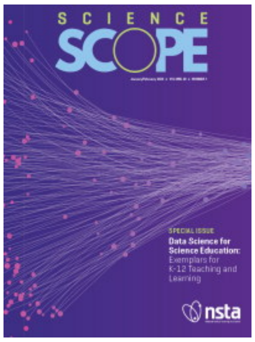


Science Scope

ISSN: 0887-2376 (Print) 1943-4901 (Online) Journal homepage: www.tandfonline.com/journals/ujss20

Embracing Uncertainty in Science: The ABCs of Data and the Confidence Updater

Joshua M. Rosenberg, Marcus Kubsch, Stefan Sorge, Simon Tautz, Cody Pritchard, Amanda Victoria Garner & Zhen XU

To cite this article: Joshua M. Rosenberg, Marcus Kubsch, Stefan Sorge, Simon Tautz, Cody Pritchard, Amanda Victoria Garner & Zhen XU (2026) Embracing Uncertainty in Science: The ABCs of Data and the Confidence Updater, Science Scope, 49:1, 44-50, DOI: 10.1080/08872376.2025.2601357

To link to this article: https://doi.org/10.1080/08872376.2025.2601357

Published online: 28 Jan 2026.

Embracing Uncertainty in Science:

The ABCs of Data and the Confidence Updater

JOSHUA M. ROSENBERG, MARCUS KUBSCH, STEFAN SORGE, SIMON TAUTZ, CODY PRITCHARD, AMANDA VICTORIA GARNER, AND ZHEN XU

ABSTRACT

Having to deal with uncertainty is familiar to scientists working in fields that range from the life sciences to data science, but it can be difficult to support students to embrace and make sense of uncertainty in the middle school classroom. In this article, we argue that teaching about uncertainty in science education is not only beneficial but necessary for helping students develop a deeper understanding of scientific reasoning and data analysis. We introduce the ABCs of Data—Account for what you know, Be open to evidence, and Consider your confidence—a framework designed to help students evaluate their knowledge and update their understanding based on evidence. To support this process, we present the Confidence Updater, a free online tool that guides students in quantifying their confidence in a hypothesis, interpreting to what extent evidence such as data supports their hypothesis, and adjusting their confidence accordingly. We also demonstrate how these strategies integrate into OpenSciEd materials. We conclude with a brief discussion of the value in making uncertainty something your students can comfortably and confidently navigate.

KEYWORDS: Data Analytics; Data Science; Uncertainty; Using Mathematics and Computational Thinking

In the life sciences, what we know about the climate has grown from initially tentative claims to an increasingly rich understanding of the interconnected systems that drive the Earth's climate. In chemistry, we teach atomic models that are useful, but in key ways inaccurate: atoms occupy regions around the nucleus in ways that can best be described "probabilistically" rather than in terms of discrete orbitals. And in physics, seemingly straightforward concepts like a *planet* have been contested as the reclassification of Pluto from planet to dwarf-planet shows. The punchline: science does not yield certain takeaways. Instead, science yields ideas that can be updated over time based on evidence that scientists negotiate within a particular discipline.

This simple assertion—science does not yield certain takeaways—is often overlooked, both in science (Cologna et al. 2025) and in our field of science education (Erduran 2022) and the middle school curriculum. There are many reasons why, but a key one is that there is an understandable perception that it is hard to teach scientific concepts in a way that accords with their uncertain nature. If we open the door to science being uncertain, will students trust it? Will they trust us? And, what if students need to grasp key, timely concepts—like how and why vaccination can improve human well-being?

In this article, we claim it is not only okay but necessary to embrace the uncertain nature of science. Doing so can both help students to develop a deeper, more nuanced appreciation of science and how it yields trustworthy takeaways (Manz and Suárez 2018; Watkins et al. 2018). Further, making progress amidst considerable uncertainty is a key part of doing data science.

The Key. We must have practical strategies and tools that make uncertainty something students can more comfortably discuss, navigate, and share their ideas about. In this article, we share strategies and tools from our work with science teachers like you inspired by a data science approach, Bayesian statistics (Rosenberg et al. 2022). First, we describe our approach to making uncertainty and this data science approach something about which students can be more comfortable—what we called in a recent research paper the ABCs of Data.

Introducing the ABCs of data

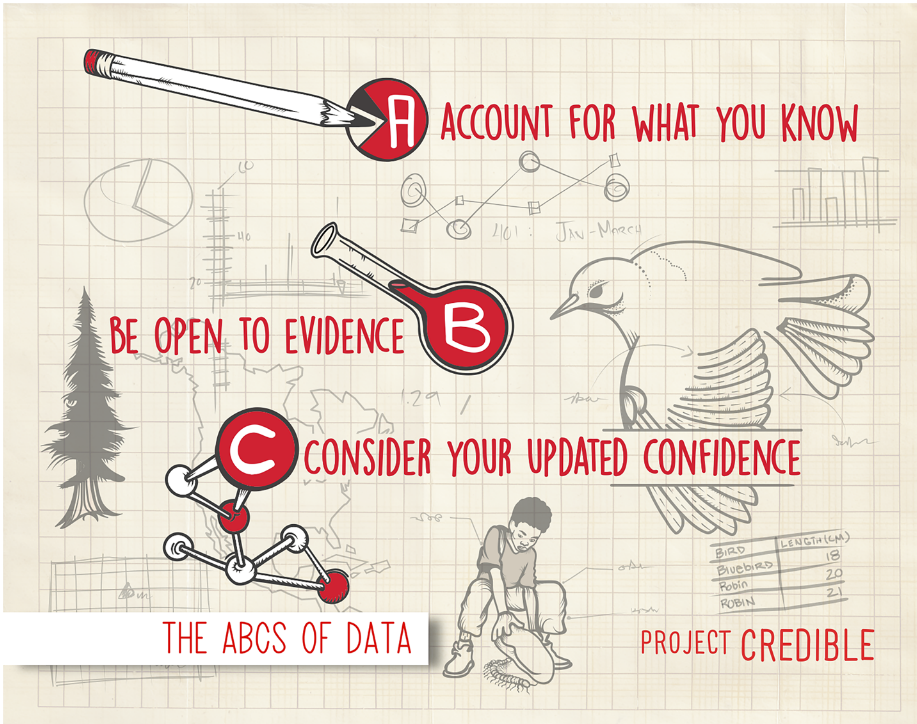
There is a growing emphasis on data analysis and data literacy across educational standards in the United States in a range of subject areas. The Common Core, for example, places significant focus on statistical reasoning from grades K–12 (National Governors Association Center for Best Practices and Council of Chief State School Officers 2009). Emerging domains including data science education increasingly emphasize computing with data, with this territory being ripe with debate and initiatives to understand where data fits best in the curriculum (Drozda et al. 2024; NASEM 2023). And, of course, the growing emphasis on data analysis and data literacy includes standards adopted by many states for science education (NGSS Lead States 2013).

In the *Next Generation Science Standards* (*NGSS*), many—if not most—of the eight science and engineering practices involve data. These practices stress the importance of planning and conducting investigations to generate data that forms the basis for evidence; selecting appropriate tools for collecting, recording, analyzing, and evaluating data; and addressing the limitations of data analysis—such as measurement errors and sample biases—when interpreting results. Additionally, they emphasize the application of scientific reasoning, theories, and models to connect evidence to claims and assess how well the reasoning and data support conclusions.

We created the ABCs of Data based on scholarship on how people and scientists interpret data (Titelbaum 2022; Rosenberg et al. 2022; see Figure 1). Their function is to make the core processes involved in the analysis and interpretation of data accessible and useful to your students. The ABCs do not explicitly involve statistics. Instead, they are meant to serve as tools to support certain types of reasoning and student thinking, giving them space to be active participants in the scientific process rather than passive recipients. The ABCs of Data has three parts:

- *A—Account for what you know.* The first step is to consider what you already know. This part is meant to encourage students to think about what they do (or do not) know about a scientific concept or idea, or a phenomenon. It is

FIGURE 1. The ABCs of Data.



important to note that this part involves supporting students to be explicit about how confident they are in what they believe or know—the more specific, the better!

- *B—Be open to evidence.* This step involves the nuts-and-bolts of analyzing data. Here, the key is to help students to try to understand what the data tells them. The crucial take-away from this part is a decision about how much the data supports (or does not support) what they already know.
- *C—Consider your confidence.* This last part involves combining the results of parts A and B to reach a data-supported conclusion. Here, support students to answer the question, given what you already know and what the evidence suggests, how confident are you now in your belief? Like for the first step, it is critical here to be as specific and concrete as possible.

You might now be thinking, how can I help students to do this? We created a free, web-based tool to support your students to readily complete each of the above three steps.

The confidence Updater app

To support students in updating their knowledge about the world based on evidence, we have developed the Confidence Updater, a free online app (see link in Online Resources). Working with the Confidence Updater involves three steps that are aligned to the ABCs: first, formulating a hypothesis and expressing one's confidence in it *quantitatively*; (b) evaluating to what extent evidence supports or contradicts, or does not relate to the stated hypothesis; and (c) updating one's confidence in the hypothesis based on the initially expressed confidence and the available evidence—again, quantitatively. We'll share examples of the app in the next section.

Integrating the ABCs of data into OpenSciEd materials

We have been integrating the ABCs of Data into OpenSciEd materials (see link in Online Resources; Edelson et al. 2021; Penuel et al. 2024). These materials are developed with a project-based learning approach that emphasizes the iterative nature of science and engages students in active, evidence-based inquiry. Although this example uses OpenSciEd materials, the ABCs of Data can be integrated into any curricular materials that relate to students' work with data.

The lesson we use to illustrate how the ABCs of Data can be integrated into OpenSciEd materials is Unit 6.1: Light & Matter. In this unit, students explore the phenomenon of one-way mirrors. They investigate key questions such as: "How does one person see themselves in the mirror?" and "Why can another person see through the one-way mirror?"

The unit addresses *NGSS* performance expectations MS-PS4-2 and MS-LS1-8. Students learn about the interactions of light with different materials and how the eye perceives light. They learn to ask scientific questions in designing their own experiments and to think using systems and models.

A—account for what you know

Students investigate their questions using a scaled box model (see Figure 2). The model consists of two cardboard boxes (or one box divided into two sections) separated by a one-way mirror. Each "room"—or part of the box—can be illuminated separately with a flashlight. Inside each room, small figures serve as observation targets.

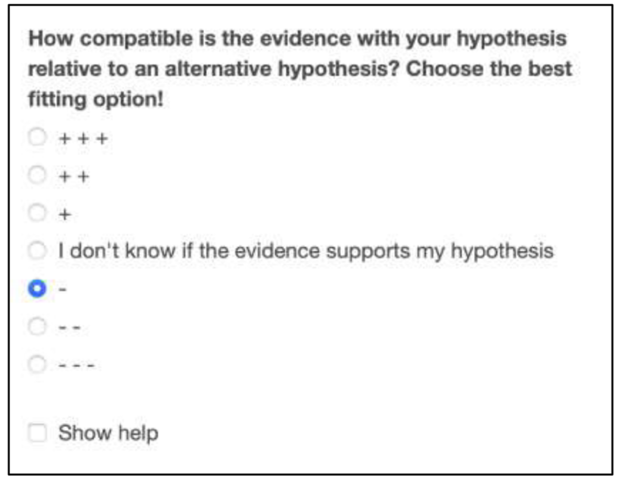
In their first investigation, students observed the phenomenon with Room A illuminated and with Room B left dark. They noticed that when looking through a hole into Room A, they could see a mirrored image of the figure on the one-way mirror. Conversely, when looking into Room B, they could see the back of the figure there and view through the one-way mirror into Room A. Students may modify the lighting setup by (a) illuminating Room B while leaving Room A dark, (b) illuminating both rooms simultaneously, or (c) keeping both rooms dark. Before choosing a lighting setup, students must draw on prior knowledge to predict what they expect to observe. They can write a hypothesis about the outcome and—using the Confidence Updater—assign a numeric value to their certainty in their predictions (see Figure 3).

Higher positive values reflect higher confidence that the hypothesis is true, lower negative values reflect higher confidence that the hypothesis is false,

FIGURE 2. Example of the box model. Room A is on the left and Room B is on the right.

FIGURE 3. Formulating a hypothesis using the confidence updater. Example for the hypothesis when illuminating Room B and leaving Room A dark.

FIGURE 4. Selecting how compatible the evidence and hypothesis are.



and 0 reflects a state of total uncertainty about the hypothesis. In this example, students were somewhat confident—they chose 55% in their hypothesis: "We will still see the reflection of the student, but darker."

This first step reflects the strategy of accounting for what one already knows both in terms of writing down a hypothesis based on one's prior knowledge and substantiating one's confidence in that hypothesis. Further, it also reflects the strategy of being open to new evidence. When students choose a value of 100% or –100%, they communicate *complete* confidence. When students choose these values and then try to update their confidence about the hypothesis based on evidence, they will find that the evidence has no effect on their confidence. In this way, being open to new evidence begins with acknowledging that our knowledge about the world is not set in stone.

B—Be open to evidence

In the second step, students decide how compatible the evidence they gathered is with their hypothesis relative to possible alternative hypotheses by selecting any of the options in Figure 4.

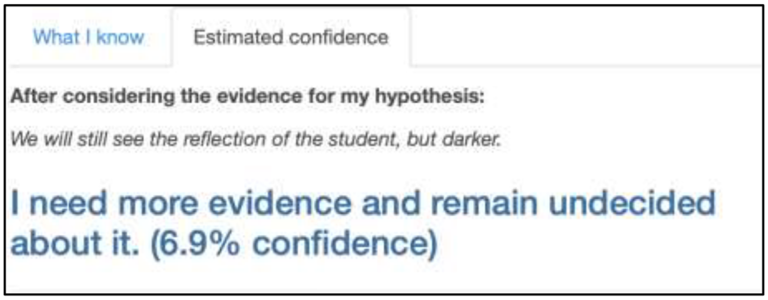
Students consider observations made from the experiment as evidence. One example would be the inversion of the one-way mirror effect when lighting room B instead of room A. Observations made by multiple students or student groups should be weighted more than observations by single students. Let's say that students' further engagement with the light box actually gave some evidence that their initial hypothesis was not seeming to be correct, reflected in their choice of "-" (indicating that their hypothesis was not supported by further evidence).

We note that this engagement can be highly complex and multifaceted—this is where students can work with data small and large to try to understand how much of their initial hypothesis is supported (or contradicted) by what they find. Like the first step, this step reflects the merits of being open to evidence as students are encouraged to weigh the available evidence against their own but also against alternative hypotheses, and to not jump to conclusions. At the end of the second step, students click on the "Run!" button to continue with the third step.

C—Consider your confidence

As students discuss their observations in a class-wide comparison, they use evidence to support

FIGURE 5. Updated confidence about hypothesis.



their claims and reflect on the limits of their conclusions. For example, what conclusions are strongly supported by the evidence? What uncertainties remain? In this stage, students revisit their evidence to evaluate whether their confidence in their initial hypothesis has changed. By using the Confidence Updater, they can quantify how their confidence changes based on the evidence. The third step (Figure 5) shows the updated confidence in the hypothesis based on the selected compatibility of the evidence with the hypothesis (in this case 55% and "-").

If the box "Show numeric confidence level" is checked, the confidence will also be displayed as a percentage value. This last step reflects the strategy of considering what one knows after updating one's knowledge based on data as it expresses confidence in knowledge in grades—in contrast to absolute—terms. When students choose the numeric confidence levels, this allows them to consider on a finer grain size how different choices in the initial confidence and compatibility of evidence lead to graded beliefs about knowledge.

The third step can be the last step in the application of the Confidence Updater. However, the Confidence Updater can also be used iteratively. Consider for example, that students generated a different hypothesis about which they are moderately confident, and they collect data and arrive at a moderately high degree of confidence, say, 65%. They can now return to the first step and set the confidence to 65% and take this value as a starting point for considering new or extended evidence. This process of building confidence in a hypothesis is comparable to how scientific communities build confidence in scientific ideas and even theories—some of which were, at the outset, only hypotheses.

Conclusion

Uncertainty is something that scientists across domains ranging from the life sciences to data science must consider when they are learning about phenomena that range from astronomical bodies and Earth systems to the nature of atoms, but it is a challenge to bring uncertainty into the middle school science classroom in a way that does not feel messy or even scary. In this article, we built on data science ideas about how scientists and data scientists can work with uncertainty in a productive way, by quantifying how confident one is about a particular idea or a hypothesis. To make these ideas more usable and meaningful, we introduced the ABCs of Data—Account for what you know, Be open to evidence, and Consider your confidence—as a way to share and update their confidence in light of uncertainty. Further, we created a freely-available tool—the Confidence Updater—that your students can use individually, in groups, or in a whole-class setting to put on the table how confident they are initially and how their analysis and interpretation of data can change, or update, their confidence. In addition to engaging students in the science and engineering practice of analyzing and interpreting data, this approach and tool can serve as a gentle introduction to the more quantitatively focused practice using mathematics and computational thinking and the use of data and statistics, more generally.

ORCID

Joshua M. Rosenberg http://orcid.org/0000-0003-2170-0447
Marcus Kubsch http://orcid.org/0000-0001-5497-8336
Stefan Sorge http://orcid.org/0000-0001-9915-228X
Amanda Victoria Garner http://orcid.org/0009-0007-4886-3816

REFERENCES

Cologna, Viktoria, Niels G. Mede, Sebastian Berger, John Besley, Cameron Brick, Marina Joubert, Edward W. Maibach, et al. 2025. "Trust in Scientists and Their Role in Society across 68 Countries." *Nature Human Behaviour* 9 (4): 713–730. https://doi.org/10.1038/s41562-024-02090-5.

Drozda, Z., J. T. Walker, K. Fisler, and D. Weintrop. 2024. "Computing in Data Science or Data in Computer Science? Exploring the Relationship Between Data Science and Computer Science in K–12 Education. In *Proceedings of the 55th ACM Technical Symposium on Computer Science Education* 2: 1527–1528. Association for Computing Machinery, New York, NY. https://doi.org/10.1145/3626253.3631654.

Edelson, D. C., Reiser, B. J., McNeill, K. L., Mohan, A., Novak, M., Mohan, L., ... & Suárez, E. 2021. Developing Research-Based Instructional Materials to Support Large-Scale Transformation of Science Teaching and Learning: The Approach of the OpenSciEd Middle School Program. *Journal of Science Teacher Education* 32 (7): 780–804.

Erduran, S. 2022. "Trust in Science and Science Education—Part 1." *Science & Education* 31 (5): 1101–1104. https://doi.org/10.1080/00368555.2024.2390547.

Manz, E., and E. Suárez. 2018. "Supporting Teachers to Negotiate Uncertainty for Science, Students, and Teaching." *Science Education* 102 (4): 771–795. https://doi.org/10.1002/sce.21343.

NASEM (National Academies of Sciences, Engineering, and Medicine). 2023. "*Foundations of Data Science for Students in Grades K–12.*" *Proceedings of a workshop*. Washington, DC: National Academies Press.

NGA Center and CCSSO (National Governors Association Center for Best Practices and Council of Chief State School Officers). 2009. *Forty-nine states and territories join common core standards initiative*. Washington, DC: NGA Center and CCSSO. *www.corestandards.org*.

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

Rosenberg, J. M., M. Kubsch, E.-J. Wagenmakers, and M. Dogucu. 2022. "Making Sense of Uncertainty in the Science Classroom: A Bayesian Approach." *Science & Education* 31 (5): 1239–1262. https://link.springer.com/article/10.1007/s11191-022-00341-3. https://doi.org/10.1007/s11191-022-00341-3.

Penuel, W. R., K. Henson, Z. B. Bracey, N. Vick, and A. Rivet. 2024. "Designing Standards-Aligned Instructional Materials That Connect to Students' Interests and Community Priorities." *The Science Teacher* 91 (5): 62–70a. https://doi.org/10.1080/00368555.2024.2390547.

Titelbaum, M. G. 2022. *Fundamentals of Bayesian epistemology 1: Introducing credences*. New York, NY: Oxford University Press.

Watkins, J., D. Hammer, J. Radoff, L. Z. Jaber, and A. M. Phillips. 2018. "Positioning as Not-Understanding: The Value of Showing Uncertainty for Engaging in Science." *Journal of Research in Science Teaching* 55 (4): 573–599. https://doi.org/10.1002/tea.21431.

ONLINE RESOURCES

Confidence Updater app—
http://confidenceupdater.com

Open SciEd—
www.openscied.org

Joshua M. Rosenberg [*jmrosenberg@utk.edu*] is a Haslam Family Professor & Associate Professor of STEM education. **Cody Pritchard** [*cprit12@vols.utk.edu*] is a doctoral candidate in STEM Education. **Zhen Xu** [*zxu50@utk.edu*] is a postdoctoral research associate, all in the College of Education, Health, and Human Services at The University of Tennessee, Knoxville. **Amanda Victoria Garner** [*avhendricks@gmail.com*] is a postdoctoral scholar at Vanderbilt University. **Marcus Kubsch** [*m.kubsch@fu-berlin.de*] is a professor of Physics Education Research at Freie Universität Berlin, Germany. **Stefan Sorge** [*sorge@leibniz-ipn.de*] is a postdoctoral researcher. **Simon S. Tautz** [*tautz@leibniz-ipn.de*] is a doctoral researcher, both at the Department of Physics Education, IPN – Leibniz Institute for Science and Mathematics Education, Kiel, Germany.