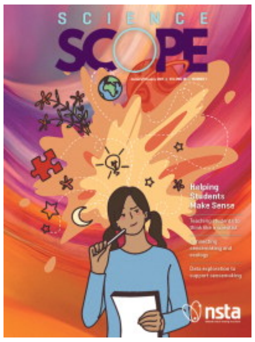

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Fostering Student Curiosity in Scientific Practices: The SUPeR Approach Using Student Uncertainty as Pedagogical Resources

Mandy Heal, Jongchan Park, Ying-Chih Chen & Michelle E. Jordan

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Fostering Student Curiosity in Scientific Practices:

The SUPeR Approach Using Student Uncertainty as Pedagogical Resources

BY MANDY HEAL, JONGCHAN PARK, YING-CHIH CHEN, AND MICHELLE E. JORDAN

ABSTRACT

This article presents an innovative instructional approach that assists teachers in designing and implementing their science unit: The SUPeR (Student Uncertainty as Pedagogical Resources) approach. The SUPeR approach suggests four phases of student learning in scientific practices and posits that student uncertainties drive the trajectory of learning. By applying the SUPeR approach, teachers can foster student curiosity and ensure a student-centered science learning environment. A sixth-grade solar energy unit is described to show how a science unit can be designed and implemented using the SUPeR approach. The article elaborates on teacher guidance for applying the SUPeR approach, how student uncertainty is used to foster student curiosity and drive the learning trajectory, how student learning can be assessed from the SUPeR perspective, and how the SUPeR science unit aligns with the *Next Generation Science Standards*.

KEYWORDS: Curiosity; Energy; Scientific Uncertainty; Solar Energy; Solar Panel

The Framework for K–12 Science Education (National Research Council, NRC 2012) emphasizes that science learning should begin with student "curiosity about what they see around them" so that they can "continually build on and revise their knowledge and abilities" (11). Learning guided by student curiosity is student-centered, engaging, motivating, and conducive to grasp a better understanding (Bradbury and Wilson 2019; Flannagan and Rockenbaugh 2010; Ashbrook 2016). In other words, student curiosity drives engagement in scientific practices.

Uncertainty is one of the factors that sparks students' curiosity to explore a phenomenon, engage in scientific practice, and develop their understanding (Litman 2008). For instance, when students express uncertainty such as "I don't get it. Why did the voltage [of the solar panel] decrease at 35 °C?" and "I am not sure about what season a solar panel works best," these uncertainties motivate student curiosity to develop a variety of wonderings and investigations of solar panel operating efficiency at different temperatures.

This article presents an innovative instructional approach that helps teachers understand how uncertainty manifests during scientific practices, enabling them to use student uncertainty as a valuable pedagogical resource for learning. It begins with an overview of the SUPeR (Student Uncertainty as Pedagogical Resource) approach, including instructional guidance and teaching strategies. General questions that can guide student inquiries throughout the SUPeR lessons are also provided. This approach is domain-general, meaning that the guidance and strategies are applicable to various units of middle school science curriculum. To exemplify how this approach can be employed to address student uncertainties and foster their curiosity in science classes, this article describes a one-week lesson in a sixth-grade energy unit.

The SUPeR approach

The SUPeR approach proposes that teachers strategically integrate scientific uncertainty and use student uncertainty as a resource to foster curiosity during scientific practices (Rapkiewcz et al. 2023). Scientific uncertainty refers to the subjective experience of being uncertain about predicting and explaining scientific phenomena (Chen et al. 2024; Jordan and McDaniel 2014). The SUPeR approach comprises four phases: Problematize a Phenomenon (Phase 1); Material Practice (Phase 2); Argumentative Practice (Phase 3); and Reflection, Application, and Transformation (Phase 4). Each phase has specific instructional and learning goals, guiding the management of student uncertainty and support for curiosity. Refer to Table 1 for a summary of goals to guide teachers and questions to guide students in the SUPeR approach.

TABLE 1: Teacher guidance for managing uncertainty and supporting curiosity in the SUPeR approach.

Goals to Guide Teachers	Questions to Guide Students
Phase 1: Problematize a phenomenon	
1. Explore a phenomenon and elicit student ideas about the phenomenon. 2. Identify students' knowledge gaps and curiosities. 3. Frame an uncertainty and develop a plan to address it.	***Knowledge:*** What am I certain about? What am I not certain about? What do I need to know? ***Question:*** What are my questions about the phenomenon?
Phase 2: Material practice	
1. Enact a plan to address the uncertainty, collecting and analyzing data. 2. Develop intuitions based on interaction with materials. 3. If needed, revise a plan to address unexpected new uncertainties and curiosities and enact it.	***Design:*** What investigation can I design to address my questions? How can I revise my investigation design to address unexpected results? ***Data:*** What data can I collect? How can I organize my data?
Phase 3: Argumentative practice	
1. Interpret data and meaning of the results of testing/experiments, including ambiguous, unexpected, or incoherent results. 2. Generate multiple perspectives, seek convergent understandings.	***Solution (individual):*** What evidence do I have to support my claim? How consistent are my results (with my expectations and across the dataset)? ***Comparison (group):*** How do my results and my ideas compare with others? What should I change about my ideas or my science practices? What can I suggest to peers to help improve their investigation/analysis/prototype?
Phase 4: Reflection, application, and transformation	
1. Think systemically, think beyond the system at hand, generalizing knowledge. 2. Generating new questions and uncertainties linked to the next unit.	***Reflection:*** How have my ideas changed on a continuum between uncertainty and certainty? ***Relevance:*** What can I do with the new knowledge? How do I situate it relative to other things I care about or know? ***New uncertainty:*** What new questions or uncertainties does this knowledge raise for me? ***Transformation:*** How do I explain my ideas to different audiences using multiple modes of representation?

In Phase 1 of the SUPeR approach, the phenomenon is problematized as an anchor for embedding scientific core ideas, allowing subsequent lessons to build on it. The phenomenon should be authentic and familiar, enhancing students' curiosity (Spektor-Levy, Baruch, and Mevarech 2013). Students share their observations, thoughts, and questions, while the teacher problematizes the phenomenon based on student ideas through whole-class discussions. During these discussions, uncertainties and questions regarding how variables impact the phenomenon are raised. Maintaining a moderate level of uncertainty is important to stimulate curiosity without overwhelming or boring students. Employing prompts to focus the discussion helps reduce excessive uncertainty, while presenting conflicting or inconsistent cases challenges students and generates a higher level of uncertainty. By the end of this phase, students are expected to generate a claim about the problematized phenomenon and develop an investigation plan to address their uncertainties and curiosity (Chen and Jordan 2024). The investigation plan outlines the independent variable to manipulate, the dependent variable to be affected, and the procedures and tools for manipulating and/or measuring variables.

In Phase 2, students interact with materials, developing an understanding of core ideas through hands-on experience. They implement the investigation plans from Phase 1, testing and revising their claims about the phenomenon. Students record and organize data using various modalities (e.g., tables, figures, graphs, diagrams, pictures). Throughout this process, investigation plans can be adapted and improved as uncertainties evolve. Teachers can support student investigations by asking questions about unexpected observations and results, fostering new uncertainties and curiosity during the material practice. Structured worksheets and group boards can be provided to facilitate data collection and organization.

In Phase 3, students construct their understanding of the phenomenon through sharing, critiquing, revising, and improving their claims and evidence. Argumentative Practice begins with students' verifying, revising, or changing their claims based on experiment results from Phase 2, interpreting and identifying patterns in the data as evidence. Students then share their claims and evidence, comparing and contrasting them with those of their peers. They reflect on their own claims, critique others' claims, and identify areas for further revision and improvement in their investigation and interpretation (Rapkiewcz et al. 2023). If necessary, students may redo experiments or reinterpret data. Teachers, as facilitators, ask questions about ambiguous, incoherent, or conflicting ideas between groups, promoting convergence of understanding. Additionally, teachers ensure students connect their arguments with core concepts to be learned.

In Phase 4, students reflect on changes in their knowledge and uncertainties, apply new understandings to current or similar situations, and transform their understandings to fit new contexts. This phase aims to foster systematic, reflective, and applicable thinking, while generating new questions, uncertainties, and curiosities for the next unit. To facilitate this process, teachers reintroduce the problematized phenomenon for reflection and present similar or new phenomena to help students generalize their understandings. During this final phase, students apply their learning and explore new possibilities, uncertainties, and curiosities to expand their knowledge. This phase provides a great opportunity to implement differentiation strategies for both special needs students and gifted students. For special needs students, the emphasis of this phase can be on reinforcing learning through reflection on

FIGURE 1: A whole-class discussion to problematize a phenomenon: How to power ranger stations using a solar panel system.

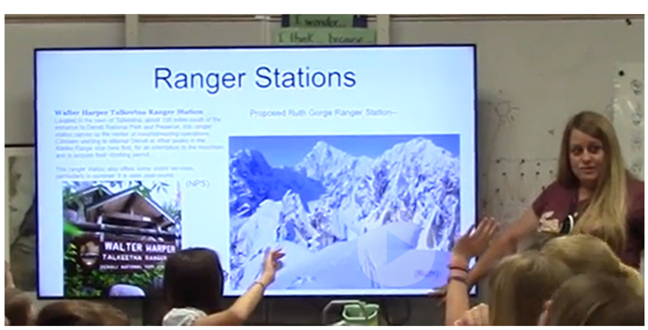
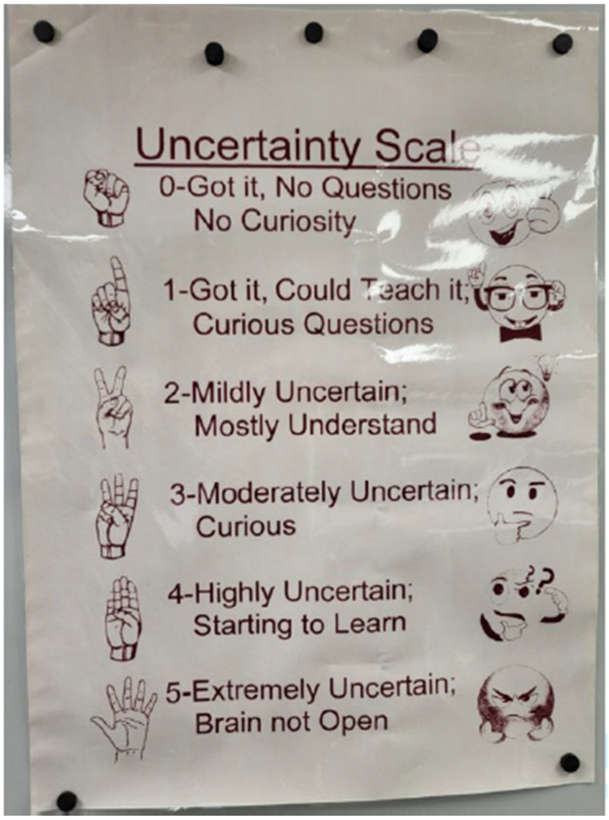


FIGURE 2: Uncertainty Scale to self-assess the degree of uncertainty and curiosity.



what they have explored using similar phenomena. For gifted students, the focus can encompass both reflection and application to novel and complex phenomena.

The SUPeR approach in a sixth-grade solar energy unit

To exemplify an application of the SUPeR approach in middle school science classes, a one-week unit on solar energy in sixth-grade science is presented. In this unit, Ms. Ellison, the teacher, tasked students with devising a solar panel system to power a ranger station in Denali National Park, located within the Arctic Circle. Throughout the unit, students were expected to grasp the impact on power generation of (a) solar panel angles and orientation, (b) shading on panel surfaces, and (c) ambient temperature. Prior to this lesson, students acquired an understanding of solar energy as a sustainable energy source and the conversion of sunlight into electricity using solar panels. Each phase of the SUPeR approach took one or two class periods—one for Phases 1 and 2, and two for Phases 3 and 4.

Phase 1: Problematize a phenomenon

To frame the unit, the phenomenon of powering a ranger station in Denali National Park with solar panels was used (see Figure 1). A national park was a familiar and natural location for students since they attend a science camp at one of the national parks annually. Students aimed to understand effective solar panel system design in such a cold area. Ms. Ellison guided students by posing questions such as "What do you see in this photo?" and "What factors should we consider when building a solar panel system here?" to elicit their ideas and uncertainties. Follow-up questions such as "So, you mentioned the weather. Does snow affect the panels? What else can cover them?" helped students recognize uncertainties and spark curiosity. Additionally, Ms. Ellison employed an Uncertainty Scale (see Figure 2) to monitor students' understanding and adjust instruction accordingly throughout the four phases. Ms. Ellison coupled the sale with several questions (e.g., Can you tell me more about why you are uncertain? About which parts you are certain and uncertain?) to decide the next steps of the lesson.

During a 20-minute, whole-class discussion, three issues of uncertainty and their corresponding variables were identified by the students and Ms. Ellison: (a) the effect of cold weather on solar panel power production, (b) the impact of shading from snow or surroundings on power production, and (c) the optimal angles and orientations for maximum power generation. Then, students worked in small groups of three to four members as assigned by Ms. Ellison. Each group selected one issue to investigate, developed initial claims and reasoning, and created an investigation plan. Using a large whiteboard, groups documented their initial claims at the top and organized their ideas in four sections: (a) How will you test? (procedures), (b) Diagram (visual representation of experiments) (c), Data (data collection and organization), and (d) Reasoning (supporting claims with data interpretation). Before proceeding to the next phase, students completed the first section regarding procedures and tools. See "Group board and individual worksheet" in Supplemental Materials.

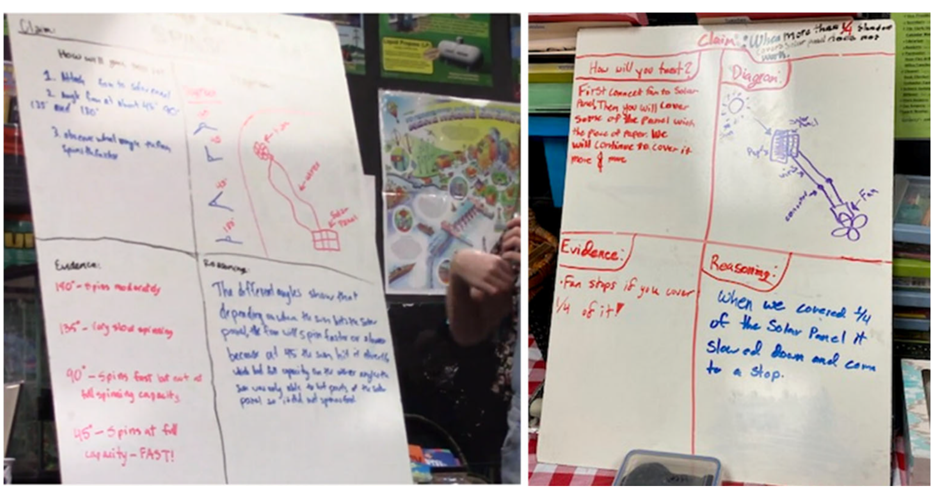
Phase 2: Material practice

After students finished their investigation planning, each group was provided with a set of tools, including two mini solar panels (Max. 460 mA, 1.5 V), 10 alligator clip wires, two mini DC motors (1.5 V ~ 3 V), two fans, and one multimeter. All the materials can be purchased from online retailers. It costs approximately $40 for a pack of 10 mini solar panels, $6 for 10 alligator clip wires, $12 for 10 mini-DC motors, $10 for a set of 32 fans, and $15 for a multimeter. The approximate total cost for six small groups (20 students) falls between $215 and $245.

Before conducting experiments outside, students received safety advice, such as avoiding direct eye contact with the Sun, being cautious while handling the fans and hot solar panels and avoiding contact with electric materials using wet hands. They were also instructed on how to use the multimeters to measure voltage and how to properly connect the alligator clips to the solar panels or motors.

Each group visually represented their experiment models on their whiteboard (in the "Diagram" section) before conducting tests. They collected data and recorded their observations in the "Data" section. Each group conducted three to four trials with varying independent variables (e.g., solar panel angles at 0°, 45°, 90°, or 120°). Ms. Ellison moved between groups, addressing uncertainty and encouraging curiosity through questions and assistance. For instance, she asked a struggling group why their fan wasn't working and prompted them to consider factors: "Why do you think it [the fan] is not working? What should we check over?" Students responded: "I think because it's in the shade," "It needs sunlight to work," "See? It spins here [unshaded area]." Then, the teacher sparked curiosity by saying, "Now it works without shade. Can you make it spin faster?" Students raised their hands high and adjusted the orientation of the solar panel toward the Sun. Ms. Ellison then prompted, "It spins faster. How will you measure the angle?" Students answered: "Well, we put it [solar panel] on the ground and measure the angle," and "When it's flat, it's 0°, and when it's standing like this [vertically standing], it's 90° and when it's in the middle, it's 45°." Through these actions, Ms. Ellison scaffolded students' learning, utilizing their uncertainty to foster curiosity about core concepts such as the

FIGURE 3: Group presentation: Variables of angle and fan speed (left), variables of shade and fan speed (right).



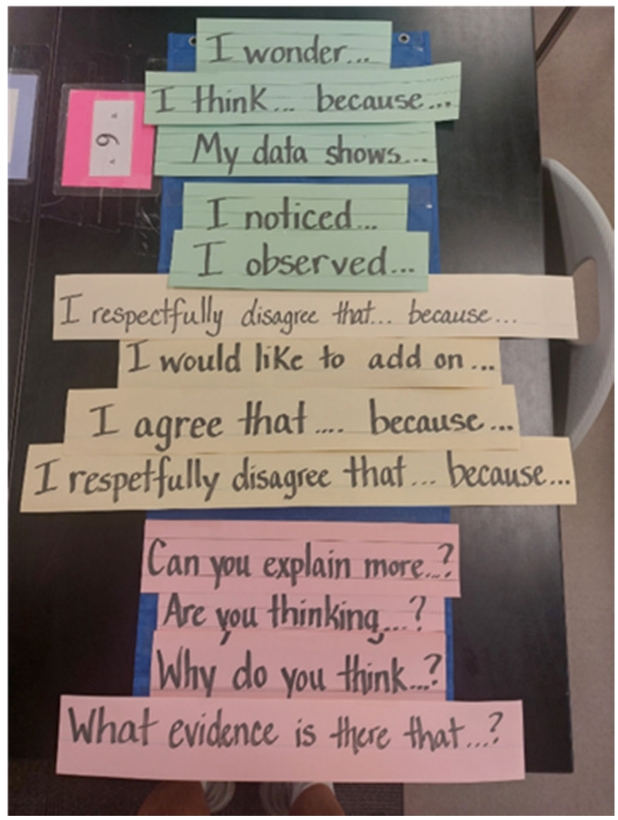
relationship between the amount of sunlight and electricity production, and the impact of angle and orientation on sunlight reception.

Phase 3: Argumentative Practice

Argumentative Practice followed data collection and organization. Students individually analyzed and interpreted the recorded data, revising their initial claims and reasoning as uncertainties evolved. Ms. Ellison prompted students to reflect on their claims and reasoning: "Have your thoughts changed? What are your new uncertainties?" Group members shared their ideas and collaboratively developed a revised group claim and reasoning. These revisions were then documented on the board. Each group presented on their chosen topics, investigation procedures, data summaries, and claims supported by evidence (see Figure 3). Other groups actively listened, compared their ideas, asked questions, and provided critique and feedback during the presentations. To facilitate a safe and active whole-class discussion, students were provided with sentence-starters (see Figure 4).

During the group presentations, Ms. Ellison facilitated a whole-class discussion focusing on conflicting claims or incoherent data patterns among different groups with the same investigation topic. She raised student uncertainties and encouraged them to reflect on the differences and explore ways to resolve the gaps. For example, two groups investigating the shading effect made different observations and claims. Group 3 argued that the fan gradually slowed down as they covered different portions of the solar panel horizontally, while Group 4 claimed the fan stopped spinning when they covered a vertical portion of the panel. Ms. Ellison highlighted these differences and requested elaborations on their procedures: "Group 3, where did you cover the solar panel and what were the results? Could you demonstrate on the screen where you covered for each trial?" She then inquired, "And what about Group 4? Can you show us where you covered?" Given the similarities and differences in the procedures and results, she used an Uncertainty Scale to prompt students to self-assess their level of uncertainty: "Were Groups 3 and 4 similar or different? It seems that we are still hesitant about this" and "So, on the Uncertainty Scale, how many of you are uncertain about whether the placement of the solar panel cover might have an impact?|" She then decided to dedicate another day to address students' curiosity. As such, the whole-class discussion revolved around student uncertainties and curiosities.

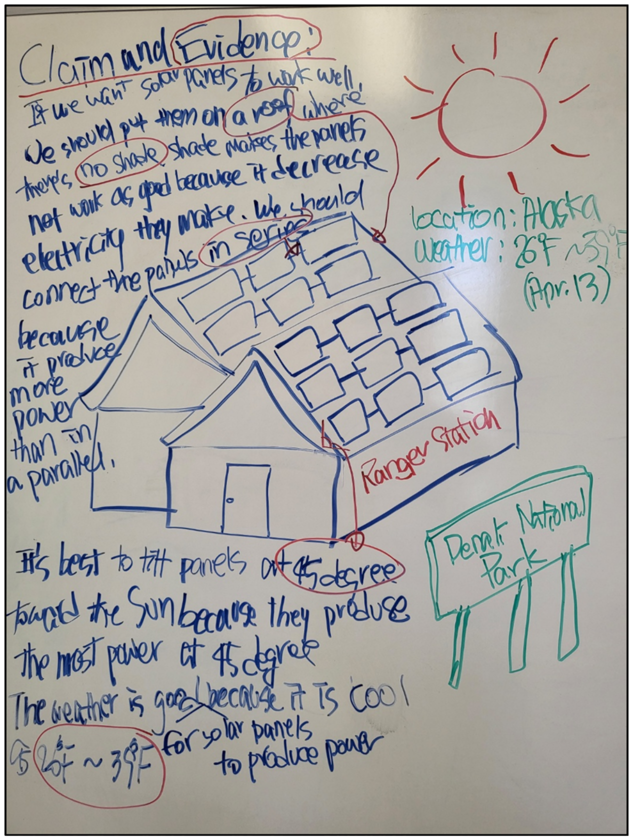
FIGURE 4: Sentence-starters for whole-group discussion. Different colors are used to indicate the various functions of each sentence in scaffolding argumentative sentence structures. Green is used for sharing one's ideas, yellow for adding or expressing agreement or disagreement with others' ideas, and pink for asking for elaborations from others.



Phase 4: Reflection, application, and transformation

On the final day of the unit, the class reviewed their group presentations and revisited the three

FIGURE 5: A group solution on powering a ranger station in Denali National Park.



investigated topics. Ms. Ellison facilitated a discussion to connect their findings with the core ideas of angle, temperature, and shading effects on solar panel power production. She particularly focused on the topic of shading, addressing a previous lingering uncertainty. To deepen the discussion, she prompted students' prior knowledge about series and parallel circuits: "What are the differences between series and parallel? What happens when we disconnect a battery in series or parallel?" This led to considering the circuit design of the solar panel the groups had used and sparked new uncertainties and curiosity. Each group drew and shared their proposed solar panel circuit design. The class then discussed the reasons behind the differences observed when gradually shading the panel horizontally or vertically.

After discussing the core ideas, the class applied their new understanding to solve the problem of powering a ranger station in Denali National Park within the Arctic Circle. Based on their understanding, students individually brainstormed the most satisfying solution given the criteria and constraints, then shared and discussed their ideas within their groups to determine the best group solution. Each group made claims supported by evidence and visually depicted their solution on the board. Group presentations were conducted to share the solutions. An example of a group solution is as follows: "To optimize solar panel efficiency, they should be installed at a high location free from shading. Shaded areas require a parallel circuit, while unshaded areas benefit from a series circuit. Panel orientation and angle should be adjusted to face the sun at a 45° angle. The climate conditions in Denali National Park are favorable for the solar panel system" (see Figure 5), which also shows another solution from another student group.

Classroom management and differentiation strategy

In the SUPeR lessons, creating an open and safe space for whole-class and small-group discussions is a key to fostering students' curiosity while managing their uncertainties. The first and the most crucial step for implementing a SUPeR unit is to give an explicit introduction about recognizing, acknowledging, and managing one's uncertainties during science learning. For example, before implementing the SUPeR unit, Ms. Ellison and her students discussed what uncertainties mean for them in science learning, why uncertainties are important for learning, how we can communicate them to peers or a teacher, and how we can support others' uncertainties collaboratively. Through the discussion, Ms. Ellison fostered students' shared understanding about and positive orientation toward managing uncertainties, such as "Uncertainty is a sign that we are learning. If you are uncertain, your friends are also uncertain and even I am uncertain too. We can learn more if you share your uncertainties," and "If you share your uncertainties, it sparks your group members' curiosity and mine as well."

In addition to the introductory discussion on uncertainty management, other types of scaffolding, such as sentence starters (as seen in Figure 4) or turn-taking ball (or stick), can be useful in managing classroom participation. While the sentence starters are generally helpful for students to shape their communication in a respectful form, they can be especially beneficial for English language learners who often struggle in communicating their uncertainties and curiosities. The turn-taking ball can be effectively used to manage classroom discussion, ensuring fair and even participation in whole-class or small-group discussions. Adaptations using balls, sticks, or cards of different colors (blue, green, purple, etc.) can be implemented to further scaffold students' discussions by signaling their expression of uncertainty, curiosity, or (dis)agreement (see the SUPeR rubric for four dimensions in Supplemental Materials). See also the *Next Generation Science Standards* chart for a summary of the alignment between the one-week solar energy unit, implemented using the SUPeR approach, and the *NGSS* chart in Supplemental Materials.

Conclusion

Managing student uncertainty to support curiosity is both challenging and essential for fostering student learning through scientific practices. The instructional guidance and strategies provided by the SUPeR approach, as introduced and illustrated in this article, can assist teachers in creating engaging and student-centered science classrooms where student uncertainty and curiosity drive the entire process of scientific practices. By understanding how student uncertainty manifests in each phase and influences the overall trajectory of learning, teachers gain valuable insights into when and how to effectively manage uncertainty to better support student curiosity. It is important to note that because the SUPeR approach provides domain-general teaching principles and design guidelines, it can be applied to any scientific domain in middle school science classes, positioning student curiosity as the starting point for scientific practices. •

SUPPLEMENTARY MATERIALS

SUPeR rubric for four dimensions

NGSS chart

Group board and individual worksheet

Supplemental data for this article can be accessed at https://doi.org/10.1080/08872376.2024.2433363

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Mandy Heal is a biology teacher at Mountain View High School in Mesa, Arizona. **Jongchan Park** (*jpark366@asu.edu*) is a grad research assistant, **Ying-Chih Chen** is an associate professor, and **Michelle E. Jordan** is an associate professor, all at the Mary Lou Fulton Teachers College at Arizona State University in Tempe.