines of the sample lessons presented to the participating teachers. All the sample lessons have the same components (i.e., phenomena, NASA resources, SEPs, CCs, and DCIs) integrated into the same format (i.e., 5E model) using the lesson template.

Table 1*Outlines of the Sample Lessons*

Lesson	NASA resource	Integrated SEPs	Related CCs
Moon Phases	https://www.jpl.nasa.gov/edu/teach/activity/moon-phases/	• Asking Questions and Defining Problems • Developing and Using Models	• Patterns • Cause and Effect
Let's Jump	https://science.nasa.gov/jump-jupiter	• Analyzing and Interpreting Data • Using Mathematics and Computational Thinking	• Patterns • Scale, Proportion, and Quantity
How Does an Airplane Fly?	https://www.nasa.gov/sites/default/files/atoms/files/bernoulli_principle_5_8.pdf	• Developing and Using Models • Analyzing and Interpreting Data	• Patterns • Cause and Effect
Modeling the Earth–Moon System	https://www.jpl.nasa.gov/edu/teach/activity/modeling-the-earth-moon-system/	• Developing and Using Models • Constructing Explanations and Designing Solutions	• Systems and System Models • Scale, Proportion, and Quantity

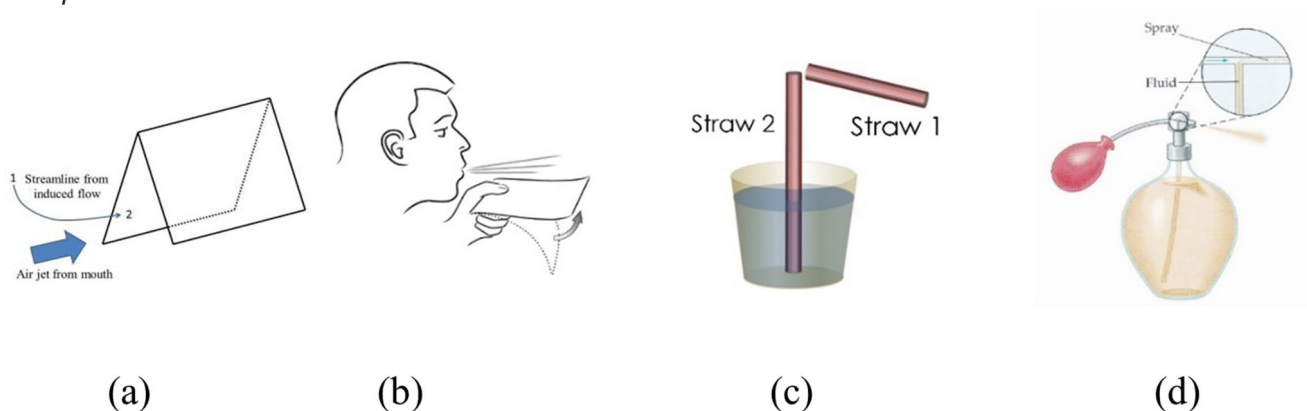
Note. See the Next Generation Science Standards (NGSS Lead States, 2013) for a complete list of the Science and Engineering Practices (SEPs) and Crosscutting Concepts (CCCs).

Making Sense of Phenomena Through 3D Into 5E

Phenomena refer to observable events occurring in the natural world that can be explained or predicted using scientific knowledge (Achieve et al., 2016). Teachers can use multiple phenomena related to the same science concepts (i.e., DCIs) to engage students in scientific investigations to make sense of the phenomena (Deverel-Rico & Heredia, 2018). These phenomena can be used in different phases of an integrated unit, such as anchoring phenomena in the Engage phase, investigative phenomena in the Explore phase, and everyday phenomena in the Extend or Evaluate phases (Achieve et al., 2016; Anderson et al., 2019; Bybee, 2013). For example, in the “How Does an Airplane Fly?” sample lesson, the first two hands-on activities shown in Figure 3 (a and b) served as anchoring phenomena in the Engage phase. These phenomena proved intriguing because the pieces of paper behaved unexpectedly when exposed to air, as depicted in Figure 3. Students then collaborated in small groups to identify patterns in their observations of the anchoring phenomena and shared their ideas with the class. Next, Figure 3c was used as an investigative phenomenon in the Explore phase. Based on their observations of the anchoring phenomena, students were required to formulate a hypothesis regarding the expected behavior of water in the cup when air is blown through Straw 1 over Straw 2 (not into Straw 2), providing a rationale for their reasoning. In the Elaborate phase, students were tasked with explaining the functionality of the perfume dispenser as an everyday phenomenon (see Figure 3d).

Figure 3

Multiple Phenomena Used in Different Phases of the 5E Model



Overview of NASA Teacher Workshop

This project received funding from the NASA Space Grant Consortium Teacher Workshop Program, which aims to promote the development and execution of STEM teacher workshops. In particular, the workshop aimed to enhance the participating teachers' abilities to create space-science lessons that integrate NASA education resources and the NGSS 3D learning approach using the 3D Into 5E framework. This was achieved through a series of carefully designed activities that aimed to provide the teachers with the necessary tools, resources, and guidance to effectively integrate space-science lessons into their classroom practices. Moreover, the workshop enhanced teachers' confidence in teaching space-science lessons, thus encouraging student engagement in exploring phenomena related to space-science DCIs. To ensure the successful implementation of space-science lessons, the workshop's schedule and activities were thoughtfully crafted and carried out, allowing participating teachers to feel adequately prepared to apply the newly acquired skills in their classrooms during the following academic year. Table 2 provides a comprehensive overview of the workshop's schedule and activities, including the topics covered, duration of each session, and corresponding materials and resources used.

Table 2
NASA Summer Workshop Schedule

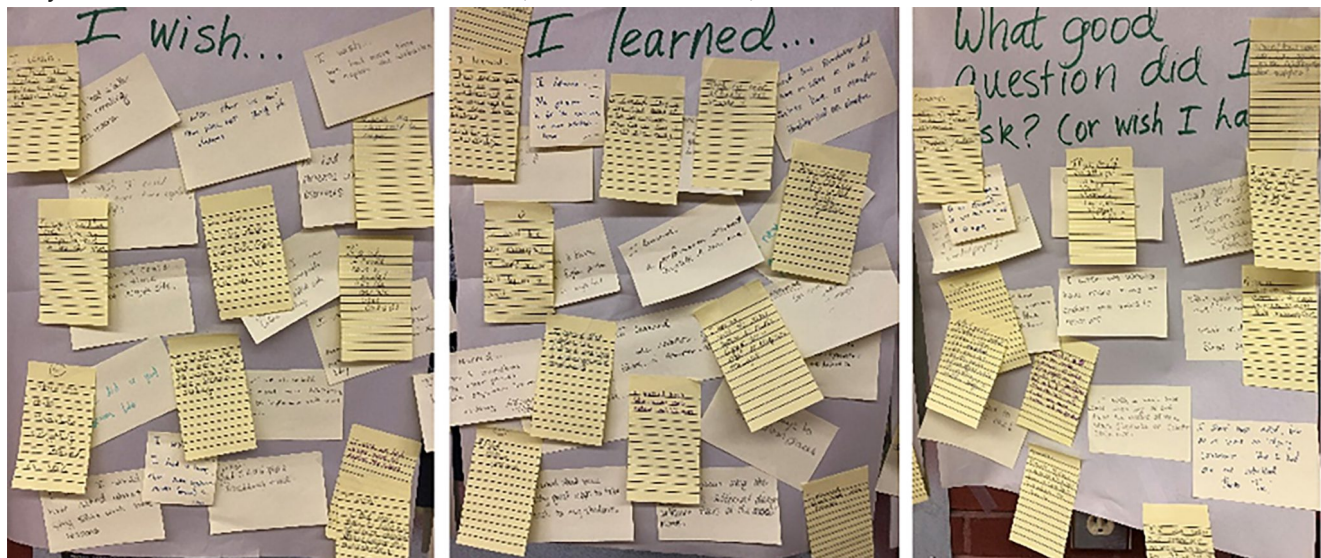
Time	Day 1 (Wednesday)	Day 2 (Thursday)	Day 3 (Monday)
8:00– 8:50	Orientation and premeasures	• Overview of the day’s agenda • Large group discussion: questions, feedback, and suggestions • Small group discussion with coaches	• Overview of today’s schedule • Two microteachings in each session in two different classrooms (A and B)
9:00– 9:50	Lesson Demo #1: Observing the Moon • Reflective discussion	• Concrete vs. abstract representations (including non-visual phenomena) • Sounds of Space - Stars, etc.	Microteaching Session 1 • Microteaching (30 minutes) • Reflective discussion (20 minutes)
10:00– 10:50	Lesson Demo #2: Let’s Jump • Deconstructing the demo lesson with NGSS 3D and phenomena • Identifying and discussing the phenomena in the lesson	• Lesson Demo #4: How does an airplane fly? • 3D Learning vs. Inquiry-Based Learning	Microteaching Session 2 • Microteaching (30 minutes) • Reflective discussion (20 minutes)
11:00– 11:50	• Using Your Senses to Study Space: Sounds, Movement, Touch, and Sight. • Concrete – Abstract Spectrum of Phenomena	• Lesson Demo #5: Solar System Scale Model • Middle School connections • Lesson Demo #6 and discussion of the concepts and misconceptions	Microteaching Session 3 • Microteaching (30 minutes) • Reflective discussion (20 minutes)
12:00– 12:50	Lunch	Lunch	Lunch
1:00– 1:50	Lesson Demo #3: Moon Phases • Reflective discussion	• (Continued) Star Brightness and discussion of the concepts, misconceptions • Seasons and misconceptions in general (e.g., seasons: direct vs. indirect or alternatively concentrated vs. less concentrated).	Microteaching Session 4 • Microteaching (30 minutes) • Reflective discussion (20 minutes)
2:00– 2:50	• NASA education resources: how to search and how to use (*5E with NGSS) • NASA’s AR/VR or web-based/computer simulations (e.g., NASA’s Eyes, Earth Now, and NASA Live: Earth from Space)	• Large group Q&A: discussion time with faculty and instructional coaches to better understand the concepts and instructional skills. • Review of the last day’s schedule for microteaching • Microteaching sign-up sheet	Microteaching Session 5 • Microteaching (30 minutes) • Reflective discussion (20 minutes)
3:00– 4:00	• Reflective discussion (small group and whole group) • Working time in groups and individually with the coaches • Overview of the next day’s agenda	Working time for microteaching a lesson next Monday • Possible ideas and supply list • Utilize current fifth-grade lessons • Purchasing materials	Microteaching Session 6 • Microteaching (30 minutes) • Reflective discussion (20 minutes)
4:10– 4:30			• Timeline and expectations for the fall semester 2019 • Summer workshop postsurveys • Comments and suggestions

Note. Between Days 2 and 3, the staff were available to assist participants with their microteaching lesson preparation from Friday through Sunday.

The program involved teachers participating in lesson activities as students, which allowed them not only to learn the targeted concepts but also experience the challenges that their students may face in the classroom. Reflective discussions were facilitated between teachers and project staff after each lesson to support teachers in understanding the targeted concepts and developing effective strategies for engaging students in sense-making processes. Additionally, teachers were paired to develop their own space-science lessons, with guidance from STEM coaches, for microteaching on the final day of the workshop. To promote self-reflection, teachers were asked to respond to prompts such as “I wish . . .,” “I learned . . .,” and “What good questions did I ask?” on a Post-it note at the end of each day (Figure 4). These responses were discussed on subsequent days to confirm teachers’ understanding of the concepts and instructional strategies covered in the workshop.

Figure 4

Daily Reflections of Teachers: Lessons Learned, Activities Evaluated, and Points for Discussion



On Day 1, the participating teachers completed the project presurveys and pretests (refer to Instrument section). Then, they were introduced to the project staff and STEM coaches as well as the schedule and expectations for the workshop. Prior to being introduced to the 3D Into 5E framework and lesson template, they participated in two sample lessons. As an engagement activity, the first lesson started with the “Observing the Moon” activity adapted from NASA’s website (<https://www.jpl.nasa.gov/edu/teach/activity/moon-phases/>). The teachers were asked to observe the Moon phases, starting from the new moon, for at least 2 weeks prior to the workshop. Following this, the teachers were engaged in a hands-on activity to investigate the changes that occur in the Moon’s phase. The teachers were then presented with the 3D Into 5E framework and lesson template, and a discussion followed on how they could use these tools to integrate NASA’s resources and hands-on activities. This workshop effectively blended theory with practice by providing educators with an immersive, hands-on learning experience. The introductory activities stimulated their interest and engagement, and the framework and lesson templates offered a structured approach to lesson planning and integration of resources.

On Day 2, the participating teachers were engaged in three sample lessons: “How Does an Airplane Fly?,” “Solar System Scale Model,” and “Star Brightness.” For example, the “How Does an Airplane Fly?” lesson was created utilizing the 3D Into 5E framework, which incorporates NASA’s resources into 3D learning. The Engage phase of the lesson involved a hands-on experiment with flying paper airplanes as an anchoring phenomenon. The Explore phase utilized an investigative phenomenon for Bernoulli’s principle. Finally, the Elaborate phase introduced everyday phenomena, such as a perfume dispenser, to

illustrate the practical applications of the concept. Throughout the lesson, the teachers were asked to consider relevant CCs, such as patterns and underlying cause-and-effect relationships, to discover Bernoulli's principle, develop hypotheses, and conduct investigations (as illustrated in Figure 5). This approach was intended to create an engaging and immersive learning experience for the teachers, enabling them to gain a deeper understanding of the concepts while also enhancing their pedagogical skills.

Figure 5

Teachers in the Sample Lesson on Bernoulli's Principle



The teachers participated in two additional sample lessons, “Solar System Scale Model” and “Star Brightness” (see Figure 6), bringing the total number of sample lessons demonstrated by the faculty and STEM coaches to four. During the afternoon on Day 2, the teachers were allocated time to engage in a collaborative activity, partnering with a colleague to develop a space-science lesson. The lesson was to be delivered during a microteaching session on Day 3, and it was required that the teachers utilize the 3D Into 5E framework and lesson template with the guidance and support of STEM coaches. This collaborative activity provided an opportunity for the teachers to apply the pedagogical strategies and content knowledge gained from the sample lessons and engage in peer-to-peer learning and constructive feedback. By promoting collaboration and peer interaction, this activity aimed to foster innovative and reflective teaching practices. Because the workshop began on Wednesday, the teachers were given adequate time to work on their lessons, from Friday through Sunday, before reconvening for the microteaching sessions on the following Monday, which was Day 3.

Figure 6

Teachers in the Sample Lessons “Solar System Scale Model” and “Star Brightness”



On Day 3, the teacher pairs presented the space-science lessons they had developed to other teachers and project staff during the microteaching sessions. Each microteaching session was followed by a reflective discussion period during which the teachers evaluated the effectiveness of their instruction, hands-on activities, and lesson materials, all of which incorporated NASA resources. Additionally, the

teachers discussed potential student misconceptions and devised strategies to facilitate students' understanding of complex concepts. This approach allowed the teachers to engage in a collaborative process of reflection, evaluation, and improvement, promoting innovation in science education and empowering the teachers to facilitate effective learning experiences for their students. The teachers' space-science lessons included:

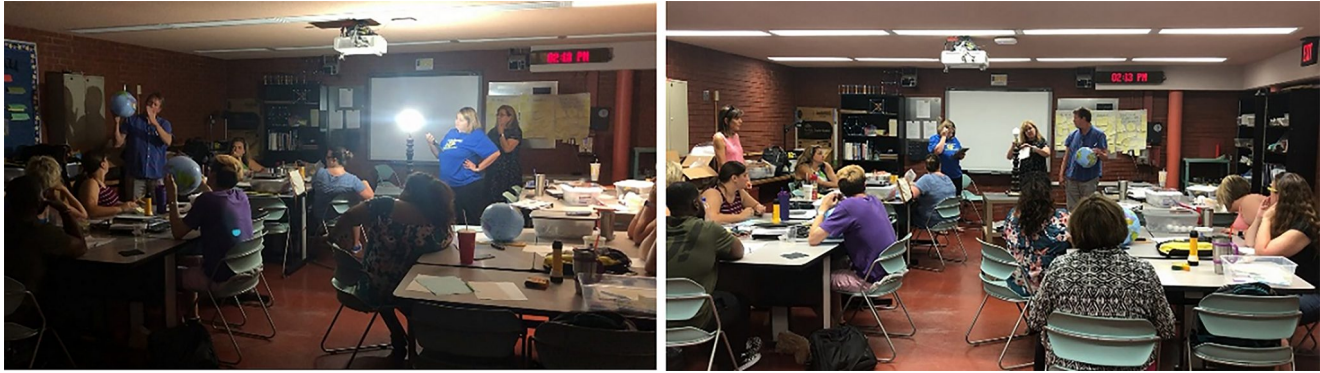
1. (developed using materials from <https://www.jpl.nasa.gov/edu/teach/activity/solar-system-scroll/>),
2. Egg Drop/Lander (developed using materials from <https://www.nasa.gov/stem-ed-resources/egg-drop-lander.html>; see Figure 7),
3. (developed using materials from https://sunearthday.nasa.gov/2007/materials/solar_pizza.pdf; see Figure 8),
4. Does the Sun Move? Furthering Understanding of Shadows (developed using materials from https://www.nasa.gov/pdf/145908main_Sun.As.A.Star.Guide.pdf), and
5. All About That Tilt (developed using materials from <https://spaceplace.nasa.gov/seasons/en/>; see Figure 7).

Figure 7

Lesson Outlines for Egg Drop/Lander and All About That Tilt

Egg Drop/Lander 5thGrade	All About That Tilt (45 minutes) Grade 5
NGSS/Science Standards: 5-ETS1-1. Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost. Science and Engineering Practices: - Asking Questions and Defining Problems Asking questions and defining problems in grades 3–5 builds from grades K–2 experiences and progresses to specifying qualitative relationships. (3-5-ETS1-1) Disciplinary Core Ideas: - ETS1.A: Defining and Delimiting Engineering Problems Possible solutions to a problem are limited by the available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account. (3-5-ETS1-1) Crosscutting Concepts: - Influence of Science, Engineering, and Technology on Society and the Natural World People's needs and wants change over time, as do their demands for new and improved technologies. Engineers improve existing technologies. (3-5-ETS1-1) NASA resources: https://www.nasa.gov/stem-ed-resources/egg-drop-lander.html Hands-on Activity: Focus Questions: - How will the materials you are using for your design protect the egg from breaking? - Why does the distance from which we launch the egg landers matter? Engagement (5 minutes): Gather partnerships around a clear trash bag. I tell them to stand facing each other around the trash bag not to stand too close. I make sure that they are a safe distance away (I might even encourage them to wear safety goggles) and I pull out a raw egg. Hand each team an egg. Prompt the students to make predictions about what will happen to the egg when they drop it from above their heads, and ask them to observe what happens when they drop the egg onto the trash bag They then drop the egg and "splat" It breaks open and oozes in the bucket. I ask the students why this happened? Many respond, because of gravity. A few even remember that we had discussed in previous lessons about how a larger object with a larger mass has a stronger gravitational pull on a	NGSS/Science Standards: 5-ESS1-2. Represent data in graphical displays to reveal the changes in length and direction of shadows, day, and night, and the seasonal appearances of some stars. Science and Engineering Practices: - Analyzing and Interpreting data Disciplinary Core Ideas: - The orbits of the Earth around the sun and the moon around the Earth, together with the rotation of the Earth about an axis between its north and south poles cause observable patterns. These include day and night, daily changes in the length and direction of shadows; and different positions of the sun, moon, and stars at different times of the day, month, and year. Crosscutting Concepts: - Similarities and differences in patterns can be used to sort, classify, communicate, and analyze simple rates of change for natural phenomena. Nasa Video: What Causes the Seasons? https://spaceplace.nasa.gov/seasons/en/ Website: Why Earth has 4 Seasons https://earthsky.org/earth/can-you-explain-why-earth-has-four-seasons Hands-on activity : Focus Questions: - What causes the length and direction of a shadow to change throughout the year? - How are shadows different in the winter compared to summer? Engagement (_10_ minutes): - Before this lesson have students observe their shadows at different times during the day and draw what they see. (Today we will provide an observation.) - Ask students: - What did you observe when you went outside at different times of day? Did your shadow change? How? - What caused it to change? - Get a beach ball globe. Attach a lego person or some small object to North America. Put a bright lamp in the middle of the room. Keeping the ball at a tilt, move the beach ball around the lamp at an angle to show the shadow at different positions around the sun. 

Figure 8
Microteaching Session on the Topic of the Sun-Earth Connection



Participants

This study recruited teachers from Grades 5–8, and 13 teachers from Grades 5–6 in the school district participated, as indicated in Table 3. The participating teachers implemented space-science lessons for their students over a period of 3–4 weeks during the subsequent school year.

Table 3
Demographic Information for the Participants (N = 13)

Characteristics	<i>n</i>	<i>M</i>	<i>SD</i>
Gender			
Male	3 (23%)		
Female	10 (77%)		
Grade Level Teaching			
5	10 (77%)		
6	3 (23%)		
Teaching experience ^a		7.85	3.69

a. Teaching experience ranged from 1 to 18 years.

To support the successful implementation of the lessons developed during the workshop, four STEM success coaches joined this effort. As depicted in Table 4, these coaches were experienced science teachers who provided valuable guidance and support to the participating teachers during a summer workshop and throughout the following school year. Each STEM coach was assigned to work with a team of three to four teachers, providing personalized guidance on targeted concepts and instructional strategies to support the successful implementation of space-science lessons.

Table 4
STEM Success Coach Information

Coach	Grade level	Gender	Teaching experience	Science subjects and leadership roles	Mentoring experience
Aron	8	M	7	•Earth and Space Sciences •Science Olympiad Coach	Yes
Brenda	5	F	10	•K–5 STEM Librarian •District Curriculum Team	Yes
Cory	5	F	13	•District Science Curriculum Leadership Team	Yes
Diana	6–7	F	14	•Astronomy, Biology, Physics, and Geology	Yes

Note. All names are pseudonyms.

Instruments

The study employed a multifaceted assessment approach to measure the participating teachers' space-science knowledge, confidence, and efficacy beliefs. This approach involved administering several instruments at different time points: at the beginning, at the end of the summer workshop, and at the end of the school year. The instruments used were a space-science content knowledge questionnaire, a pedagogy of science teaching questionnaire, a survey for confidence in teaching space science, and the Science Teaching Efficacy Belief Instrument (STEBI-A). The STEBI-A, comprising 23 items on a 5-point Likert scale ranging from *strongly agree* to *strongly disagree*, was used to assess the confidence of preservice teachers in their ability to teach (Enochs & Riggs, 1990). The Space-Science Content Knowledge Questionnaire was adapted from TIMSS and PISA test items (Drechsel et al., 2011; Martin et al., 2012). Upon completion of the content-knowledge test, teachers rated their confidence in teaching the content on a 5-point Likert scale, ranging from *not at all confident* to *very confident*, as part of the Survey for Confidence in Teaching Space Science. The Pedagogy of Science Teaching Questionnaire comprised six scenario-based questions on classroom instruction of space sciences, adapted from the Pedagogy of Science Teaching Test (Cobern et al., 2014). Furthermore, an exit survey was administered at the end of the workshop to evaluate project activities and assess teachers' confidence in teaching space-science lessons. The exit survey consisted of nine 5-point Likert scale questions and 16 open-ended questions, including a query on teachers' confidence in teaching space-science lessons after the workshop.

Workshop Outcomes

Quantitative Data

Paired samples *t*-tests (Cohen, 1988) were conducted to compare the means of all pre and post survey and test results. The findings indicated significant improvements in teachers' confidence in teaching science, as measured by STEBI-A ($M = 3.87$ to 4.12 , Cohen's $d = .94$, $p = .006$), following the summer workshop. Similarly, there was a notable increase in teachers' space-science content knowledge ($M = 58.45\%$ to 77.69% , $d = 1.55$, $p = .000$) and their self-reported confidence in teaching space sciences ($M = 3.00$ to 3.83 , $d = .94$, $p = .005$). Additionally, teacher responses to the exit surveys showed an increase in confidence in translating NASA resources into their own space-science lessons using the 3D Into 5E template (from *Very Low* to *High* or *Very High*; see Table 5). However, the pedagogy of science teaching survey did not show any significant changes between pre- and post-tests ($M = 3.31$ to 3.40 , $d = .27$, $p = .377$).

Table 5

Comparison of Teacher Confidence Levels in Teaching Science Before and After the Summer Workshop (N = 13)

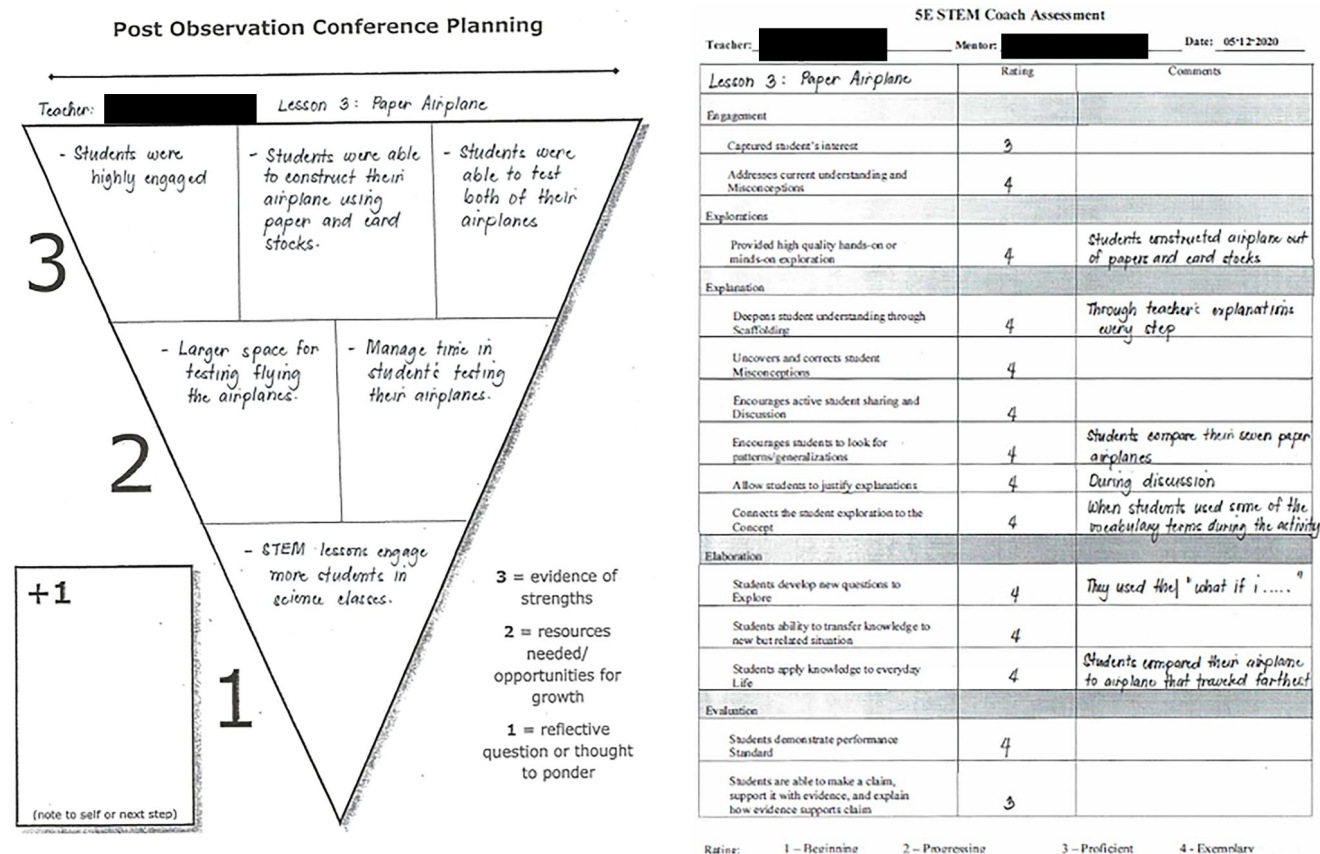
	Before the workshop					After the workshop				
	Very low	Low	Average	High	Very high	Very low	Low	Average	High	Very high
Knowledge about NASA education resources	2	7	3	1	0	0	0	1	9	3
Teaching a space-science lesson	3	1	8	1	0	0	0	2	7	4
Use of the NASA education resources	5	6	1	1	0	0	0	1	10	2

Qualitative Data

In addition to the questionnaires, we utilized a comprehensive approach to evaluate the impact of our professional development program on the classroom practices of participating teachers. Specifically, we requested that the teachers submit their lesson plans and videos of their classroom instruction, which were evaluated by their assigned STEM coaches using a classroom observation form. Figure 9 is an example of a completed observation form, which was used to assess the alignment of classroom instruction with the performance expectations outlined in the NGSS. The results of the coaches' observations indicated that the majority of the teachers adeptly engaged their students in hands-on, NGSS-aligned activities related to space science. The integration of classroom observations and feedback with the survey data allowed for a more comprehensive understanding of the professional development program's impact on teachers' instructional practices.

Figure 9

Coach Assessment of Teacher Lesson Implementation Example



The data collected from teachers' lesson plans and coaches' evaluations indicate that the teachers not only implemented the 5E model in their space-science lessons but also effectively utilized multiple phenomena and CCs to facilitate their students' learning. The teachers integrated multiple phenomena throughout all 5E phases, such as using them to generate questions in the Engage phase, to investigate in the Explore phase, and to explain the phenomena with reference to targeted core ideas and CCs in the Explain phase. According to the reported observations of the teachers, the use of CCs appeared to facilitate students in comprehending the phenomena and improving their understanding of the targeted DCIs. Moreover, exit surveys completed by the teachers at the end of the school year reported that their students demonstrated great enthusiasm for learning space sciences, thanks in part to the exciting and engaging hands-

on activities used in the lessons. Several teachers also reported that the activities sparked their students' interest and motivated them to conduct additional research on their own. To address students' misconceptions, some teachers reported that they compiled a list of misconceptions and used them as the basis for their space-science lessons. The teachers also reported that they enjoyed their students' genuine questions and getting them to uncover their misconceptions. The teachers found the sample lessons to be of great value, which demonstrated ways to engage students in hands-on space-science activities. Some teachers felt that the workshop exceeded their expectations by providing them with opportunities to expand their space-science knowledge and learn to teach hands-on lessons. Additionally, the teachers appreciated the STEM success coaches' assistance in walking them through difficult learning points and reducing their stress about teaching microlessons and incorporating NASA educational resources into their space-science lessons. Additionally, we believe that the teachers' excitement for teaching space science and their enjoyment of teaching their students were also significant outcomes of the project. Teacher sample comments about workshop benefits included the following.

- "The most valuable part of the workshop was learning about the lessons that are available through the NASA sites because they have great lessons that will also extend some of the current ones that I work with."
- "Exceeded my expectations by providing me with collaboration with colleagues, time to plan a microlesson, and greatly expanded my space-science knowledge."
- "Learning to teach hands-on things that are not usually hands-on. Keeping kids engaged with space science is difficult without an activity. This will help me keep my class on task."

Discussion

It is pertinent to acknowledge that the primary objective of this article was to provide a comprehensive and detailed account of the distinct approach adopted in the project, including the specific instructional strategies and resources utilized, rather than persuade readers of the workshop's efficacy. Notwithstanding, the data collected through exit surveys provided insightful feedback from participating teachers, who reported two significant themes regarding their experiences in the project. First, they found that there were many existing space-science lessons that they could adapt and modify for their own classrooms. Second and more importantly, they felt confident in their ability to teach the newly learned instructional strategies and resources after participating in the project. The teachers expressed excitement about teaching space-science lessons and observing their students engaging in hands-on activities. The teachers also valued the 3D Into 5E framework and lesson template, which challenged them to create their inquiry-based lessons using the framework and template. The 3D Into 5E framework and lesson template, along with the model lessons that were demonstrated during the workshop, were cited as particularly helpful in assisting teachers in integrating NASA's educational materials into NGSS 3D learning. Additionally, the emphasis on using NGSS CCs throughout the model lessons was viewed as an effective way to help teachers see how these resources could be integrated into 3D learning. Integrating NASA's resources with NGSS CCs provides a practical and engaging method for educators to promote interdisciplinary learning and the development of scientific skills such as critical thinking, problem-solving, and scientific reasoning. By offering students real-world examples and contexts, educators can enhance their understanding of scientific concepts and encourage the transfer of knowledge across different domains. This approach aligns with the goals of NGSS, which emphasize the importance of interdisciplinary learning and the integration of scientific practices, concepts, and crosscutting concepts. Overall, the 3D Into 5E framework used in this project demonstrated the potential to effectively assist teachers in integrating NASA's educational resources and NGSS's three dimensions into their classroom instruction. Future research could explore the extent to which this framework could be adapted and applied to other STEM domains.

Based on our observations of the teachers and their responses to the exit surveys, we propose some suggestions for teacher educators to utilize the professional development materials and activities used in this study. First, project staff and coaches did not explain the targeted concepts until the teachers figured them out by themselves during the sample lesson demonstrations. This showed them a proper instructional model like the one they would use in their classrooms. Second, reflective discussions between the teachers and project staff after each sample lesson helped the teachers recognize how the staff modeled the use of instructional strategies used to engage them in a sense-making process for the phenomena. Third, the teachers noted the distribution of time. Less lecture time meant more time for the teachers to participate in model lessons and reflective discussions, develop their own lessons, and microteach to peers. The teachers greatly valued the challenges of being asked to figure out a phenomenon by themselves as well as the time they worked

with their peer teachers and coaches to develop their own space-science lessons. They also appreciated doing the tasks in pairs or groups because it reduced their pressure on developing a space-science lesson and performing microteaching in front of other teachers and project staff.

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