FEATURE ARTICLE

Using Student Uncertainty as a Pedagogical Resource (SUPeR) Approach to Support Students' Productive Struggle in the Biology Classroom

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Abstract

Productive struggle is a process in which students expend effort to grapple with perplexing problems and make sense of something that is not immediately apparent and beyond their current level of understanding and capacity. The experience encourages students to reflect on and restructure their existing knowledge toward a new understanding of scientific concepts and practice. Scientific uncertainty is common in scientific sensemaking practice and is one of the major factors provoking student struggle. A teaching approach called Student Uncertainty as a Pedagogical Resource (SUPeR) is introduced to encourage teachers to engage students in the practice of productive struggle. The SUPeR approach is composed of four phases: (1) problematize a phenomenon, (2) engage in material practice, (3) participate in argumentative practice, and (4) engage in reflection, transformation, and application. An example from an eighth-grade biology class unit on Mendel's Law of Segregation is used to demonstrate how the SUPeR approach can be implemented in the classroom.

Key Words: *Productive struggle; Scientific uncertainty; Inquiry; Teaching approach; Authentic Science.*

○ Introduction

Traditional teaching often emphasizes scientists' successes while neglecting their struggles in developing knowledge. This narrow perspective on scientific practice can lead students and teachers to believe that science follows a linear path toward a final product (Sagan & Druyan, 2011), rather than understanding it as an ongoing process involving grappling with phenomena, formulating tentative claims, conducting investigations, and interpreting data as evidence to refine those claims. As Nobel Prize winner Richard Feynman (2009) pointed out, "I do not want us to forget the importance of the struggle. . . . If you know that you are not sure, you have a chance to improve the situation" (p. 14). If students focus solely on memorizing the final outcomes of scientific knowledge and seeking correct answers to reach predetermined conclusions, we miss valuable opportunities for them to authentically engage in the practices of inquiry and struggle that are inherent to scientific exploration (Buxton, 2006; Chinn & Malhotra, 2002; Furtak & Penuel, 2019; Roth, 1995).

While the process of resolving scientific uncertainty enhances students' knowledge of a topic, it also develops their ability to navigate increasingly complex levels of uncertainty.

Struggle is essential to learning as it helps students develop persistence, tenacity, and the ability to pursue learning goals and potential solutions, leading to a robust understanding of content (Fries et al., 2021; Keen & Sevian, 2022; Warshauer, 2015). Productive struggle in the classroom is a process in which students attempt to make sense of concepts that are initially beyond their understanding, ultimately leading to deeper comprehension (Hiebert & Grows, 2007). However, unproductive struggles can also occur when students cease their exploration due to a lack of perceived value or necessity in the struggle for their learning tasks.

Uncertainty is a major factor contributing to scientists' struggles (Haskel-Ittah, 2023; Kampourakis & McCain, 2019; Kirch, 2010). While uncertainty drives scientific inquiry and knowledge advancement, incorporating uncertainty into classroom practices presents challenges for both teachers and students, as many are unfamiliar with how scientists manage uncertainty. This lack of familiarity becomes problematic when designing learning environments where students engage in scientific practices without considering how to support productive struggle with uncertainty (Manz & Suárez, 2018). Teachers often hesitate to address students' uncertainty and may seek to remove it from their pedagogical strategies and curriculum designs (Starrett et al., 2024). Students may experience anxiety and resistance when faced with open-ended problems and uncertainty. The prevailing attitude toward uncertainty tends to view it as a barrier to be overcome, rather than a potential resource for the learning

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process (Chen et al., 2019). Rarely do teachers or students perceive uncertainty as a valuable tool for learning.

We currently lack effective teaching approaches to guide teachers in utilizing student uncertainty as a pedagogical resource for productive struggle (Watkins & Manz, 2022). Consequently, teachers often struggle to conceptualize student uncertainty positively and fail to leverage uncertainty to support student learning (Starrett et al., 2024). In this article, we define scientific uncertainty within the framework of cognitive learning and differentiate between two important types: conceptual and epistemic uncertainties (Chen et al., 2024). Expanding upon this definition, we introduce an approach called "Student Uncertainty as a Pedagogical Resource (SUPeR)" to address these issues, illustrating how student scientific uncertainty plays a vital role throughout the inquiry process. We present an example from an eighth-grade classroom focusing on Genetics and Mendel's Law of Segregation. Although this example is specific to an eighth-grade lesson, the SUPeR approach is adaptable and beneficial across various grade levels, from kindergarten to high school.

○ Scientific Uncertainty and Struggle for Learning

Scientific uncertainty refers to situations in which individuals experience a subjective feeling of being unsure or lacking confidence in their scientific understanding of a particular phenomenon or the prediction of future outcomes (Chen et al., 2024; Lamnina & Chase, 2019). For example, students may lack confidence in how to apply their existing understanding to explain a phenomenon they encounter, determine what data to collect in response to a question, interpret data as evidence to support their claims, or draw reasonable conclusions based on evidence. Scientific uncertainty can lead to what Piaget (1972) termed "disequilibrium," where students confront inadequacies, ambiguities, inconsistencies, or conflicts between their understanding of a topic and its explanation.

The experience of scientific uncertainty often generates "struggles" (Warshauer, 2015) that prompt students to reassess their existing knowledge and devise solutions to resolve their scientific uncertainties. This experience underscores students' cognitive engagement in grappling with the substance of their struggles, including disciplinary connections between their ideas, prior knowledge, language, lived experience, and culture, as well as their cognitive processes (Chen et al., 2024). While the process of resolving scientific uncertainty enhances students' knowledge of a topic, it also develops their ability to navigate increasingly complex levels of uncertainty.

○ Two Types of Scientific Uncertainty: Conceptual and Epistemic

To assist teachers in managing scientific uncertainty more effectively, we categorize it into two types based on scientific understanding: conceptual and epistemic (Chen, 2024; Ha et al., 2024). Figure 1 illustrates the relationship between and definitions of scientific, conceptual, and epistemic uncertainties.

Conceptual uncertainty refers to students' subjective experience of feeling unsure or lacking confidence in their conceptual understanding of a topic or what they know. Conceptual understanding

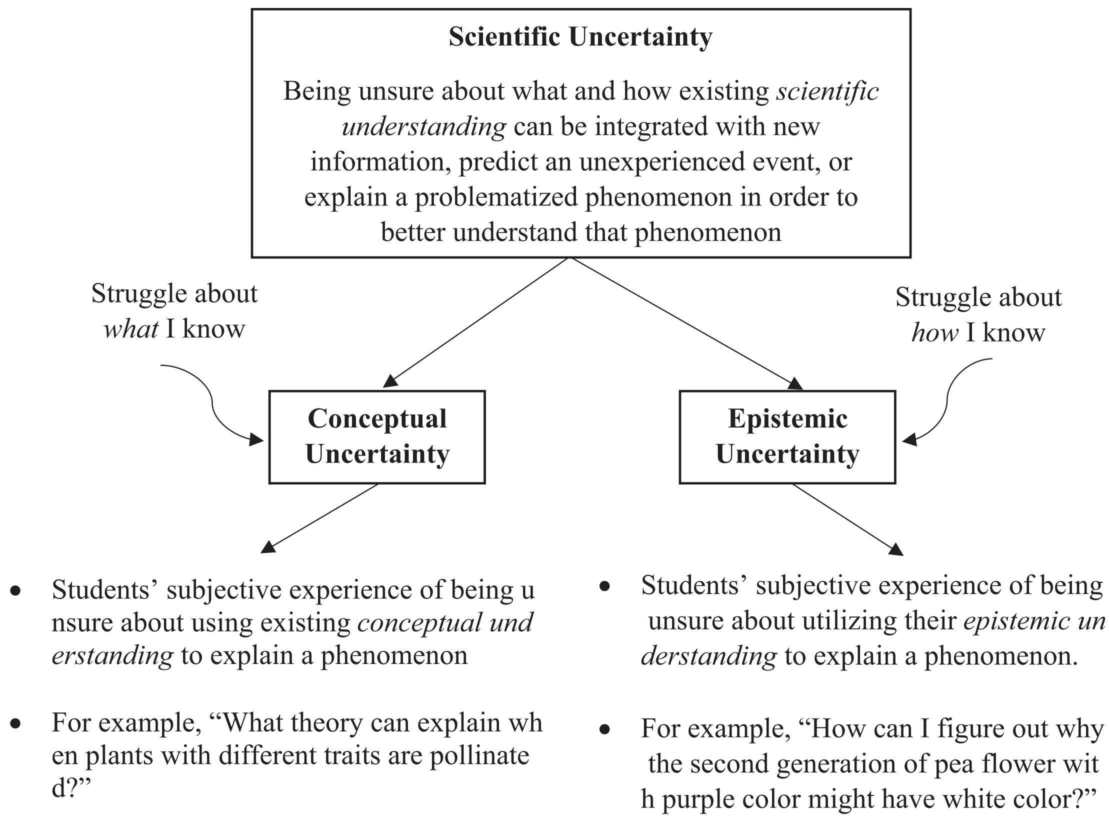


Figure 1. Two Types of Scientific Uncertainty: Conceptual and Epistemic.

encompasses mastery, comprehension, and practical grasp of both formal knowledge (e.g., knowledge acquired through schooling) and everyday knowledge (e.g., informal knowledge and common sense gained through daily experiences and observations) related to a particular topic. When explaining a phenomenon they encounter, students not only draw on content knowledge acquired from previous lessons but also rely on their everyday knowledge, as observed by Barton and Tan (2009), Silseth (2018), and Warren et al. (2001).

Epistemic uncertainty, on the other hand, refers to students' subjective experience of feeling unsure or lacking confidence in their epistemic understanding of a topic or how they know (Chen, 2022; Tiberghien et al., 2014). Perkins (1992) defined epistemic understanding as "know-how concerning justification and explanation in the subject matter" (p. 85). Expanding upon Perkins's concept, Shaffer (2006) defined epistemic understanding as a framework to guide students in understanding (a) how to initiate inquiries to unpack a phenomenon, (b) what constitutes appropriate claims and evidence for evaluation, (c) which methods to employ for gathering evidence to support a claim, and (d) how to make decisions or transition to different issues.

○ The SUPeR Approach

This article introduces *SUPeR* approach, which aims to immerse students in an environment that facilitates recognizing, exploring, and resolving scientific uncertainty while simultaneously practicing scientific literacy and learning science concepts (Chen & Jordan, 2024; Rapkiewcz et al., 2023). Through this approach, students not only learn scientific concepts but also gain insight into how scientists grapple with developing knowledge through scientific practices. The SUPeR approach consists of four phases: (1) problematizing a phenomenon, (2) material practice, (3) argumentative practice, and (4) reflection, transformation, and application (see Table 1). It is designed to assist science teachers in incorporating conceptual and epistemic uncertainties into their scientific inquiry lessons. Aligned with the three dimensions of the Next Generation Science Standards (NGSS Lead States, 2013), SUPeR functions as an inquiry approach with a procedure similar to other authentic inquiry approaches, such as the 5E model. However, the SUPeR approach explicitly emphasizes learning as a process of struggle and the use of student uncertainty to drive

Table 1. 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. Elicit an uncertainty and link it to the core concept.	*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? What are my wonderings?
Classroom Products	
1. Core concepts to develop 2. Variables to explore (e.g., dependent, independent) 3. Researchable and testable/solvable problems to address	
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?
Classroom Products	
1. Investigation design/procedures/prototype 2. Data set organized by different modalities (e.g., tables, figures, graphs, diagrams, pictures)	
Phase 3: Argumentative Practice	
1. Write and talk about students' interpretation of data and meaning of the results of testing/experiments, including ambiguous, unexpected, incoherent, or conflicting results 2. Generate multiple perspectives, seek convergent and collective 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?
Classroom Products	
1. Collective interpretation/consensus of the phenomenon 2. Recognize claims, understandings, processes that need clarification	

Continued

Table 1. *Continued*

Phase 4: Reflection, Application, and Transformation	
1. Think systemically, think beyond the system at hand, generalize 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?
Classroom Products	
1. Connection of the developed knowledge to theory (conceptually) 2. Application of the developed knowledge to make a prediction in a new situation (practically)	

Note. This table is adapted from Chen & Jordan (2024)

this process. This approach can be adapted to different grade levels, from kindergarten to high school. To illustrate how the SUPeR approach might function in a biology classroom, we describe an eighth-grade, one-week lesson in which students grapple with scientific uncertainty to learn genetics.

Phase 1, Problematizing a Phenomenon, begins with exploring an everyday phenomenon. Here, students draw on their prior understanding, everyday experiences, culture, and language to recognize the gap between what they know and what they do not know about it. Conceptual uncertainties typically arise from this gap, leading students to wrestle with their conceptual understanding (e.g., content and everyday knowledge) to explain the phenomenon (Ha et al., 2024). Epistemic uncertainty often stems from generating appropriate questions and determining how to narrow down the focus to important variables for further investigation.

Phase 2, Material Practice, focuses on assisting students in designing an investigation plan to seek solutions to questions raised in Phase 1. Conceptual uncertainty emerges as students struggle to use their prior conceptual understanding to guide the process. Epistemic uncertainties in this phase revolve around issues such as how to design an investigation, which data to collect, what information to search for, and how to organize and represent data (e.g., tables, figures, diagrams, pictures, and/or drawings).

Phase 3, Argumentative Practice, provides a space for students to write, read, and discuss their interpretation of the data to shape scientific evidence. Conceptual uncertainty in this phase prompts students to restructure and integrate empirical evidence, lived experience, and peer arguments to reinterpret the phenomenon. Epistemic uncertainties stem from students' struggles to interpret data as evidence to test their claims related to the guiding question.

Phase 4, Reflections, Transformation, and Application, engages students in reflecting on which uncertainties they have resolved, why some uncertainties remain, what new uncertainties have arisen, and how they can apply their new knowledge to everyday experiences. Conceptual uncertainty emerges as students struggle to generate and connect their agreed-upon arguments and consensus established in Phase 3 with scientific theory. Epistemic uncertainty results from students' struggles to extend their new understandings to new situations and to continuously define which methods and variables they can explore.

○ An Eighth-Grade Lesson on Genetics

The lesson presented here particularly focuses on Mendel's Law of Segregation, which states that individuals possess two alleles, and a parent passes only one allele to his or her offspring. The core concept of the lesson is that genes come in pairs and are inherited as distinct units, one from each parent. Stewart (1982) found that students often struggle to explain how meiotic division and segregation of chromosomes are related to their manipulation of symbols in Punnett squares. Although several inquiry activities introduce Mendel's Law of Segregation and Mendel's pea plants to teach genetic concepts, they are typically designed for high school (e.g., Cartier et al., 2006) or college level (e.g., Kudish, 2015) without explicitly framing students' scientific uncertainty as a pedagogical resource driving the struggle process. This article reframes the inquiry activity surrounding Mendel's pea plants around students' scientific uncertainty. We introduce how a science teacher framed scientific uncertainty as a pedagogical resource to drive the lesson on Mendel's Law at the middle school level.

Phase 1: Problematize a Phenomenon

The teacher began by introducing a picture of pea flowers taken from her garden in January. The picture showed that all pea flowers were purple (see Figure 2). The teacher explained that she used the seeds produced from these flowers or from another round of plants within the next four months. However, she did not obtain all purple flowers; instead, some were white, and some were purple. This phenomenon, stemming from the teacher's experience and related to students' lives, sparked students' curiosity about why white flowers appeared when the seeds came from purple flowers.

The teacher then asked additional questions to heighten students' uncertainty about this problematized phenomenon, eliciting responses and explanations to maintain uncertainty and stimulate further discussion on ideas, examination of experiences, and connections to prior knowledge and beliefs. Table 2 provides examples of how the teacher's questions raised student conceptual and epistemic uncertainties about the pea flowers.

Following a whole-class discussion, students were divided into groups of three or four to further explore their uncertainty about this phenomenon. Figure 3 depicts a worksheet designed to guide

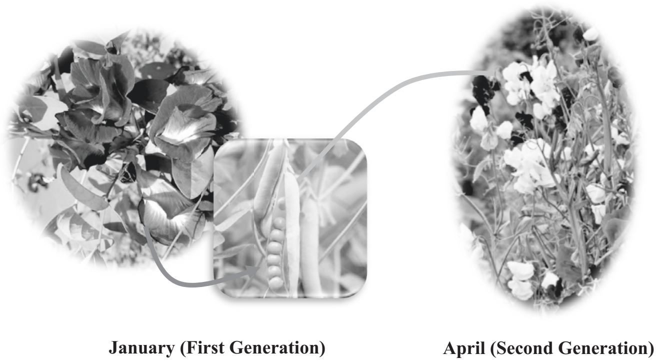


Figure 2. A Phenomenon Introduced in Phase 1.

Table 2. Teacher Questions to Raise Student Conceptual and Epistemic Uncertainty.

Type of uncertainty	Example questions
Conceptual	What is a trait? What is inherit? Why do pea plant flowers have different colors?
Epistemic	What are the possible reasons why the second generation of pea flower with purple color might have white color? What evidence can support your claims? What happens when we cross a purple flower with a white flower? How can we generate a testable question to guide the investigation? What methods can we employ to test the hypothesis? Why do you think that happened?

students in discussing, unpacking, and documenting their initial uncertainties. After group discussions, students had several questions and wonders. In this classroom, the teacher addressed questions generated by each group. Eventually, a testable question was formulated to guide further inquiry: What happens when plants with different traits are pollinated?

Phase 2: Material Practice

The teacher then initiated the next phase, termed "material practice" (Milne & Scantlebury, 2019; Tang, 2022), where she encouraged her students to engage in scientific investigation akin to those of a scientist, such as Gregor Mendel. At the outset of this phase, students were tasked with working in groups of three or four to formulate their initial claim regarding the testable question. During group work, students were prompted to reflect on their existing knowledge and uncertainties regarding the different traits of flowers and their reproductive processes. This facilitated the navigation of conceptual uncertainties surrounding the testable investigation question.

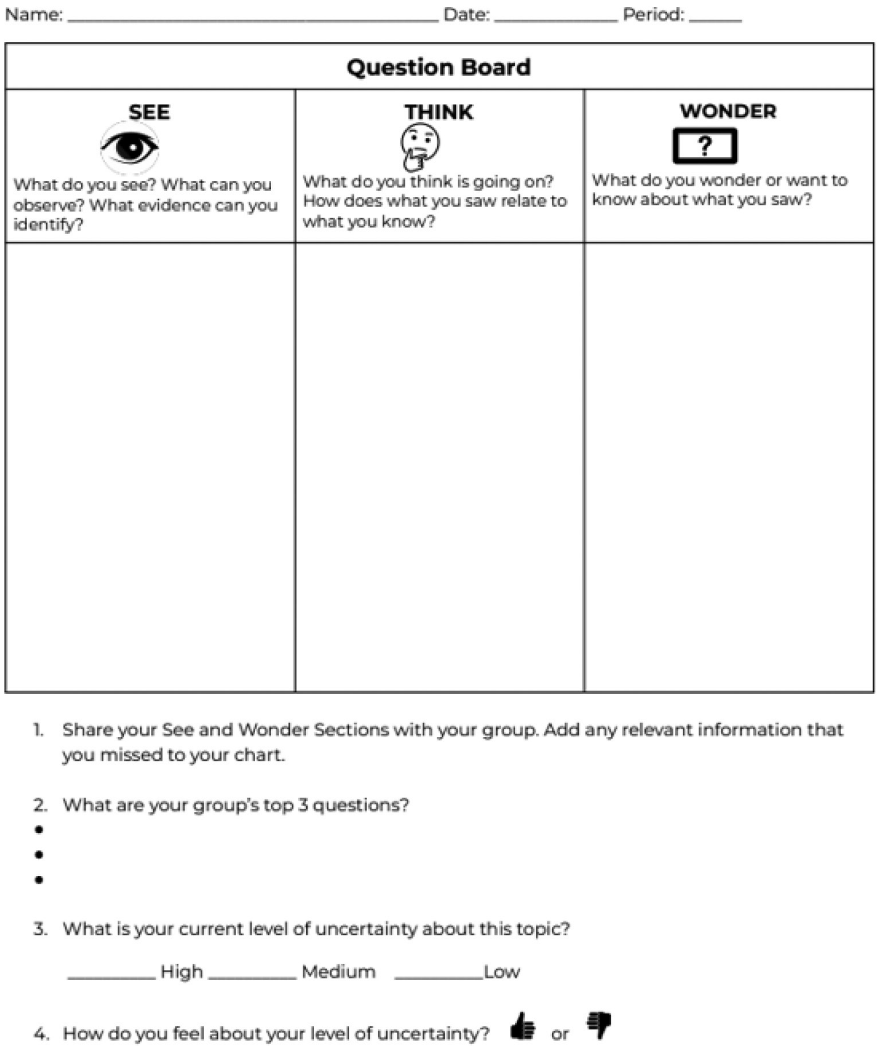
Once each group had established their claim, the teacher and students engaged in discussions on possible investigation designs, focusing on the pollination of pea flowers of different colors, purple and white, to potentially address the investigation question. As students grappled with designing their investigation, epistemic uncertainties emerged regarding how to devise feasible procedures, collect and analyze data, and ensure the validity and reliability of their investigations. The teacher aided students in navigating these epistemic uncertainties by posing questions such as these: "How would your investigation be structured? What procedures would you follow? How large of a sample size should we use? What type of data would you need, and how will you collect it? How many generations should we observe? How much time would you need to gather evidence for your claim?"

In response to these prompts, students recognized the time and space limitations of their investigation, realizing the need for months of observation and expansive, secure spaces to grow flowers. This realization aligned with the teacher's intention from the outset, as she had prepared an alternative method for conducting the material practice. This alternative approach allowed students to vicariously experience the gathering and organization of experimental data from Mendel's experiments. Materials for this vicarious investigation included worksheets for data organization and recording, as well as three envelopes containing sets of sample data from Mendel's experiments, such as photos of pea flowers from three consecutive generations (see Figure 4). Each envelope represented one generation, equating to two to three months of time. The teacher instructed students to follow the procedures outlined on the worksheet.

First, students were given data-organization worksheets and three envelopes containing photos of pea flowers of each generation. Then, students were asked to open the first envelope marked as "parental generation." It contained one purple and one white pea flower. Students placed them on the first row of a group worksheet. They were then encouraged to predict the second generation of pea flowers. The investigation question then became more specific in response to students' uncertainties about their predictions. Students were uncertain and curious about the question "What color would the second generation of pea flowers have?" Students' predictions varied as they discussed: "They might have something between purple and white, like lavender." "I guess it will be fifty-fifty. Half of them will be purple, and the other half will be white." Students were encouraged to organize their uncertainties and curiosities in the See-Think-Wonder section of their individual worksheet.

With the varying predictions elicited, the teacher then let students open the second envelope marked as "F1 Generation," which contained photos of four purple pea flowers. After students placed the photos on the second row of a group worksheet, they had brief discussions about why all flowers have the color purple, why there were no white pea flowers in this generation, and what color the third generation would have. This time, student uncertainties and curiosities varied more greatly: "Is a white flower a mutant?" "I wonder if the third generation would have all purple flowers again."

Lastly, students opened the last envelope marked as "F2 Generation" containing photos of three purple pea flowers and one white pea flower. After students organized all the photos on the group worksheet, the teacher asked students to analyze any pattern they noticed in the sample data and compare the sample data to what they had predicted (see Figure 5). The teacher specifically asked why



Name: ______________________________ Date: __________ Period: _____

Question Board		
SEE	**THINK**	**WONDER**
What do you see? What can you observe? What evidence can you identify?	What do you think is going on? How does what you saw relate to what you know?	What do you wonder or want to know about what you saw?

1. Share your See and Wonder Sections with your group. Add any relevant information that you missed to your chart.
2. What are your group's top 3 questions?
   -
   -
   -
3. What is your current level of uncertainty about this topic?

   ________ High ________ Medium ________Low
4. How do you feel about your level of uncertainty? or

Figure 3. A Worksheet to Guide Students to Unpack Their Uncertainties.

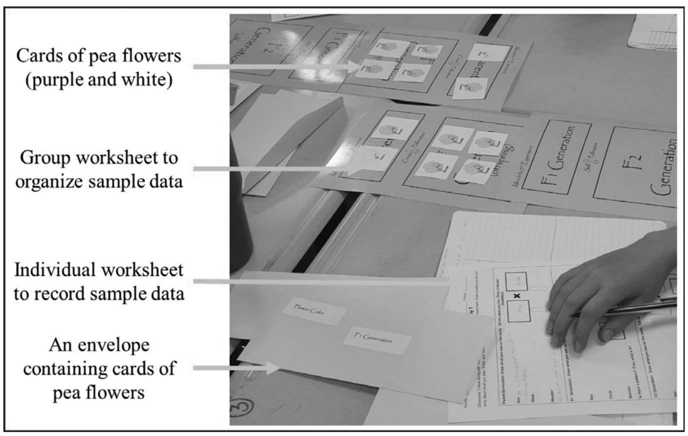


Figure 4. Materials for Simulating Mendel's Experiments.

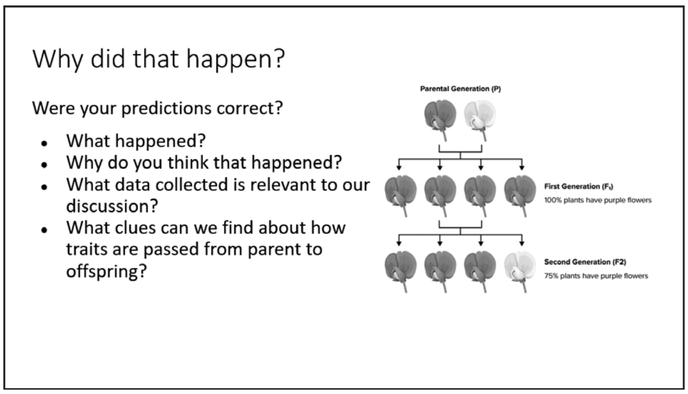


Figure 5. A Lesson Slide for Data Analysis in Simulating Mendel's Experiment.

there was one white pea flower in the F2 generation even though there was no white pea flower in their parents, in other words, the F1 generation. This time, the investigation question evolved: "In F1, why were the same color (i.e., purple) flowers reproduced from parents with different traits, whereas one-fourth of the flowers in F2 were a different color from their same-trait parents?" These questions helped students to analyze what they have observed and be prepared for the next phase, Argumentative Practice.

Phase 3: Argumentative Practice

In this phase, students have opportunities to practice constructing arguments about the evolved question: "Why were the same color (i.e., purple) flowers reproduced from parents with different traits, whereas one-fourth of the flowers in F2 were a different color from their same-trait parents?" Each group works together to support their claims with evidence they observed and collected during the previous phase. Students are allowed to use verbal and visual representations in constructing their arguments. A sample group answer is shown in Figure 6.

Once the group argument sharing is complete, the teacher prompts students: "So, all of you agreed that the white flower in G3 might have inherited its trait from the grandparent (G1). But how? How did the white flower get the white color while the others got purple? How can we explain it?" This question raises both epistemic and content uncertainties. Students struggle with using the collected data to answer the prompt as well as recalling relevant previous conceptual understanding.

To support students in addressing these scientific uncertainties, the teacher offers content information about Punnett squares, dominant and recessive traits, and phenotype and genotype. Students are informed of how Punnett squares can be used to represent dominant and recessive traits, and the phenotype and genotype of each generation. With this additional information, the teacher asks students to use Punnett squares to revise their arguments. As a result, each group generates their revised arguments. As can be seen in Figure 7, group arguments become conceptually more

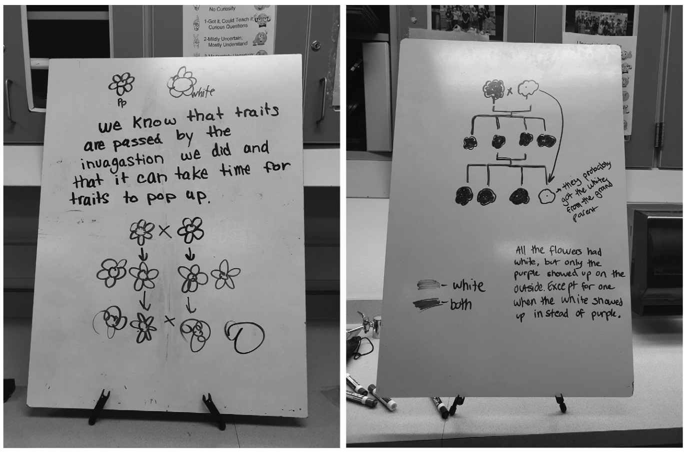


Figure 6. Group Arguments Using Diagram and Written Explanations.

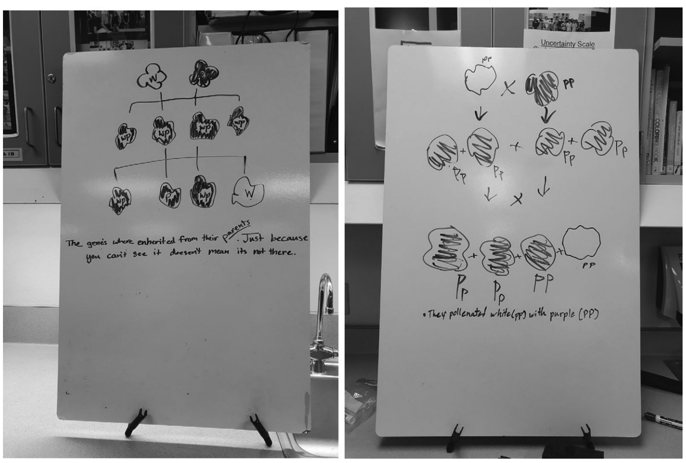


Figure 7. Revised Group Arguments Using Punnett Square.

sophisticated, with more information on each generation added (e.g., Punnett square "Pp" indicating genotype, and the color purple indicating phenotype).

In this phase, students had opportunities to share their arguments with the whole class. To support students effectively and productively engage in discussing their uncertainties, ideas, and arguments, argumentative cues were provided for students to enhance their communication skills (see Table 3). Studies have suggested that cues significantly impact the types and quality of student discussion (Cavagnetto & Kurtz, 2016; Knight et al., 2015). The argumentative cue consists of four components: express, comprehend, critique, and construct.

Express refers to students' actions to convey their uncertainties, ideas, and opinions to peers. To engage in productive expression, students were encouraged and guided to articulate their voices supported with evidence. *Comprehend* refers to students' attempts to mentally grasp and understand peers' voices and help peers explore their uncertainties. *Critique* refers to students' efforts to evaluate and judge peers' ideas when they may have different interpretations of the same data or phenomenon. Critique may create a space to raise and maintain uncertainty because students may have different explanations. The purpose of critique does not aim to decide who wins the argument, but to try to understand the differences and weaknesses of each explanation, eventually establishing a better understanding. *Construct* refers to students' collaboration in building a collective understanding and consensus. Overall, the goal of argumentative practice is not only to provide a space for students to share their work, but it is also a place to navigate their uncertainty

Table 3. Argumentative Cues to Support Students to Discuss Their Ideas.

Express
• I noticed. . . ; I observed. . . ; I wonder. . . ; I struggle. . . ; I think. . .because. . .
• My explanation/reasoning/interpretation is. . .because. . .
Comprehend
• Can you explain more about. . .?
• Are you saying. . .?
• Why do you think. . .?
• How did you generate your claim?
• What reasoning can you use to support the evidence?
• I do not understand this point. Can you elaborate more?
Critique
• I respectfully disagree that. . .because. . .
• Your reasoning does not make sense to me because. . .
• I understand why you say that, but I do not agree with this part because. . .
Construct
• I agree with that idea because. . .
• I would like to add on. . .
• If you revise/add this. . ., the argument would make sense to me.

through raising, maintaining, and reducing it to establish a better understanding (Chen & Techawitthayachinda, 2021).

Some students often "dominate" the opportunity and "time" during whole-class discussion, while others may be shy to share their uncertainties and perspectives. To support every student in having equitable opportunities to engage in whole-class argumentation, a discussion circle format is suggested to monitor the frequencies of each student's talk. The teacher can draw a circle associated with student names on the whiteboard, use lines to track the sequence of student talk, and number the frequency of each student's talk on the discussed topic (Chen et al., 2013). The teacher can also encourage students who may be shy to talk by using the argumentative cues provided in Table 3 to share their ideas.

Phase 4: Reflection, Application, and Transformation

In this phase, a 3-2-1 writing strategy (see Figure 8) was implemented to help students reflect on three new ideas they learned from Phases 1 to 3, two uncertainties they still harbored, and one final argument consisting of a claim supported with evidence. This writing strategy supported students in reflecting on what they had learned and what uncertainties they still had, as well as considering what methods they could apply to address them.

After students had the opportunity to engage in individual writing and organize their ideas and uncertainties, the teacher collaboratively worked with students to reflect on the uncertainties they had solved and those that remained from Phases 1 to 3. They also discussed the unsolved uncertainties and new uncertainties to consider what further investigations could address them. Figure 9 shows a concept map projected on the board to guide whole-class discussion about the inheritance of traits.

To further explore the question and extend the problematized phenomenon from Phase 1, the teachers asked more questions by introducing new phenomena (see Figure 10): Why do these twin girls look so different? What makes them look different? (Figure 10-1) Can you roll your tongue? Why can some roll the tongue but some cannot? (Figure 10-2) Do you have a widow's peak? Can you explain why some have a widow's peak? (Figure 10-3) This created more uncertainties that led students to apply what they had learned to extended phenomena and may lead to potential topics after exploring Mendel's principles.

○ The SUPeR Approach in the Voice of Students

Semi-structured interviews were conducted to understand how students oriented and reacted to scientific uncertainty after experiencing the SUPeR approach. Twenty-eight students consented to participate in the Institutional Review Board (IRB) approved research # STUDY00014026. All procedures were followed in accordance with the approved protocol. Five interview questions targeted five aspects: (a) overall understanding of uncertainty in science classes, (b) orientation toward uncertainty navigation to learning, (c) the relationship between uncertainty and curiosity, (d) affective reactions to uncertainty, and (e) self-efficacy in navigating uncertainty. The interview questions were designed as follows:

1. Overall: In science classes, what does uncertainty mean to you?
2. Orientation toward uncertainty navigation to learning: Do you think dealing with uncertainty is helpful for your learning? Why or why not?
3. Uncertainty and curiosity: When you don't understand something, how much does it spark your curiosity?
4. Affective reaction to uncertainty: How do you feel when you experience uncertainty during science classes?
5. Self-efficacy in managing uncertainty: How confident are you in managing uncertainty during science classes?

A constant comparative method (Boeije, 2002) was used to analyze each interview. The research team met weekly to collectively review the data and narratively describe each case. By comparing each interview, five themes and representative quotations from student interviews were identified through the iterative process of review and interpretation. These themes are shown in Table 4.

Our interview data with 28 students after engaging in the SUPeR approach indicates that the SUPeR approach benefits students' productive struggle in learning science. First, the interview results show that uncertainty triggers students' curiosity to explore a problematized phenomenon. Uncertainties prompt students to acknowledge the limitations of their existing knowledge and identify what knowledge they need to acquire to explain the phenomenon. Therefore, it leads students to develop a better understanding of the phenomenon and acquire conceptual and epistemic understanding. We also found that students could positively view their struggles even though they might feel anxious, overwhelmed, stressed, or nervous. Students consider that the struggles drive them to find solutions, and the sense of accomplishment brings them positive emotions, such as joy and fulfillment.

○ Conclusions

The experience of struggle can lead students to productively reflect on, respond to, and restructure their existing knowledge toward a new understanding of scientific concepts and practices. Student scientific uncertainty is one of the major constructs that causes students to struggle during science learning (Barnett, 2007; Chen et al., 2024; Zaslavsky, 2005). While struggling with scientific uncertainties, students can engage in authentic scientific inquiry, providing them with opportunities to think and practice like scientists.

The SUPeR approach is a teaching approach that teachers can use to engage students in productive struggle for developing deeper understandings and practices. The SUPeR approach not only responds to what NGSS emphasizes about scientific practices (e.g., asking questions, planning and carrying out investigations, arguing from evidence), but also highlights engagement in productive struggle, which is missing in current reform teaching. It is important to note that students' uncertainties play a critical role in determining the struggles students experience across the four phases and drive the process. It is time to move our teaching away from an emphasis on a "success-based" approach to a "struggle-based" approach, in which students can experience authentic science learning and construct meaningful understanding for themselves.

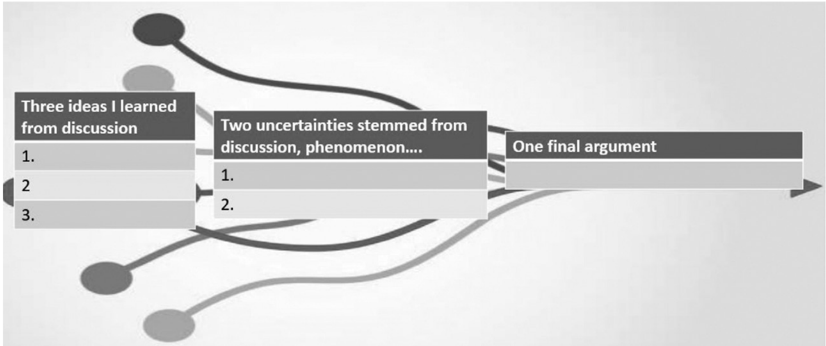


Figure 8. 3-2-1 Writing Strategy.

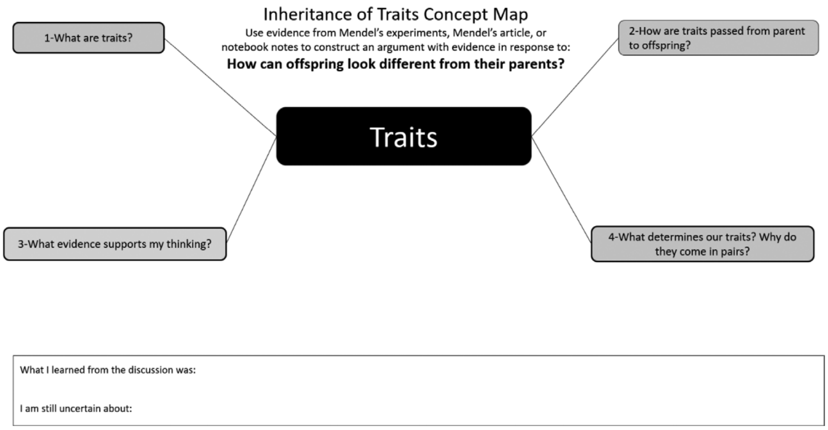


Figure 9. Uncertainty Discussion and Reflection through Traits Concept Map.

Figure 10-1. Uncertainty raised from the picture: Why are these twin girls look so different? *Picture source: https://www.boredpanda.com/black-white-skin-twin-sisters-lucy-maria-aylmer/

Figure 10-2. Uncertainty raised from the picture: Why can some roll the tongue but some cannot?

Figure 10-3. Can you explain why some have widow's peak?

Figure 10. New Problematized Phenomena after Students Develop Understanding about Mendel's Law of Segregation.

Table 4. Five Themes on Students' Voice after Experiencing the SUPeR Approach.

Theme 1: Uncertainty sparks students' curiosity to explore an encountered phenomenon
• I kind of like struggle with my uncertainty. I'm burning with curiosity. Uncertainty makes me think about what I already know and I do not know. • If you don't have any answer or you don't know. It makes me struggle but helpful. It's really getting like into your brain and pushing me to know the answer. It's [uncertainty] being useful. • If I was highly uncertain about something, I would get more curious because I want to know I'd want to know the answer, the solution to this thing so that I can have that knowledge of that.
Theme 2: Uncertainty helps students to develop better understanding
• When you're uncertain, you get to figure it out. You get to work through it [uncertainty], and when you work through it, it makes you understand it more than just like doing one thing. I like I learned a little bit by solving my uncertainty at a time which ends up doing good. • You're getting more understanding as the lessons go because you solved your uncertainties time by time. You want to ask more questions after you know more.
Theme 3: Uncertainty causes student to struggle with negative emotion which may drive them to figure out solutions and thus reduce their struggles
• When I don't understand something it's like I get like stressful. And take a second and then get back into it, I kind of just slowly do it, and then I start to understand it. Then I start to get more like joyful about it. • The negative emotions are not kind of bad things for your curiosity, but it's kind of pushes you to figure out something what you don't know at that moment. • When I have high uncertainty, I'm panicky and nervous. But I need to catch up in order to come less uncertain and be more solid.
Theme 4: Students view negative emotion in a positive light when struggling with uncertainties during SUPeR approach
• It [panicking] is kind of motivated. . .it sounds like bad, but it helps. . .not necessarily a bad thing. • If you don't understand it a lot, and you get mad at it might be a bad thing. But for me it's a good thing, because I like learning about this kind of stuff.
Theme 5: In the SUPeR environment, students enhance self-efficacy in managing their uncertainty
• I totally feel comfortable and confident sharing things with students around me in this class. The environment who you are with is kind of important for you to maintain your confidence. • I become more confident and I know I can do it. I may fail and not resolve it. I am still confident and I'm going to keep doing it.

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