What We Call Misconceptions May Be Necessary Stepping-Stones Toward Making Sense of the World

Todd Campbell, Christina Schwarz, and Mark Windschitl

The title of this article highlights a view of science learning uncommon in schools today—one in which teachers and students view misconceptions as useful for making sense of the world (NRC 2008). What are misconceptions? Many consider them to be student ideas inconsistent with science and sometimes hard to change. One example is the idea that "A ball eventually stops after I push it because the ball 'holds force' until the force runs out and stops." While we teachers may be tempted to quickly reject the idea of objects "holding force," simply telling students the idea is incorrect has little effect on their thinking. Such ideas might, however, become part of a sense-making conversation that can support reasoning and learning.

By sense-making, we simply mean working on and with ideas—both students' ideas (including experiences, language, and ways of knowing) and authoritative ideas in texts and other materials—in ways that help generate meaningful connections. This can involve asking students to talk about their thinking, to compare ideas, to test these ideas, and to see if they can be used to explain natural events and processes. These types of reasoning episodes occur often during students' engagement with science practices such as arguing from evidence, constructing explanations, or revising models. Learning as sense-making is emphasized in the *Next Generation Science Standards* (NGSS Lead States 2013).

In the past, when students have offered explanations inconsistent with science (such as ascribing the seasons to the changing distance between the Earth and the Sun), these ideas were seen as problematic misconceptions needing to be "stamped out" by the teacher with the correct ideas "stamped in." In this strategy, the teacher generally asked students to replace the wrong idea with the correct one (such as the tilt of the Earth and its revolution around the Sun causing the seasons). While providing accurate scien-

tific information to students is useful, an early focus on finding and fixing misconceptions can confuse students about why their own ideas aren't accurate and fails to engage students in reasoning or idea revision. When their misconceptions are "corrected," students learn that their own ideas need to be replaced by other ideas that they don't fully understand. When this happens, students will likely memorize official "school" knowledge but fall back on their original ideas when thinking about and explaining the outside world, since they naturally reason with their own real-world experiences, language, and rules for validating claims.

More recently, a resources perspective on learning has offered an alternative to repairing misconceptions (diSessa 1993; Hammer et al. 2005; Warren et al. 2001). Rather than seeing student knowledge from a deficit view, where "wrong" answers need to be eliminated, a resources perspective emphasizes how students can reason with different kinds of valuable knowledge to make sense of new situations and ideas. These resources include partial understandings, nonstandard ideas, everyday experiences and ways of talking. In this view, students activate the ideas, experiences, or language they think will help develop explanations or solve problems in the particular context (e.g., the social and physical environment) in which they find themselves. The *NGSS* uses this resources perspective and prioritizes sense-making in advocating for a new vision for science teaching. The goal is for students to engage in science and engineering practices as they use their developing understanding of disciplinary core ideas and crosscutting concepts to make sense of phenomena or solve problems. Science and engineering practices are tools the classroom community uses to recognize when an idea is or isn't productive in the context in which it is being used.

FIGURE 1 Strategies for supporting student sense-making

Strategy	Rationale/Explanation
Include some level of uncertainty in students' science activities rather than using activity to confirm authoritative science ideas.	Uncertainty is an important part of scientific activity that leads to engagement in reasoning (Manz 2014) and to seeing the usefulness of science practices as tools for sense-making (Manz 2015).
Engage students in using their own ideas and experiences to construct and revise explanations of phenomena or solving problems.	Constructing and revising explanations of phenomena and solving problems can bring out students' prior ideas and helps students apply and coordinate different scientific ideas that can be useful in developing and revising explanations. It can also connect science learning to experiences in their daily lives inside and outside of school.
Model out loud how a person reasons about ideas (comparing ideas, changing them in response to evidence). Invite students in small groups to rehearse conversations about evidence and explanations.	Make sure that everyone (teachers and students!) in the class asks one another questions and provides evidence and reasons for their ideas—rather than saying it's true because the teacher or text stated it (Forman and Ford 2014). The desired student "performance" is to change ideas and explanations over time, which is authentic to science.
Emphasize collective sense-making as an important goal (Carlone and Smithenry 2014). Ask students or student groups who have contrary explanations to share their thinking in whole class settings.	Engaging in collective sense-making shows how reasoning can be done at the community level in addition to the individual level. Working with ideas takes time and response from the teacher and other students. The payoffs are large—stronger and longer-lasting learning.

If students have the guidance and space to reason aloud with one another, they can fill the classroom with ideas about how to solve problems and why the ideas make sense in the particular context being examined (Cohen and Ball 1990). As students identify the strengths and weakness of their ideas, they position themselves to better understand the problems at hand, the extent to which the ideas may offer solutions (Bransford and Schwartz 1999), and how these ideas might help in similar contexts later. It's helpful for us as teachers to think less about correcting misconceptions and more about helping students engage in science reasoning to try out, evaluate, and refine their resources (ideas, ways of thinking about the world) to explain real-world phenomena or solve problems.

To highlight this shift, we first show how reasoning through classroom discussion can set the stage for learning. We then share teachers' contrasting responses to student reasoning and strategies for supporting small-group and whole-class discussions. Finally, we offer guidance to support teachers in considering whether this sense-making discourse supports student learning.

An example of reasoning as opportunities to "work on ideas"

In the following episode, fourth graders share ideas as a class to explain whether the weight or the volume of an object causes the water level to rise when the object is dropped in water and sinks.

Mathais: "Well, [in] my group … we found out that … it was because of the volume, because … the volume in the water level were the same, but the weight was different. And I thought that if, um, there's more weight, um, in the copper cube than the … aluminum cube, then I think it just should depend on … the volume because … if … the copper cube is more, then it would have more volume. It … really depended on the weight."

Teacher: "Okay. Does anyone want to respond to that? Flevor, go ahead."

Flevor: "I, um, agree with what you said because … for example, like if you … had big um, like if you got a big cup of water and you put … an eraser in there, like the eraser over there, if you put something like that in a big cup of water, the water level would rise a lot, and, if you put in a copper cube … it's not going to rise that much, even though that copper cube would weigh more, than a eraser" (Michaels and O'Connor 2012, p. 17).

In this episode, we see how messy "first draft" attempts at reasoning can be. However, we can see Mathais use evidence to support his claims (i.e., "because … if … the copper cube is more, then it would have more volume"), and we can see Flevor try to generalize what he learned to other similar contexts (i.e., "like if you got a big cup of water and you put… an eraser in there... the water level would rise a lot"). Even though the students are not immediately stating accepted scientific theory, they advance their collective sense-making. These productive classroom discussions do not happen spontaneously. Teachers have to invite these comparisons. They must model and ask for the use of evidence and create safe spaces for students to work together on ideas.

In this example, you can see that students engage in productive reasoning using their resources as they move toward making sense of this phenomenon. And, while it may not be especially obvious in the episode, there are teaching strategies that can support student reasoning as an opportunity to learn (Figure 1).

Ways teachers might respond to and extend student reasoning

In episodes where students reason by sharing their ideas in their first draft talk, a teacher might respond in several ways. In Figure 2, middle school students try to explain what happens to strawberries in a resealable plastic bag at room temperature after 20 days; two possible teacher responses follow.

In Response A, the teacher heard Tori give what she considered to be a wrong answer. Instead of asking for clarification, guiding the students to consider other aspects, or pointing out the problem with Tori's idea, the teacher presented the correct idea. The problem with Response A, among other things, is that the teacher has asked follow-up questions that have shifted the focus from reasoning about the unresolved issue of similarities between decomposition and rotting to accepting the position from the teacher and recalling the definition of biotic and abiotic processes. In this episode, only the teacher is working on these ideas; active reasoning by students has been closed down. This approach may work for the few

students with sufficient background knowledge to resolve the inconsistencies in their own heads. However, for most, this approach emphasizes superficial recall without understanding.

Response B, in contrast, shows the teacher (1) revoicing Tori's ideas, (2) asking her for clarification, specifically about the critical issue of whether these processes might be different or related, and (3) asking other students to work with her to resolve these ideas by drawing on their knowledge and experiences. In this episode, student resources the teacher could ask about include "mold-gathering nutrients," "mold digestion," and "becoming compost." The teacher provides additional time and scaffolding for Tori or others to continue to build on their partial understandings of mold growth by drawing on everyday experiences or observations.

Extend Response B with even more student-to-student turns of talk, where students inquire about and respond to one another's ideas. Teachers can use resources like Michaels and O'Connor's (2012) Talk Science Primer to interject and guide students' talk so they are (1) sharing, expanding, and clarifying their own thinking, (2) listening carefully to one another, (3) deepening their reasoning, and (4) thinking with others. These discussions require practice but can significantly advance students' reasoning and sense-making about the world. They can also make science learning more engaging, meaningful, and similar to how science is actually practiced. Figure 3 provides other useful strategies for supporting small-group and whole-class discussions in classrooms that focus on developing scientific sense-making.

Is student reasoning moving in a promising direction?

Another challenge teachers face when engaging students in sense-making is limited instruction time. Discussions and reasoning are nonlinear and messy and do not always move from less to more sophisticated. Instead of always being able to predict how students will work toward explaining phenomena, as teachers, we can consider how well they are collaboratively attending to their idiosyncratic ways of thinking. Additionally, we can consider how effectively they have

FIGURE 2 Example responses to student reasoning

Middle School Episode

Alex: What is happening overtime in the ziplock bag is that strawberries are rotting or decomposing. What is happening is. . .it might be that the mold grows overtime and gathers the strawberries nutrients through digestion and the strawberries start to shrivel up and break.

Teacher: Great. So what you said was that the strawberries are rotting and decomposing. Is that the same thing or are they two different things that are going on? And this can be a question for anybody.

Tori: I think that rotting is taking all of the nutrients up to the surface so that the mold can, I guess, digest it. And, decomposing is when the strawberry starts to fall apart and become compost.

(*Tools for Ambitious Science Teaching 2015*)

Teacher Response A	Teacher Response B
That's not quite correct, Tori. Rotting and decomposing are defined in the same way as the process that breaks organic substances into much simpler forms of matter, either through abiotic or biotic processes. Can anyone tell me what an abiotic process is? How about a biotic process?	Tori, it sounds like you are saying that rotting and decomposing are two different processes. Tell us more about how these processes might be similar to or different from each other. Do you think they are related? [pause, then a student responds…] "What do some of the rest of you think about this idea?" Do you agree, disagree, or want to build on Tori's idea? What did you see in your own experiences that might support or disagree with this idea?

FIGURE 3 **Discourse prompts that teacher or students can use for supporting sense-making talk in small-group and whole-class discussions**

When trying to make sense of phenomena

When trying to (initially) understand an event or process (whole class)

- What do you/we see going on here?
- What did you/we notice when ___ happened?
- When or where does ___ occur?
- Do we see any patterns in what happened?

When trying to elicit ideas (whole class or small groups)

- What do you/we think is causing this?
- What has happened here? (at level of inference)
- What would happen if ___?

When pressing for possible explanations (whole class or small groups)

- What might be going on here that we can't see?
- Why do you/we think this happens this way? (emphasize cause)
- What do you/we think causes ____?

When working on summarizing ideas and selecting those to work on throughout a unit (whole class)

- What are some things we are not sure about here?
- How could we test our ideas?
- What kinds of information or experiences do we need to learn more?

When pressing students to construct or revise evidence-based explanations and explanatory models

When working to get students to reason about gaps or contradictions in explanations/models (small groups)

- Can you tell me/us what role [idea X, or aspect Y] has in your explanation/model?
- How does this part of your explanation/model fit with the rest?
- Does your explanation or model provide an account for how and why the phenomenon/a happens?

When preparing students to persuade others with evidence and scientific theory (small groups)

- Let's focus on just one part of your explanation (such as before, during, or after an event) or model (e.g., the cause and effect or mechanism), and then an activity we've done that helps you/us understand that part of the explanation/model.
- Why did that activity convince you that [part of the explanation/model] is true?
- Is there a 'fit' between your evidence and your explanation/model?
- How does your model fit with other ideas that we have learned about in science?

When facilitating public comparison of evidence-based explanations or explanatory models (whole class)

- Compare this group's explanation/model with yours? Is it similar? Different? How?
- Does their use of evidence or reasoning make you re-think any part of your own explanation/model?
- Can more than one explanation/model be supported by evidence or theory?"

When considering final adaptations to final evidence-based explanations/explanatory model (whole class)

- Should we go back and revise our models/ explanations?
- What puzzles do we still have?

Note: These strategies were taken from the AmbitiousScienceTeaching.Org discourse tools Eliciting Students Ideas and Adapting Instruction and Pressing for Evidence-Based Explanations. An additional tool is also available for Supporting Ongoing Changes in Thinking as students are at work throughout the unit of instruction.

used science and engineering practices to try out, evaluate, and refine their resources in constructing explanations. Are students attending to and negotiating one another's ideas and ideas offered by you, the text, or other resources? It is important to think about and invite students to think about the extent to which new ideas are being supported by underlying reasoning in classroom contexts (Michaels and O'Connor 2012; Russ et al. 2009). In this way, students can argue for the basis of their claims either to support them or recognize the need for more revision. Finally, among other strategies, as teachers we can consider how well students' ideas are accounting for evidence in the world, how consistent these ideas are with other scientific ideas they have already come to understand, and whether there is consistency in how students' ideas can be used in explaining similar phenomena.

Conclusion

The vision of *NGSS* "requires a dramatic departure from approaches to teaching and learning science occurring today in most science classrooms K–12" (Reiser 2013, p. 2). In this article we emphasize the importance of examining student misconceptions and correcting them with sense-making activities supported by the *NGSS*. Specifically, we suggest using activities that engage students in science and engineering practices that will help them develop their understanding of disciplinary core ideas and crosscutting concepts and, subsequently, the world around them. We hope these strategies will be a helpful guide for working with student ideas in the future and will support our collective efforts as a science education community to support student learning. ■

References

Bransford, J.D., and D.L. Schwartz. 1999. Rethinking transfer: A simple proposal with multiple implications. In *Review of research in education*, vol. 24, ed. A. Iran-Nejad and P.D. Pearson, 61–100. Washington, DC: American Educational Research Association.

Carlone, H., and D. Smithenry. 2014. Creating a "We" culture: Strategies to ensure all students connect with science. *Science and Children* 52 (3): 66–71.

Cohen, D.K., and D.L. Ball. 1990. Policy and practice: An overview. *Educational Evaluation and Policy Analysis* 12 (3): 233–239.

diSessa, A.A. 1993. Toward an epistemology of physics. *Cognition and Instruction* 10 (2–3): 105–225.

Forman, E.A., and M.J. Ford. 2014. Authority and accountability in light of disciplinary practices in science. *International Journal of Educational Research* 64: 199–210.

Hammer, D., A. Elby, R.E. Scherr, and E.F. Redish. 2005. Resources, framing, and transfer. In T*ransfer of learning from a modern multidisciplinary perspective*, ed. J. Mestre, 89–120. Greenwich, CT: Information Age Publishing.

Manz, E. 2014. Representing student argumentation as functionally emergent from scientific activity. *Review of Educational Research* 85 (4): 0–38.

Manz, E. 2015. Resistance and the development of scientific practice: Designing the mangle into science instruction. *Cognition and Instruction* 33 (2): 89–124.

Michaels, S., and C. O'Connor. 2012. Talk Science Primer. Cambridge, MA: TERC. *http://bit.ly/XWYt1m*.

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

National Research Council (NRC). 2008. *Ready, set, science: Putting research to work in K–8 science classrooms*. Washington, DC: National Academies Press.

Passmore, C., J.S. Gouvea, and R. Giere. 2014. Models in science and in learning science: Focusing scientific practice on sense-making. In *International Handbook of Research in History, Philosophy and Science Teaching*, ed. M.R. Matthews, 1171–1202. Dordrecht, Netherlands: Springer.

Reiser, B. 2013. What professional development strategies are needed for successful implementation of the *Next Generation Science Standards?* Paper written for the Invitational Research Symposium on Science Assessment.

Russ, R.S., J.E. Coffey, D. Hammer, and P. Hutchison. 2009. Making classroom assessment more accountable to scientific reasoning: A case for attending to mechanistic thinking. *Science Education* 93 (5): 875–891.

Tools for Ambitious Science Teaching. 2015. Transcribed excerpt from the video Middle School · Fungi and life processes · Legacy Series. University of Washington. *http://ambitiousscienceteaching.org*.

Warren, B., C. Ballenger, M. Ogonowski, A.S. Rosebery, and J. Hudicourt-Barnes. 2001. Rethinking diversity in learning science: The logic of everyday sense-making. *Journal of Research in Science Teaching* 38 (5): 529–552.

Todd Campbell (*todd.campbell@uconn.edu*) is an associate professor at the University of Connecticut in Storrs, Connecticut; ***Christina Schwarz*** (*cschwarz@msu.edu*) is an associate professor at Michigan State University in East Lansing, Michigan, and ***Mark Windschitl*** (*mwind@uw.edu*) is a professor at the University of Washington in Seattle.