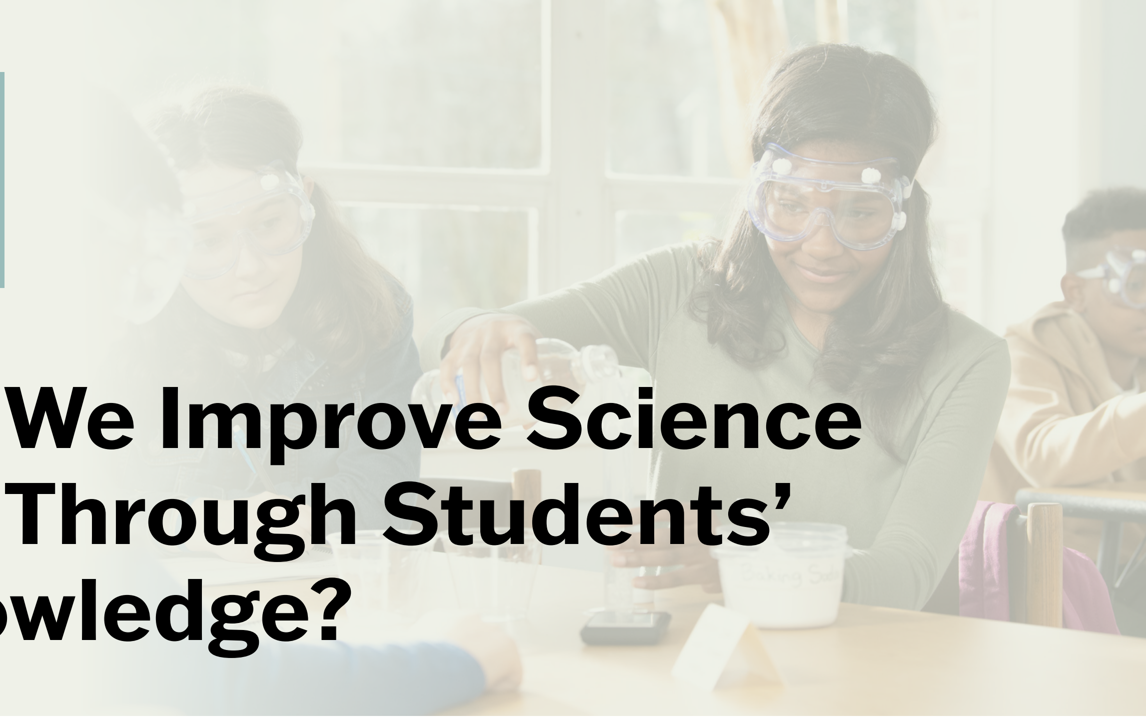
GREAT MINDS

every child is capable of greatness



How Can We Improve Science Learning Through Students' Prior Knowledge?

QUICK LINKS

For too long, K–12 science education has been less of an instructional priority than English language arts and math, especially in the early grades. Treating each content area in silos has prevented many schools from finding time for science instruction in the early grades, and students have missed out on opportunities to make cross-curricular content connections and begin to build enduring knowledge.

Research shows that to help students build enduring science knowledge, science curricula for all students, including young learners, must offer rich content and coherently build knowledge. However, research also reveals that curriculum materials often not only fail to provide students with these content-rich experiences—they also frequently underestimate what students are capable of in the early grades. Many programs lack rigor and engaging content for students, and they often reduce science instruction to a set of disconnected facts and processes.

Therefore, there is a clear call to action from the science education community: To meet the demands of the jobs of the future *and* to provide students with the knowledge and skills they need to be citizens of the world, science education in the US must combine scientific ideas, practices, and concepts through a three-dimensional approach starting in the earliest grades. By grappling with science through multiple dimensions, students can build knowledge by doing the work of scientists.

What Research Tells Us Students Can Do, and How Current Expectations for Students Fall Short of Their Potential

In *Taking Science to School*, the National Research Council (2007) argues that all young children are able to learn science but curricula too often underestimate what young children are capable of understanding in science. In chapter 3, the council evaluates a body of research to conclude the following: "Even when they enter school, young children have rich knowledge of the natural world, demonstrate causal reasoning, and are able to discriminate between reliable and unreliable sources of knowledge. In other words, children come to school with the cognitive capacity to engage in serious ways with the enterprise of science" (vii).

Not only are young students ready to engage deeply in science learning, but they arrive to the classroom having already started to engage informally in science. In an article that evaluates how to effectively implement the Next Generation Science Standards (NGSS), Carlson, Davis, and Buxton (2014) note that from an early age, students "[build] on prior knowledge, through experience with natural phenomena and engagement with others. Each person's understandings are shaped by his or her cultural, linguistic, and economic backgrounds and contexts among other factors" (1). Students begin to make sense of the world by constructing their own understanding of how the world works even before they enter school.

When students do begin school, educators have an opportunity to leverage this prior science knowledge to build a science learning community in the classroom. However, when students bring inaccurate or incomplete knowledge to the science classroom, a common instructional approach is to immediately try to correct their misunderstanding. This approach may prevent students from reconciling their existing knowledge with what they learn in school (Campbell, Schwarz, and Windschitl 2017). To leverage students' existing knowledge effectively, instructional materials should encourage students to engage in scientific sense-making, to ask questions, and to build from their existing knowledge authentically.

What exactly is scientific sense-making? A review of studies on scientific sense-making led researchers Cannady et al. (2019) to conclude that the most effective science instruction includes "both a body of knowledge and a set of processes by which the knowledge is produced" (1). Science is not just a body of knowledge, but it is often taught as such: The student's role is simply to receive information. This approach to science instruction does students—and the scientific community as a whole—a disservice because many science questions remain unanswered, and many discoveries have yet to be made.

To that end, research indicates that teachers should guide students to see science from a constructivist standpoint—to encourage them to not only learn about science but also to engage as scientists themselves, actively investigating scientific phenomena, asking questions, and taking a journey of discovery. Furthermore, as students learn about past discoveries, they should also explore *how* scientists made their discoveries. To meet their full learning potential and develop their potential as participants in the scientific community, students must be exposed to robust science instruction that helps them develop scientific sense-making, build enduring knowledge of science, and understand how to approach science phenomena.

Current Science Instruction and Its Effect on Student Knowledge Building

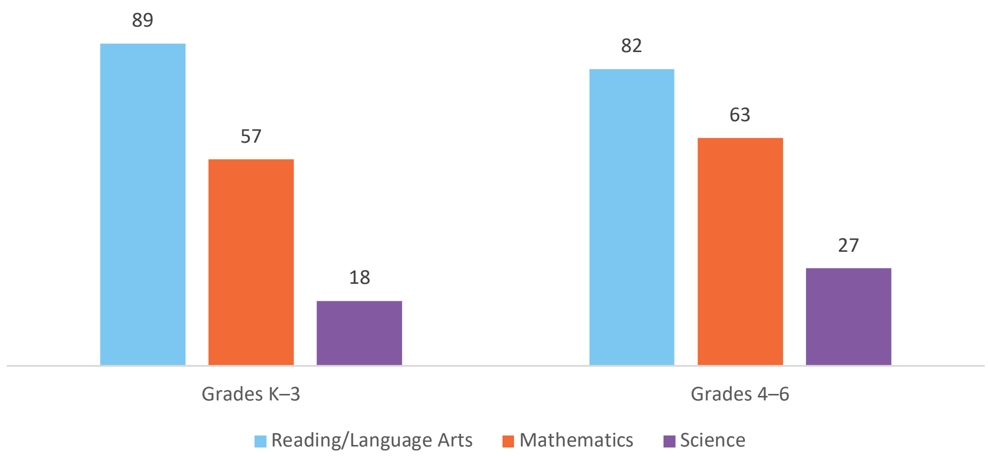
Common Features of Current Science Instruction

Students need the opportunity to make sense of the world and of science, which requires more than learning science facts and processes in isolation; it requires a coherent, engaging learning experience that promotes scientific discourse and that clearly illustrates how scientific ideas, practices, and concepts relate. But for many students across the US, science instruction—when it occurs—is not coherent, engaging, and in-depth.

Carlson, Davis, and Buxton (2014) detail how science curricula and learning experiences in the US vary across and between the elementary and secondary levels, and the researchers share the instructional issues that exist at both levels. One major issue is the lack of instructional time devoted to science teaching. They note that in many schools, at the elementary level in particular, science is taught infrequently. When science instruction does occur, it tends to focus on activities rather than sense-making.

Recent National Assessment of Educational Progress (NAEP) Science survey results confirm the paucity of science instruction. For instance, 24 percent of grade 4 students had teachers who reported spending less than two hours a week teaching science (The Nation's Report Card, n.d.). The 2020 National Survey of Science & Mathematics Education reveals similar results: Teachers in grades K–3 reported spending an average of only 18 minutes per day on science instruction, and teachers in grades 4–6 reported spending an average of only 27 minutes per day.

Average Number of Minutes Per Day Spent Teaching Each Subject in 2018



Data source: *2018 NSSME+: Trends in US Science Education from 2012 to 2018*.

Further Reading: Science Should Not Be an Elementary School Elective

Moreover, when elementary students do have the opportunity to engage in science, they often do not have the opportunity to integrate their prior knowledge with the information they encounter in the classroom. As Campbell, Schwarz, and Windschitl (2016) explain, the traditional approach to teaching science often advocates "stamping out" misconceptions and "stamping in" correct ideas (69). As a result, instead of integrating new knowledge with prior understandings, students simply replace their existing knowledge with, or memorize, "correct" information that they may not fully understand. Additionally, science instructional materials often fail to address gaps in students' prior knowledge. Instead, many textbook authors "write as if the reader has as much prior knowledge as they do" (Ulerick, n.d.). To truly understand science, students must build from a foundation of prior knowledge—and then they must evaluate, grapple with, and update this knowledge in light of new information.

At the secondary level, science instruction often alternates between fact-oriented lectures and laboratory experiments designed to reinforce key ideas. However, too often these lectures and experiments do not provide a coherent learning experience, and they deny students the opportunity to apply science to an authentic context. Laboratory experiments, in particular, can be prescriptive and constraining, thereby preventing students from exploring, testing, and gathering evidence the way a scientist in the field or a lab might (Carlson, Davis, and Buxton 2014). When students are limited to experiments in which the steps are already mapped out, they do not authentically engage in the work of investigating an unknown. Through such experiments, students merely demonstrate that they can follow a process to arrive at the intended outcome; they do not demonstrate their ability to solve science problems or to think critically about science questions.

Do Students Who Engage in Science Activities Regularly Build More Knowledge?

Unfortunately, far too few students in the US engage in activities that involve scientific inquiry. The survey administered as part of the 2019 NAEP Science assessment asked grade 4 teachers to indicate how often their students engaged in scientific inquiry–related activities, including "working with other students on a science activity or project; talking about the measurements and results from their hands-on activities; discussing the kinds of problems that engineers can solve; and figuring out different ways to solve a science problem" (The Nation's Report Card, n.d.). According to the survey results, 30 percent of all grade 4 students had teachers who reported engaging their classes in inquiry-related activities "never to once or twice a year" (The Nation's Report Card, n.d.).

The NAEP survey results also reveal a direct correlation between student engagement in scientific inquiry–related activities and student performance on the NAEP science assessment. The same 30 percent of grade 4 students who had the fewest opportunities to engage in inquiry-related activities had an average score of 149 on the NAEP science assessment, while students who engaged in inquiry-related activities "once or twice a month" had an average score of 154 and those who engaged in these activities "once or twice a week to every day" had an average score of 157 (The Nation's Report Card, n.d.) These data indicate that students who engaged in scientific inquiry performed better on the NAEP science assessment.

The NAEP science assessment administered the same survey to grade 8 students. Even in grade 8, 42 percent of students reported that they participated in scientific inquiry–related activities "never to once in a while" (The Nation's Report Card, n.d.). And as with grade 4 students, grade 8 students who had fewer opportunities to engage with inquiry-related activities performed lower on the NAEP science assessment. The 42 percent of students who engaged least often with these activities had an average score of 152, while students who engaged in inquiry-related activities "sometimes" had an average score of 158 and those who engaged in these activities "often to always" had an average score of 157.

When instructional materials present science as a series of facts for students to memorize and processes for them to execute, students are not able to build enduring knowledge about science. To understand science content and build enduring knowledge, all students must engage in scientific inquiry–related activities, beginning in the early grades. Students must have opportunities to cement scientific ideas (Disciplinary Core Ideas) by engaging in scientific practices (Science and Engineering Practices) and by applying the concepts (Crosscutting Concepts) that underlie these ideas. This three-dimensional, NGSS-centered approach allows students to reconcile their existing knowledge with new learning. This approach to science knowledge acquisition teaches them how to make sense of the world around them, both within and across science domains, and it provides them with the tools they need to acquire in-depth knowledge throughout their lives.

Four Steps for Improving Your Students' Science Education

1. **Select a science curriculum that focuses on coherence within and across grades, beginning in elementary school.**

   Current practice: Science instruction is squeezed out of the school day, and when science instruction does occur, it neither promotes a deep understanding of science nor facilitates knowledge building.

   Research in action: Science instruction should begin in early grades and should support knowledge building from the outset. In an article about critical features of science curricula, Roblin, Schunn, and McKenney (2017) conclude that "materials with a larger scope, such as comprehensive curricula or curriculum sequences, were more likely to yield positive student outcomes" (16). These findings support earlier research that found "curriculum materials with a larger scope (e.g., a three-year curriculum covering all key contents for middle school science or a sequence of three coordinated units about energy) may help students build their understanding over time and develop increasingly sophisticated ideas (Fortus, Sutherland Adams, Krajcik, and Reiser, 2015; Stevens, Delgado, and Krajcik, 2015) thereby generating a positive impact on student learning" (Roblin, Schunn, and McKenney 2017, 4–5). Furthermore, Shin et al. (2009) summarize research conducted by Schmidt, Wang, and McKnight (2005) on the Third International Mathematics and Science Study (TIMSS) that found that a coherent curriculum is the primary predictor of student achievement in science.

Similarly, Carlson, Davis, and Buxton (2014) report that "effective curriculum materials are coherent, rigorous, and focused on big ideas. These materials have lessons sequenced to unfold sensibly, with ideas building on one another toward the development of an integrated understanding and support for students to see the coherence (Roseman, Linn, & Koppal, 2008)" (2). In the same article, the authors assert that instructional materials laid out in this way help students develop sense-making by promoting increased discourse in the classroom (3). This discourse allows students to develop critical thinking and language skills while learning science.

Further, a 2020 report from the Southern Regional Education Board (SREB) emphasizes the importance of providing students with knowledge-building curriculum materials in early grades. According to the report, "waiting until the middle grades to give science an equal place among the academic subjects not only handicaps students' performance in reading—background knowledge is necessary for comprehension—it means they have less time to develop important thinking skills that will benefit them in all subjects" (1).

To build enduring science knowledge, students need early exposure to a coherent knowledge-building curriculum that harnesses their natural curiosity and fosters the critical thinking and language skills scientists rely on. This kind of curriculum equips students for deeper engagement in science and for continual knowledge building as they progress through school.

2. **Integrate rather than isolate science instruction.**

Current practice: Science is treated as a discrete subject, and curricula rarely help connect science with English language arts (ELA) and math instruction in ways that reinforce learning across all content areas.

Research in action: Science instruction should reinforce ELA and math concepts and help students build knowledge and as they make content-specific and cross-curricular connections. The 2020 SREB report notes a tendency in instruction to view science as a separate subject from reading and math. This occurs even in elementary school, when one academic discipline can be more easily integrated into others than in later years. In fact, they argue, students can develop vocabulary and background knowledge at the same time as scientific content knowledge: "Knowledge and reading skills are inextricably intertwined" (3). The report highlights that as students engage with texts, "they practice skills important to both reading and scientific inquiry: metacognition, acquiring information, solving problems and making connections" (3). In other words, reading texts during science instruction helps students develop their understanding of science concepts—and in turn, that understanding serves as background knowledge that aids reading comprehension. A 2021 guide from the Council of Chief State School Officers on how to use science to bolster literacy skills in elementary education offers example models for how educators can integrate science content with literacy instruction.

Math also integrates well with science instruction. The SREB report points out that both science and math require "the ability to analyze and interpret data, find patterns in that data, and develop models to make predictions. The logical and analytical nature of mathematical thinking, in turn, strengthens one's ability to engage in scientific inquiry" (3). Incorporating math in science instructional materials reinforces math concepts and helps students develop scientific sense-making.

The National Academies of Sciences, Engineering, and Medicine sum up the recommendation to integrate English and math into science education. In their 2021 report, *Call to Action for Science Education: Building Opportunity for the Future*, the committee argues that "even the youngest children are capable of engaging in science investigations. Making science a fundamental part of K–5 instruction leverages their natural curiosity about the world. In addition, science provides a rich context for building competencies in math and English/Language Arts and for developing language" (38).

3. **Integrate scientific ideas, practices, and concepts through three-dimensional learning.**

Current practice: Science is presented as a series of facts. Science instruction rarely illustrates how scientific ideas relate to science practices and concepts.

Research in action: Instructional materials should illustrate to students how scientific ideas relate to fundamental concepts and should encourage students to build knowledge by engaging in the science practices that scientists follow. The *Framework for K–12 Science Education* (2012) asserts that "a narrow focus on content alone has the unfortunate consequence of leaving students with naïve conceptions of the nature of scientific inquiry and the impression that science is simply a body of isolated facts" (41). The *Framework*, therefore, calls for science instruction to follow a three-dimensional approach that synthesizes Disciplinary Core Ideas, or content, with Science and Engineering Practices and Crosscutting Concepts, or inquiry-related activities. Students can deepen their understanding of the Disciplinary Core Ideas and develop their scientific sense-making by engaging in Science and Engineering Practices and applying the lens of Crosscutting Concepts. Educators can support students' three-dimensional learning by guiding students to apply Crosscutting Concepts to reconcile their existing knowledge and their new learning.

Science curriculum must teach students in a three-dimensional manner, with equal attention to each component. Students should focus on sense-making, but they will still require explicit instruction to help guide them through content acquisition. While student inquiry that taps into curiosity should be at the forefront of science education, educators play a crucial role in guiding knowledge development.

4. **Connect science to students' experiences.**

   Current practice: Instructional materials often treat science as a series of settled facts that are unrelated to students' lives and experiences.

   Research in action: In its 2021 report *Call to Action for Science Education: Building Opportunity for the Future,* the National Academies of Sciences, Engineering, and Medicine calls for science instruction that encourages students to "make connections between the experiences they have in their homes and communities and the content they are learning in science" (23). Research shows that from a young age, students use their experiences to begin making sense of the world. For students to engage deeply with science instruction—for them to apply the content they learn and connect it to their existing knowledge—students must find science relevant to their lives.

   It is therefore important that instructional materials select science phenomena that students can potentially relate to phenomena they may have observed in their own lives. For example, perhaps students studying hurricanes have never experienced a hurricane but have experienced a tornado or severe flooding. Students can draw connections between the impact of an unfamiliar natural disaster and that of a weather event they have experienced. Similarly, perhaps students learning about orbit and rotation can draw from their firsthand knowledge about where in the sky the Sun and Moon are visible at different times of day. So often, students can observe in the real world the topics that are taught in a textbook. Science instruction should allow for students to develop scientific explanations for their experiences and learn to see science as part of their daily lives.

The *Framework for K–12 Science Education* and the development of the Next Generation Science Standards ushered in a new era of opportunity for science education. Unfortunately, in the 10 years since the NGSS emerged, science instruction has made too little progress toward providing all students with the rigorous, coherent, knowledge-building experiences they need to become informed citizens of the world. When taught in early elementary school, science instruction still too often fails to spark students' innate curiosity. And secondary science instruction is still often taught as settled information and rote processes, reducing learning to disconnected facts and activities rather than encouraging students to apply content through inquiry-related activities. From the first day of school, all students deserve a high-quality, coherent, knowledge-building curriculum that builds on their existing knowledge through authentic experiences, supports literacy and mathematical learning, and helps them achieve greatness.

WORKS CITED

Campbell, Todd, Christine Virginia Schwarz, and Mark Windschitl. 2016. "What We Call Misconceptions May Be Necessary Stepping-Stones Toward Making Sense of the World." Science and Children, 83(3): 69–74. https://doi.org/10.2505/4/sc16_053_07_28.

Cannady, Matthew, Paulette Vincent-Ruz, Joo Man Chung, and Christian D. Schunn. 2019. "Scientific sensemaking supports science content learning across disciplines and instructional contexts." Contemporary Educational Psychology. Volume 59. https://doi.org/10.1016/j.cedpsych.2019.101802.

Carlson, Janet, Elizabeth Davis, and Cory Buxton. 2014. "Supporting the Implementation of the NGSS through Research: Curriculum Materials." National Association for Research in Science Teaching. Accessed January 20, 2022. https://narst.org/sites/default/files/2019-10/Curriculum_Materials_061914.pdf.

NAEP Report Card: Science. n.d. "Student Experiences." Accessed January 20, 2022. https://www.nationsreportcard.gov/science/student-experiences/?grade=4.

National Academies of Sciences, Engineering, and Medicine. 2021. Call to Action for Science Education: Building Opportunity for the Future. Washington, DC: The National Academies Press.

National Research Council. 2007. Taking Science to School: Learning and Teaching Science in Grades K–8. Washington, DC: The National Academies Press.

National Research Council. 2012. A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. The National Academies Press.

Roblin, Natalie Pareja, Christian Schunn, and Susan McKenney. 2017. "What are critical features of science curriculum materials that impact student and teacher outcomes?" Science Education. Volume 102: Issue 2, 260–282. https://doi.org/10.1002/sce.21328.

Schmidt, William H., Hsing Chi Wang, and Curtis C. McKnight. 2005. "Curriculum coherence: an examination of US mathematics and science content standards from an international perspective." Journal of Curriculum Studies. Volume 37, Issue 5: 525–559. https://doi.org/10.1080/0022027042000294682.

Shin, Namsoo, Shawn Y. Stevens, Harry Short, and Joseph Krajcik. 2009. "Learning Progressions to Support Coherence Curricula in Instructional Material, Instruction, and Assessment Design." Paper presented at the Learning Progressions in Science (LeaPS) Conference, June 2009, Iowa City, IA. Accessed January 20, 2022. https://education.msu.edu/projects/leaps/proceedings/Shin.pdf.

Smith, P. Sean. 2020. 2018 NSSME+: Trends in US Science Education from 2012 to 2018. Horizon Research Inc. http://horizon-research.com/NSSME/wp-content/uploads/2020/04/Science-Trend-Report.pdf.

Southern Regional Education Board. 2020. "Elementary Science: Equipping Students Through Inquiry and Integration." Accessed January 20, 2022. https://www.sreb.org/sites/main/files/file-attachments/sciencebrief_may2020.pdf?1591981783.

Ulerick, Sarah L. n.d. "Using Textbooks for Meaningful Learning in Science." *National Association for Research in Science Teaching*. Accessed January 20, 2022. https://narst.org/research-matters/using-textbooks-for-meaningful-learning.