STUDENT UNCERTAINTY AS A PEDAGOGICAL RESOURCE (SUPeR):

Using the SUPeR Approach to Investigate Electromagnetic Force

BY JAMIE RAPKIEWCZ, JONGCHAN PARK, YING-CHIH CHEN, AND MICHELLE E. JORDAN

As suggested in *A Framework for K–12 Science Education* (National Research Council 2012), "Scientific knowledge is a particular kind of knowledge with its own sources, justifications, ways of dealing with uncertainties . . . and agreed-on levels of certainty" (p. 251). That is, whenever scientists develop scientific knowledge, they must wrestle with a certain degree of uncertainty stemming from multiple sources, such as insufficient information, ambiguous experiment results, and incoherent or conflicting data patterns (Chen and Qiao 2019; Park et al. 2022). It follows that for students, learning science should involve coming to understand the nature of scientific knowledge and its development through opportunities to struggle with uncertainties (Chen 2022; Falk and Brodsky 2013). Such opportunities are best generated through engagement in science practices during project-based learning (PBL) because PBL requires students to identify a problem through a target phenomenon, seek coherent understandings or solutions, and apply the new understanding to complete the project. All these processes entail the navigation of scientific uncertainties.

This raises a practical pedagogical issue of how teachers can incorporate and support the management of students' scientific uncertainties for productive struggle in PBL (Park et al. 2022). That is, how can teachers incorporate and support students to navigate their scientific uncertainties to make sense of scientific phenomena when they engage in PBL?

This article introduces an approach called Student Uncertainty as a Pedagogical Resource (SUPeR) that can help teachers prepare for, respond to, and productively manage scientific uncertainties to develop students' scientific knowledge through PBL. A two-week PBL unit from a seventh-grade science class, focusing on a study of electromagnetism integrating solar energy, is described to illustrate how the SUPeR approach can be applied in science classrooms.

The SUPeR approach

In the SUPeR approach, student scientific uncertainties play key roles in designing lessons and drive the process of

student sensemaking related to a natural phenomenon. Various sources can give rise to scientific uncertainty during student learning; for example, insufficient prior knowledge about the topic, ambiguous information and instructions, and incoherent and/or conflicting understanding of learning concepts can make students uncertain.

Thus, it is crucial for teachers to help students productively manage their scientific uncertainties to construct scientific knowledge (Watkins and Manz 2022). In this regard, the SUPeR approach offers a framework for teachers so that they can take specific actions to incorporate and/or reduce student scientific uncertainties to facilitate students' navigation of their uncertainties. The SUPeR approach consists of four phases and suggests key elements of instruction and learning for each phase (see Table 1 for detailed guidance of the SUPeR approach): problematizing a phenomenon; material practice; argumentative practice; and reflection, transformation, and application.

The SUPeR approach in a seventh-grade electromagnetism unit

Here, a seventh-grade PBL unit on electromagnetism that took place over two weeks is described to illustrate how the SUPeR approach works. The unit addressed the *NGSS* standard MS-PS2 Motion and Stability: Forces and Interactions, with an emphasis on MS-PS2-3 (ask questions about data to determine the factors that affect the strength of electric and magnetic forces). It was designed to teach the disciplinary core idea of PS2.B Types of Interactions, promote an understanding of crosscutting concepts of Cause and Effect (with secondary emphases on Systems and System Models), and engage students in asking questions and defining problems, among other scientific and engineering practices (NGSS Lead States 2013). Through this project, students were expected to learn two objectives: (a) how electromagnetic force is produced using solar panels, and (b) what influences the degree of electromagnetic force. As a project challenge, students were required to build the most powerful electromagnetic crane possible. In a previous unit, the students had explored (a) solar as a sustainable energy source, (b) how solar panels generate electricity, and (c) what influences the efficiency of electricity generated from solar panels. Therefore, in this electromagnetism unit, students already had knowledge of solar panels.

Phase 1: Problematize a phenomenon

During the first phase of the SUPeR approach, an anchoring phenomenon is problematized to raise student scientific uncertainties in the form of curiosity, wondering, and/or doubt; anchor further learning processes; and elicit productive struggle (Achieve 2017; Suárez, 2020). In the beginning of the electromagnetism unit, the teacher asked students to discuss how a crane can move recyclable scrap metal at salvage yards (Figure 1). Then, the phenomenon was problematized by the teacher introducing the electromagnetic crane project focusing on two learning goals: how to generate

CONTENT AREA

Physics

GRADE LEVEL

6–8

BIG IDEA/UNIT

Electromagnetic force, solar energy

ESSENTIAL PRE-EXISTING KNOWLEDGE

Electric circuit, magnetic force

TIME REQUIRED

Five 55-minute class periods

COST

~$500

SAFETY

Safety gloves and glasses when working on electric circuits; careful use of sharp copper wire

TABLE 1: Detailed guidance for the SUPeR approach.

Goals to guide teachers	Questions to guide students
Phase 1: Problematize a phenomenon	
1. Explore a phenomenon and identify students' knowledge gaps and curiosities. 2. 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	***Design:*** What investigation can I design to address my questions? ***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. Generate 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?

electromagnetic force and how to increase size of the force using solar panels (or batteries) as sources of power (Figure 1). To help students recognize and focus on their scientific uncertainties, several possible variables related to the phenomenon were discussed to be explored: (a) the number of solar panels (or batteries), (b) the number of wraps of copper wire around a nail (Figure 2), and (c) the distance between interacting objects. Students were asked to share their uncertainties about the phenomenon during a whole-class discussion. As the term *uncertainty* was unfamiliar to the students, it was reformulated as follows: "What are you confused about? What are you wondering about? What are you curious about?

What do you want to explore more?" Following the discussion, students were prompted to generate one or more questions they would like to investigate to address their uncertainties. They were then instructed to communicate their questions using sticky notes (Figure 2).

At the end of Phase 1, the teacher briefly surveyed students' degree of perceived uncertainty scaled by a number of fingers (see Figure 3). Each degree of uncertainty was rephrased to enhance students' understanding of the scale as shown in Figure 3 (e.g., The "highly uncertain" rating of 4 indicates a stage where their uncertainties are significant enough to "start their learning process," but not so overwhelming as to result in "their brain being not open," as represented by the rating of 5 on the scale). This brief survey was then used in all the other phases as well. It was helpful in that the teacher could easily monitor students' uncertainty status, and the students had opportunities to self-evaluate and reflect on the degree of their perceived uncertainties as they evolved across the project.

FIGURE 1: Introduction of the phenomenon (the electromagnetic crane project).

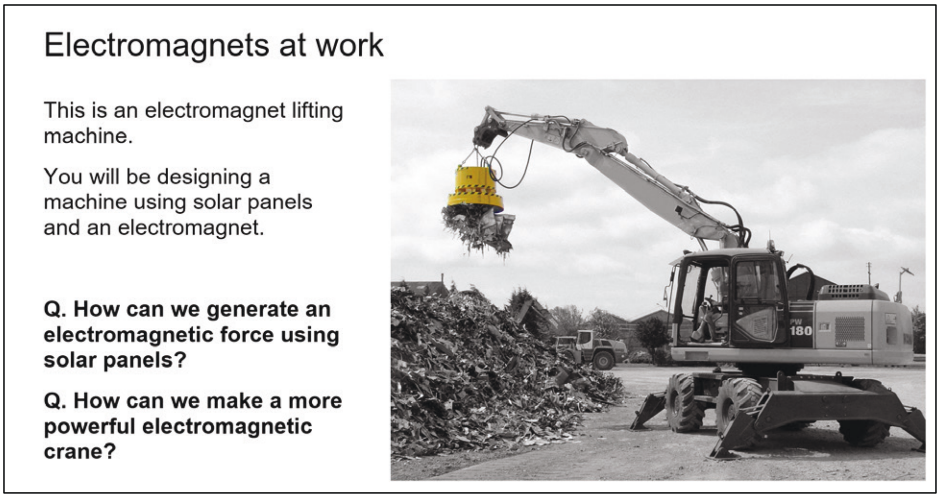
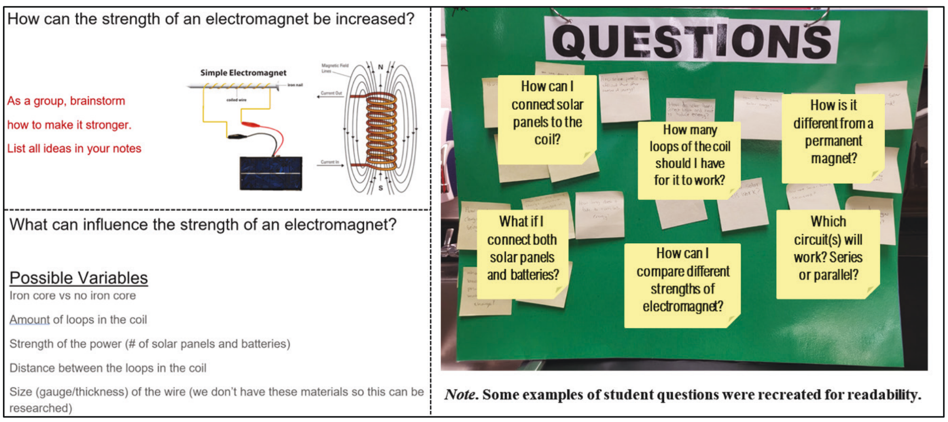
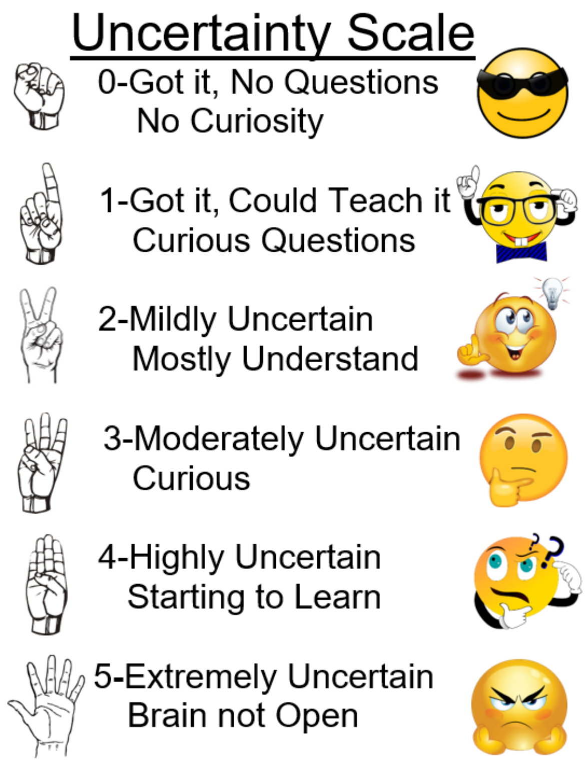


FIGURE 2: Problematization: Elicited key aspects of (left) and student-generated questions about (right) the crane phenomenon.



Note. Some examples of student questions were recreated for readability.

FIGURE 3: A brief uncertainty survey using fingers to indicate the degree of uncertainty.



Phase 2: SUPeR material practice

The main purpose of Phase 2 of the SUPeR approach—material practice—is to engage students in a hands-on activity to address their scientific uncertainties that were raised in Phase 1. Students are first required to plan their investigations based on possible variables that they are uncertain about related to the phenomenon. Then, they carry out their investigation plans and generate data they can use to test their initial ideas or assumptions regarding the elicited scientific uncertainties. They may create tables, graphs, or diagrams to organize their data.

In this class, students were given a set of equipment that included an electromagnetic crane kit (perpendicular blocks, dowel, hole plate, etc.), two solar panels (Max. 460mA, 1.5V), a five-meter-long copper coil, 15 alligator clip wires, three 1.5 V batteries and battery holders, a 50 mm screw, and several alligator clips. A set of tools for measuring electrical output (a multimeter) and variables that impact solar panel efficiency (a temperature gun and illuminance light meter) were also provided to students (Figure 4).

Students were asked to design and build an electromagnetic crane, plan investigations to explore possible variables that may influence the sizes of electromagnetic force, and improve their crane design to strengthen the force. Figure 5 shows an example of student-generated investigation plans.

Each group had freedom to explore different crane designs and manipulate different variables (e.g., the number of solar panels or batteries, the number of wraps of copper wire around a nail) as they enacted the experiments they had planned based on their uncertainties. The teacher moved among groups, observing their investigation process and supporting students to navigate through their uncertainties. The teacher encouraged them to maintain, expand, or revise their uncertainties along the way to support productive struggle and tune their understanding of core ideas related to the phenomenon of electromagnetism. On the basis of their evolving uncertainties, students revised and tested their prototypes, devising further experiments when necessary. Students completed a data collection form as they conducted multiple rounds of investigation with teacher support (see student work sample of group data collection in Supplemental Materials).

Phase 3: SUPeR argumentative practice

The argumentative practice phase aims to engage students in analyzing and interpreting data and constructing plausible arguments for their investigation questions so they can resolve their uncertainties (Chen, Benus, and Hernandez 2019). Thus, students' arguments should include *claims* that address their scientific uncertainties and *evidence* derived from their interpretations of collected data.

Once each group finished their crane investigations and organized their collected data, they were required to construct individual and group arguments that could resolve their uncertainties by analyzing and interpreting data. Students were asked first to create individual explanations of what they had investigated, then to share their ideas with and give feedback to group members as well as other

FIGURE 4: A set of experimental kits and measurement tools

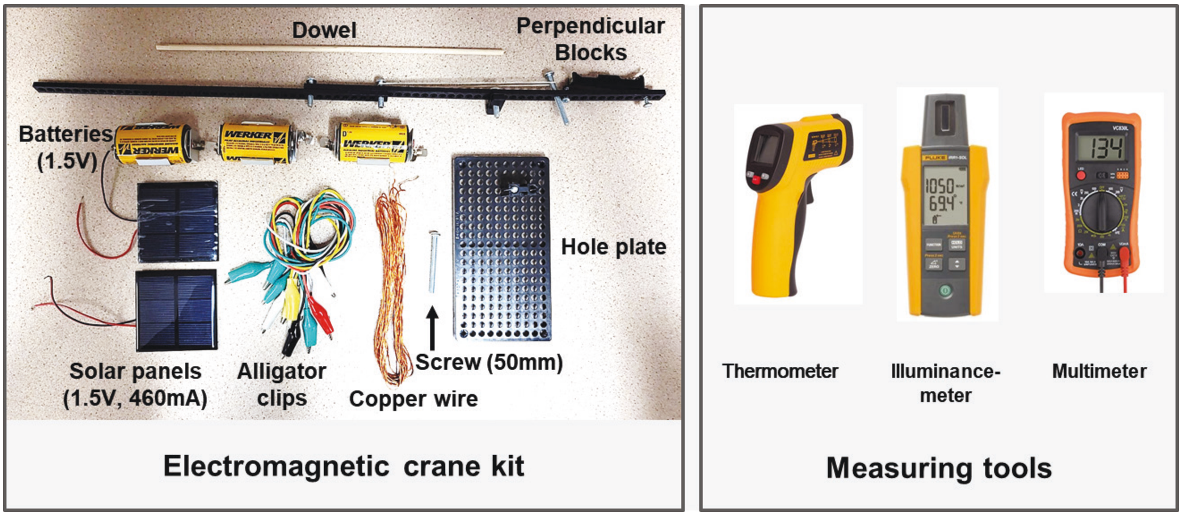
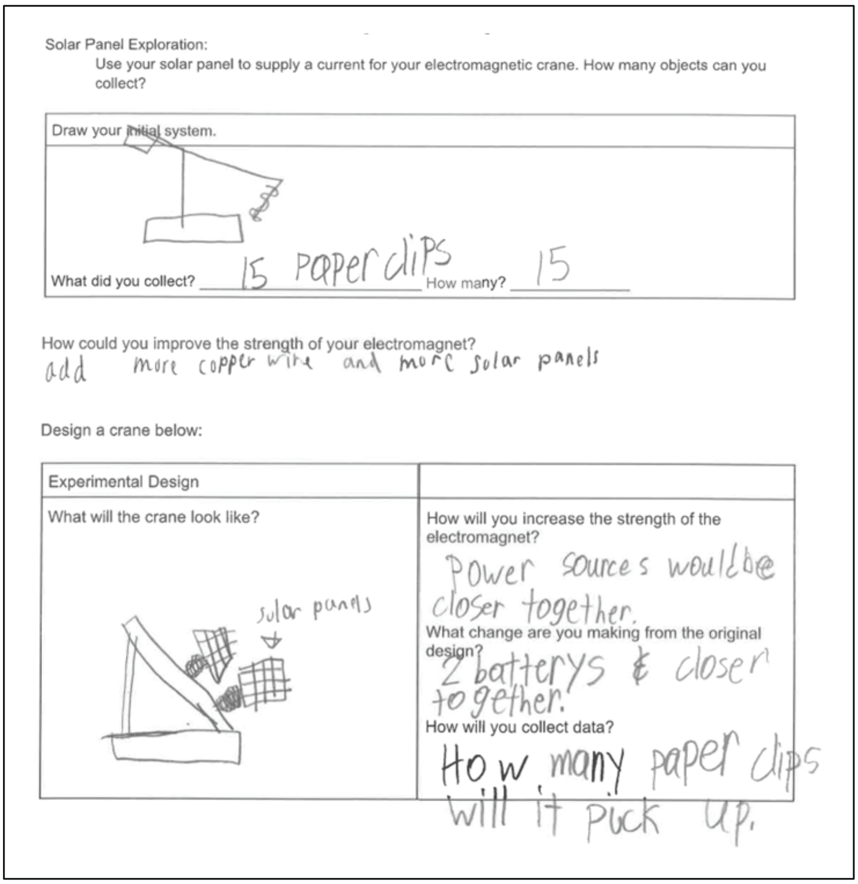


FIGURE 5: An example of a group plan for their investigations of the electromagnetic crane.


Solar Panel Exploration:
Use your solar panel to supply a current for your electromagnetic crane. How many objects can you collect?

Draw your initial system.

What did you collect? 15 paper clips How many? 15

How could you improve the strength of your electromagnet?
add more copper wire and more solar panels

Design a crane below:

Experimental Design	
What will the crane look like? (solar panels)	How will you increase the strength of the electromagnet? Power sources would be closer together. What change are you making from the original design? 2 batterys & closer together. How will you collect data? How many paper clips will it pick up.

groups, and finally to construct final arguments incorporating other students' ideas and feedback. See the flow of argumentative practice and examples of student arguments in Supplemental Materials.

A set of sentence starters were provided to students to facilitate individual and collective argumentative practices (see individual and collective argumentative practices in Supplemental Materials). In this phase, students had opportunities to resolve their uncertainties through scientific argumentation. New and revised uncertainties emerged as students collectively discussed their ideas (e.g., "I'm wondering, what if you also reduce the number of wraps of copper wire when you're testing it with two solar panels?"). The new raised uncertainties became resources to advance student understanding about what influences the size of electromagnetic force.

Phase 4: Reflection, transformation, and application

Scientific uncertainties are not static but changing, evolving, and transforming (Jordan and McDaniel 2014). Scientific uncertainties throughout a scientific investigation may also be varying, revised, and evolving as students continuously work through their uncertainties. Thus, the last phase of the SUPeR approach is designed to give students opportunities to reflect on what they have done regarding their uncertainties in earlier phases, transforming as well as applying their newly obtained understandings to address other aspects of the phenomenon and expanding to other related phenomena about which they are uncertain.

As a last activity of this unit, the teacher facilitated a whole-classroom discussion, asking students to share how their ideas and uncertainties about electromagnetic forces had changed across the unit. They were also introduced to and asked to explain a related phenomenon, a flapping toy that uses electromagnetic force powered by solar energy (see Supplemental Materials), based on their newly gained understandings.

Classroom management and safety tips

Each phase of the SUPeR approach usually requires one or two class periods. However, during material practice, it is advised to ensure at least two whole-class periods: one for building a crane and one for testing and revising prototypes. Additionally, one extra class period might be needed for material practice depending on issues that emerge during prototype testing and troubleshooting revisions.

In terms of grouping, teams consisting of three to four members are recommended for this collaborative project. This grouping will help students to (a) collaboratively design and build their cranes, (b) measure variables (e.g., voltage, temperature, and/or time) while manipulating the corresponding parts of the prototype, and (c) share ideas to revise and improve their prototypes.

For safety, students should wear safety gloves and glasses throughout their investigation. They should be advised to be careful when they are using sharp copper wires. Also, electric circuits including batteries and solar panels should be kept away from water and disconnected when not in use. Between the first and second days of the material practice, students' working prototypes should be placed away from their desks and sinks to avoid potential safety risks.

Formative assessment

Besides self-evaluations on their perceived uncertainties throughout four phases, the teacher also assessed the overall SUPeR project regarding their investigations, data analysis, and argumentation, as well as their understanding of electromagnetic forces. The assessment was conducted primarily based on students' worksheets. However, careful observation of students' discourse during group talk and/or answering teacher's questions were also considered for formative assessment especially for students who had difficulty with writing. A set of questions for formative assessments included: "Why did you choose to measure voltage and temperature three times?", "What aspects of your plan are you still uncertain about?", "Why do you think the results of your experiment support your claim?", "Why did you use three 1.5V batteries in addition to two solar panels to power your crane?", and "What have you learned from this investigation?" A rubric was used during the assessment (see Supplemental Materials).

Conclusion

The SUPeR approach was created to help teachers design lessons using scientific uncertainties as a pedagogical resource for student sensemaking. The illustrated four phases of the SUPeR approach are cyclical and iterative. Teachers and students can move back and forth between the phases depending on the structures of the unit design or spontaneous needs as the unit unfolds. For example, in the case of the electromagnetism unit, if students are not familiar with and have uncertainties about how solar panels generate electricity, the beginning phase after the project is introduced can focus on understanding solar energy instead of problematizing the phenomenon of electromagnetic cranes. Other prerequisite disciplinary core ideas that any particular student group lacks (e.g., forces, magnets, series and parallel circuit) can also be explored with an initial round of SUPeR problematization of different phenomena interspersed with any of the other three phases. It is important to note that students' scientific uncertainties play critical roles in determining what phases they are engaged with, which aspects of the phenomenon are featured, and what activities are needed for each phase.

The SUPeR approach can guide teachers to design science units that incorporate all three dimensions of the *Next Generation Science Standards* (NGSS Lead States 2013). The experience students have in lessons using the SUPeR approach can also directly or indirectly guide their understandings that scientific uncertainties are not impediments that should be removed immediately, and that struggling with uncertainties can productively drive their knowledge development in science.

REFERENCES

Achieve. 2017. *Using phenomena in NGSS-designed lessons and units*. Washington, DC: Achieve.

Chen, Y.-C. 2022. Epistemic uncertainty and the support of productive struggle during scientific modeling for knowledge co-development. *Journal of Research in Science Teaching* 59 (3): 383–422.

Chen, Y.-C., M.J. Benus, and J. Hernandez. 2019. Managing uncertainty in scientific argumentation. *Science Education* 103 (5): 1235–1276.

Chen, Y.-C., and X. Qiao. 2020. Using students' epistemic uncertainty as a pedagogical resource to develop knowledge in argumentation. *International Journal of Science Education* 42 (13): 2145–2180.

Falk, A., and L. Brodsky. 2013. Incorporating models into science teaching to meet the Next Generation Science Standards. *Science Scope* 37 (1): 61–69.

Jordan, M. E., and R.R. McDaniel, Jr. 2014. Managing uncertainty during collaborative problem solving in elementary school teams: The role of peer influence in robotics engineering activity. *Journal of the Learning Sciences* 23 (4): 490–536.

National Research Council. 2012. *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.

NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states*. Washington, DC: National Academies Press.

Park, J., E. Starrett, Y.-C. Chen, and M.E. Jordan. 2022. *Facilitating productive struggle in science education: The possible benefits of managing scientific uncertainty during sensemaking*. In *Proceedings of the 16th International Conference of the Learning Sciences–ICLS* 2022, eds. C. Chinn, E. Tan, C. Chan, and Y. Kali, 1117–1120. Hiroshima, Japan: International Society of the Learning Sciences.

Suárez, E. 2020. "Estoy Explorando Science": Emergent bilingual students problematizing electrical phenomena through translanguaging. *Science Education* 104 (5): 791–826.

Watkins, J., and E. Manz. 2022. Characterizing pedagogical decision points in sense-making conversations motivated by scientific uncertainty. *Science Education* 106 (6): 1408–1441.

SUPPLEMENTAL MATERIALS

Student work sample of group data collection—*https://tinyurl.com/ykmfefzz*

Individual and collective argumentative practices—*https://tinyurl.com/46fzxnmt*

Flapping toy using electromagnetic force and solar panels—*https://tinyurl.com/2asds94r*

Flow of argumentative practice and examples of student arguments—*https://tinyurl.com/35tka37s*

Rubric to assess the SUPeR project—*https://tinyurl.com/yvxhwxpc*

Connecting to the *Next Generation Science Standards*—*https://tinyurl.com/3j5f8jz8*

Jamie Rapkiewcz is a science teacher at Stapley Junior High School in Mesa, Arizona. **Jongchan Park** (*jpark366@asu.edu*) is a graduate research assistant, **Ying-Chih Chen** is an associate professor, and **Michelle E. Jordan** is an associate professor, all in