FEATURE ARTICLE

Quantitative Reasoning in the Context of Science Phenomena

PAUL K. STRODE, LOUISE S. MEAD, MOLLY STUHLSATZ, MELISSA K. KJELVIK, ELIZABETH H. SCHULTHEIS, ALEXA R. WARWICK, AUDREY MOHAN, JULIE A. MORRIS, ROBERT MAYES

Abstract

Over the last decade, reform in science education has placed an emphasis on the science practices as a way to engage students in the process of science and improve scientific literacy. A critical component of developing scientific literacy is learning to apply quantitative reasoning to authentic scientific phenomena and problems. Students need practice moving fluidly (or fluently) between math and science to develop a habit of mind that encourages the application of quantitative reasoning to real-world scenarios. Here we present a student-facing model that challenges students to think across these two fields. The model brings together math and science with a goal to increase scientific literacy by engaging students in quantitative reasoning within the context of scientific questions and phenomena. In the classroom, the model serves to help students visualize the logical and necessary moves they make as they use quantitative reasoning to connect science practices with mathematical thinking.

Key Words: *scientific literacy; data literacy; phenomenon; NGSS; quantitative reasoning; science practices; contextualization.*

○ Introduction

Developing students' scientific literacy is dependent on building and supporting their quantitative reasoning skills and ability to work with data. As they progress through their education, students need to develop quantitative skills that include understanding and interpreting graphical and tabular data as well as generating, analyzing, processing, visualizing, and making sense of raw data. Unfortunately, the United States continues to lag behind other nations on performance in these skills, as measured by standardized testing. For example, the U.S. student sample ranked 17th and 34th globally in science and math skills, respectively, on the most recent Programme for International Student Assessment (PISA) of 15-yr-olds (OECD, 2023). Studies from the last several decades indicate minimal improvement in quantitative literacy among students in the United States between the 1970s and 2015 (Mullis et al., 2015). Scores from the Trends in International Mathematics and Science Study (Egan et al., 2022) and a report on the status of quantitative literacy in the United States (Wilkins, 2000) also suggest that although U.S. students tend to be confident about their mathematical ability, their ability to apply quantitative skills falls short.

The science education experience should engage students in moving freely between science and math so that they are able to use data to evaluate, defend, and support or reject claims.

○ Integrating Quantitative Reasoning with a Natural Phenomenon or Scientific Problem

Quantitative reasoning has been defined in different ways across the literature, but generally refers to a habit of mind pertaining to the power and limitations of quantitative evidence in the evaluation of real-world scenarios (Mayes & Myers, 2014; Kjelvik & Schultheis, 2019). To improve students' quantitative reasoning ability, math and science education reforms have shifted the focus away from memorization of facts and toward the acquisition and application of skills and practices within disciplinary context. For example, both the Common Core State Standards (CCSS; National Governors Association, 2010) and the Next Generation Science Standards (NGSS; NGSS Lead States, 2013) contain math standards focused on quantitative reasoning. The reforms endorse the application of mathematical tools in context, stating that mathematically proficient students can use mathematics to solve problems or investigate phenomena arising in everyday life (National Governors Association, 2010). Similarly, *A Framework for K-12 Science Education* (National Research Council, 2012) and the NGSS include integration of analysis and interpretation of data and mathematics and computational

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thinking within the context of science by engaging students in Science and Engineering Practices (SEPs). There are many intersections between these sets of standards (Stage et al., 2013). Indeed, using models appears in *CCSS M4 - Model with mathematics*, *NGSS SEP2 - Develop and use models*, and *NGSS SEP5 - Use mathematics and computational thinking*. However, many skills needed for quantitative reasoning are solely within mathematics education (e.g., *CCSS M2- reason abstractly and quantitatively*) or science education (e.g., *NGSS SEP4 - analyze and interpret data*).

We argue here that educational reform within disciplines is not enough. Quantitative reasoning should be taught across subject areas, and not as a discrete subject within mathematics (Capraro et al., 2014). The science education experience should engage students in moving freely between science and math so that they are able to use data to evaluate, defend, and support or reject claims. An effective model for integrating quantitative reasoning into science education goes beyond the vision of NGSS and instead requires the back-and-forth movement between the content of science—within the context of a natural phenomenon or scientific problem—and mathematical skills, modeling how most science is done. This approach combines appropriate mathematical tools with real scientific questions, intentionally engaging students in quantitative reasoning.

Quantitative reasoning when applied within authentic scientific scenarios emphasizes the importance of math, and the inexorable links between the disciplines (Mayes et al., 2014; Steen, 2004; Schultheis & Kjelvik, 2020). In a study of undergraduate students, Uzpen et al. (2019) found that scientific literacy is correlated with quantitative literacy and they suggest that improving scientific literacy requires the development of quantitative literacy skills. As Madison (2009) notes, significant change in developing quantitative reasoning skills in students requires a concerted effort across all educational levels and disciplines, especially as quantitative reasoning skills become increasingly important in the workplace as well as everyday life (Dumford & Rocconi, 2015). Scientists apply quantitative reasoning skills directly in context of the system they are studying and are trained to undergo these transitions from math to science seamlessly and without categorization. Mirroring the work of scientists, students can engage in learning experiences that reflect how science is actually done, for example using an authentic dataset to answer a scientific question relevant to personal decision-making or a scientific phenomenon under investigation by the scientific community today (Kjelvik & Schultheis, 2019; Schultheis & Kjelvik, 2020).

○ A Model for Applying Quantitative Reasoning in the Classroom

Quantitative reasoning is more than simply using mathematical concepts and algorithms; it requires taking mathematics out of the abstract and making connections to real-world problems, thereby drawing out and elucidating the importance of mathematics and the use of quantitative reasoning within context (called QR-C). Mayes and Myers (2014) define QR-C as "mathematics and statistics applied in real-life, authentic situations that impact an individual's life as a constructive, concerned, and reflective citizen." Indeed, a primary and critical role of the science teacher is to provide students with as many opportunities as possible to practice QR-C in a scientific context.

While some research areas in science primarily utilize qualitative and descriptive methodologies (e.g., cataloging newly discovered species, mapping geological formations), many scientists employ QR-C in most aspects of their work as they identify variables and accumulate data to test hypotheses, evaluate data using statistical tests, and develop mathematical models to further delineate possible causal relationships (e.g., measuring the effect of a drug on blood pressure, predicting the growth rate of bacteria under different conditions, modeling climate change). Eventually, scientists return to their original questions or hypotheses to evaluate the scientific contribution of their findings in the context of other research. This habit of mind reflects how science is done and should be intentionally integrated across all science education.

Figure 1 proposes a pathway for integrating QR-C into science education instruction. Students on the pathway move back and forth between scientific concepts and mathematics to explore phenomena and solve problems commonly encountered in authentic studies. Students begin by foregrounding science as they engage with an authentic scientific problem or phenomenon. For example, a teacher may instruct students to go outside, make observations of the natural world, look for testable patterns, and describe a suspected pattern with a generalizing hypothesis (Strode, 2015; Lane, 2024). Students then move into the area of QR where they consider the observation, pattern, or problem numerically or in a quantitative way, identifying variables and thinking how quantitative sampling and measurement can be applied to the problem (Mayes & Myers, 2014). Students then foreground math in their work to engage with the problem, for example, through measurement, proportional reasoning, and descriptive statistics, and have an opportunity to develop quantitative reasoning skills. More advanced students may develop a quantitative model in order to explore trends and make predictions related to the problem. Students then move back through QR and back into science as they reason with the processed data in the context of the problem or natural phenomenon, engaging in interpretation, constructing explanations, defending claims based on the evidence, applying inductive reasoning to the original natural phenomenon, and generating an explanatory hypothesis (Strode 2015). The transparency of the QR-C approach for students is important and teachers should consider showing students the visualization of QR-C provided by Figure 1 and describing the process for them.

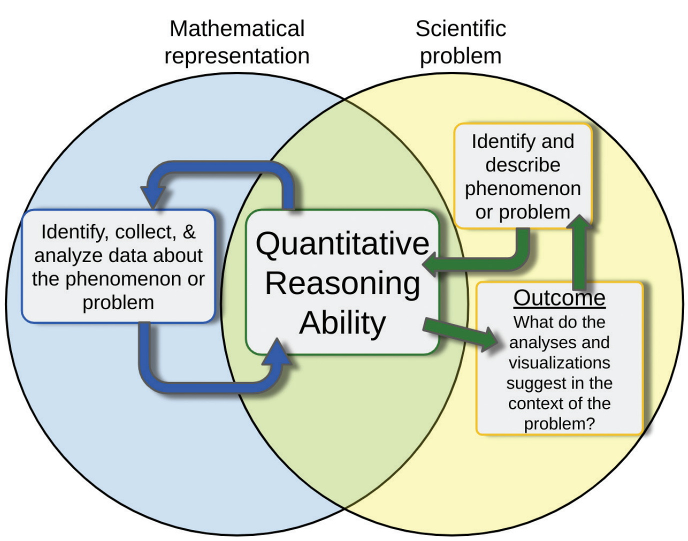

Figure 1. General graphical representation of a path that engages students in quantitative reasoning in the context of a phenomenon or scientific problem.

○ Theory into Practice: Examples from the Biology Classroom

Engaging students with authentic data improves data literacy and makes learning scientific concepts more meaningful and exciting for students (Kjelvik & Schultheis, 2019). As an example of this practice, specifically in light of QR-C, one of us (Strode) with two of his former high school students, describe a data collection activity in his high school biology course that engages students in using pitfall traps and diversity indices to develop quantitative reasoning to test edge effect theory (Prinster et al., 2019). Before they engage in the authentic data collection activity, student groups are provided with hypothetical counts of individual species of birds in two distinctly different communities (the phenomenon) and are asked to quantify and compare the numbers of species in each community (i.e., species richness). The students are then challenged to use all of the data—species richness *and* the number of individuals within each species—to determine mathematically which community has greater species diversity (the problem). As student groups struggle, they are provided with hints, for example to notice that the individuals among species in the two communities are distributed unevenly. Students begin to reason that species diversity must account for both richness and evenness. Students are also asked to think about and discuss in what ways the two communities might function differently—for example, how competition for food might look different in each community. Student groups begin designing ways to use math to describe both species richness and evenness in the two communities. In large classes, at least one group is likely to suggest calculating the proportion of the total number of individuals in each community occupied by individuals within each species. Indeed, calculating proportions is the first step in calculating diversity indices and students are foregrounding math at this point. Ideas from all groups are considered before students are shown the Simpson's and Shannon's Diversity equations (see Prinster et al., 2019) and discuss how the indices are interpreted. Students are also shown the general QR-C model (Figure 1) followed by Figure 2 to illustrate the logical process with which they have just engaged. As mentioned above, at this point in a course, students could already

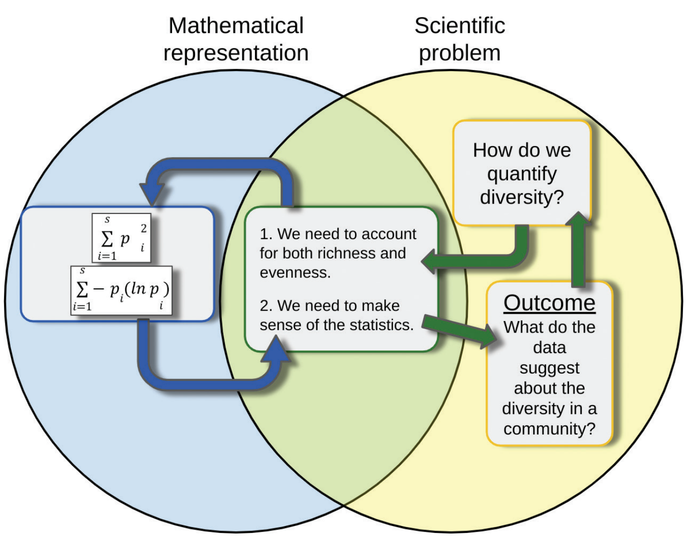

Figure 2. A specific example of the pathway where students use QR-C to develop a mathematical model for quantifying both the richness and evenness of species in a target community.

be familiar with the QR-C approach and the visualization of QR-C provided by Figure 1.

Too often teachers provide students with a mathematical equation and then show them how it is used in the context of biology. Instead, we encourage teachers to identify the activities in their courses where the QR-C approach can be employed, then allow their students to do the "heavy lifting" of investigating the phenomenon or solving the scientific problem with math. Again, as an example from one of our classrooms (Strode), students are provided a simple challenge during a cell cycle unit to derive a mathematical method for creating a relative abundance of mitotic cells from onion root tip or whitefish blastula slides before they are shown how the mitotic index is used in tumor histology. A more complex challenge shown to work well in a hybrid AP/IB Biology course has students derive the Hardy-Weinberg (H-W) equation by asking them to quantify the distribution of three genotypes in a population where the proportion of two alleles is known. Students are then shown how H-W is used in practice. For example, how H-W is used in the context of the conservation of endangered species suffering from an extinction vortex and the loss of genetic diversity (e.g., Blyth et al., 2020) or how H-W is used to predict the incidence of human diseases in populations by estimating, for example, the number of carriers of sickle cell trait in a population (e.g., Piel et al., 2016).

○ Resources and Research for Bringing QR-C into the Classroom

Implementation of QR-C-focused curricula at the K–12 level faces many challenges, including curriculum and assessment development, teacher training, and the educational research required to test and validate methods. Moreover, additional curricula need to be developed to address QR that aligns with NGSS (Krajcik et al., 2014).

To implement this fundamental shift in their classrooms, teachers will need support and time to reflect on student thinking and adapt their teaching to meet student needs (Wilson, 2013). In a survey of 330 teachers in the United States, the majority reported a limited scope of datasets and tools that they use in their classrooms, even though the availability of data and educational tools continues to increase rapidly (Rosenberg et al., 2022). Providing professional development for science educators that reflects an emphasis on pedagogical content knowledge for QR-C is essential to support future implementation of instructional materials in the classroom. Effective strategies need to be explicit and teachers need additional guidance with the scientific practices to implement instructional materials with fidelity. If we expect teachers to increase the sophistication and depth of QR-C discussions with their students, we must ensure that teachers are comfortable with their own ability to discuss and solve QR-C problems. This expectation requires opportunities for teachers to develop and hone the skills necessary to implement QR-C in authentic ways they have experienced themselves, such as data-rich research immersion experiences and training on how to use QR-C-focused educational resources with their students. Leveraging existing school or district-based professional learning communities may be a mechanism to provide long-term support to teachers as they begin to integrate new strategies and knowledge in their classrooms. At the college level, progress in this area has already begun with the initiation of faculty mentoring networks across institutions (see the Quantitative Undergraduate Biology Education and Synthesis project: QUBES, https://qubeshub.org; Donovan et al., 2015) and institutional-based professional development opportunities focused on integrating disciplinary content with the practices of science (Cooper et al., 2015).

Our understanding of student QR abilities, and how students develop these abilities over time, is just beginning. Mayes et al. (2014) developed a learning progression for QR in the context of environmental science through interviews and written assessments with students in grades 6–12. Through an iterative analysis of student responses, the researchers identified four components of quantitative reasoning in context and describe student levels for each. This learning progression provides a framework that could be used by teachers to assess the current competency of their students and identify appropriate skills and tasks to move students to the next level (see Table 2 in Mayes et al., 2014). While this learning progression has been around for over a decade, it is not currently in a format that is easily accessible for teachers. Work still needs to be done to make classroom and teacher-friendly tools available. A recent review of data literacy assessments determined this to still be an emerging field in need of high-quality tools (Cui et al., 2023).

At the undergraduate level, efforts have documented what faculty view as QR competencies and whether their students are prepared with those skills and abilities (Cleveland et al., 2024). Several programs have made steps to assess student understanding in QR. Angra and Gardner (2018) developed a rubric to assess student abilities surrounding graph creation and interpretation, key QR-C skills. With colleagues, they used this rubric to determine undergraduate student abilities in graphing practices in both digital (GraphSmarts) and pen-and-paper environments (Gardner et al., 2021). In addition, Data Nuggets, resources designed to provide students with opportunities to explore authentic datasets and scientific research (Schultheis & Kjelvik, 2015), have developed an assessment tool to measure student QR attitudes and abilities. When engaging with a Data Nuggets activity, students apply QR skills in context to construct and interpret graphs, conduct data analysis, and construct scientific explanations. Assessment of these skills showed that when using Data Nuggets to practice QR in context, students improved in the QR-C skills of constructing scientific explanations and using data as evidence to support claims (Schultheis et al., 2022). The assessment developed for this study is available to be used to study student QR abilities in the context of data literacy and attitudes about science (Schultheis et al., 2022).

Research on science teaching and student learning should include the following five key concepts: generating ideas, framing those studies in a research setting, examining the research questions in small studies, generalizing the results in larger more refined studies, and extending the results over time and location (Scheaffer, 2008). These research efforts should help us to understand how students build on prior knowledge as they practice QR in the context of natural phenomena and scientific problems, and could be used to develop assessment tools to measure student development over time.

○ Conclusion

Numbers have both the "power to influence and the power to inform" (Lutsky, 2008). Today it is imperative that all students complete their education with the quantitative reasoning (QR) abilities necessary to navigate an ever-increasing quantitative landscape where analytical skills that allow us to move back and forth between scientific concepts and mathematics are essential. Indeed, the COVID-19 global health crisis of 2020–2021 put a spotlight on a general lack of public QR skills as the misinformation and disinformation "infodemic" was able to be spread by everyday citizens who may have been unable to critically process a flood of (scientific) health concepts and data (Calleja et al., 2021). The goal for education should be for students to not limit themselves to either science or math but rather engage in QR throughout their learning and in the context of a specific problem or phenomenon. By integrating QR into curricula using relevant and real-world scientific questions and phenomena, students will move beyond a basic understanding of mathematical concepts and develop their ability to interpret, compare, reason using evidence, and apply that reasoning to real scientific scenarios. Providing students with experiences in these areas should lead to improved understanding of the process of science and the ability to defend and critique claims encountered in public discourse using a scientific approach.

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References

Angra, A., & Gardner, S. M. (2018). The graph rubric: Development of a teaching, learning, and research tool. *CBE—Life Sciences Education, 17*(ar65).

Blyth, C., Christmas, M. J., Bickerton, D. C., Faast, R., Packer, J. G., Lowe, A. J., & Breed, M. F. (2020). Increased genetic diversity via gene flow provides hope for *Acacia whibleyana*, an endangered wattle facing extinction. *Diversity*, *12*(8), 299.

Calleja, N., AbdAllah, A., Abad, N., Ahmed, N., Albarracin, D., Altieri, E., Anoko, J. N., Arcos, R., Azlan, A. A., Bayer, J., Bechmann, A., Bezbaruah, S., Briand, S. C., Brooks, I., Bucci, L. M., Burzo, S., Czerniak, C., De Domenico, M., Dunn, A. G., … & Purnat, T. D. (2021). A public health research agenda for managing infodemics: methods and results of the first WHO infodemiology conference. *JMIR Infodemiology*, *1*(1), e30979.

Capraro, R. M., Capraro, M. M., & Morgan, J. R. (2014). *STEM project-based learning: An integrated science, technology, and mathematics (STEM) approach* (2nd ed), Sense Publishers.

Cleveland, A., Sezen-Barrie, A., Peterson, F., & Lindsay, S. (2024). Quantitative reasoning competencies for student success in introductory biology. *Journal of College Science Teaching*, *54*(3), 212–226.

Cooper, M. M., Caballero, M. D., Ebert-May, D., Fata-Hartley, C. L., Jardeleza, S. E., Krajcik, J. S., Laverty, J. T., Matz, R. L., Posey, L. A., & Underwood, S. M. (2015). Challenge faculty to transform STEM learning. *Science*, *350*(6258), 281–282.

Cui, Y., Chen, F., Lutsyk, A., Leighton, J. P., & Cutumisu, M. (2023). Data literacy assessments: A systematic literature review. *Assessment in Education: Principles, Policy & Practice, 30*(1), 76–96.

Donovan, S., Eaton, C. D., Gower, S. T., Jenkins, K. P., et al. (2015). QUBES: a community focused on supporting teaching and learning in quantitative biology. *Letters in Biomathematics, 2*(1), 46–55.

Dumford, A. D., & Rocconi, L. M. (2015). Development of the quantitative reasoning items on the National Survey of Student Engagement. *Numeracy*, 8(1), 5.

Egan, L., Tang, J. H., Ferraro, D., Erberber, E., Tsokodayi, Y., Stearns, P., & Malley, L. (2022). *U.S. Technical Report and User Guide for the 2019 Trends in International Mathematics and Science Study (TIMSS)* (NCES 2022-049). U.S. Department of Education, National Center for Education Statistics.

Gardner, S. M., Suazo-Flores, E., Maruc, S., Abraham, J. K., Karippadath, A., & Meir, E. (2021). Biology undergraduate students' graphing practice in digital versus pen and paper graphing environments. *Journal of Science Education and Technology, 30*(10), 431–446.

Krajcik, J., Codere S., Dahsah, C., Bayer, R., & Mun, K. (2014). Planning instruction to meet the intent of the Next Generation Science Standards. *Journal of Science Teacher Education*, *25*(2), 157–175.

Kjelvik, M. K., & Schultheis, E. H. (2019). Getting messy with authentic data: Exploring the potential of using data from scientific research to support student data literacy. *CBE—Life Sciences Education*, *18*(2), es2.

Lane, J. (2024). Guest Commentary: Creating a focus on nature with strategies for outdoor learning. *The American Biology Teacher*, *86*(4), 191–192.

Lutsky, N. (2008). Arguing with numbers: Teaching quantitative reasoning through argument and writing. In *Calculation vs. Context: Quantitative Literacy and its Implications for Teacher Education* (pp. 59–74).

Madison B. 2009. All the more reason for QR across the curriculum. *Numeracy*. *2*(1), 1.

Mayes, R. L., Forrester, J. H., Schuttlefield Christus, J. D., Peterson, F., & Walker, R. (2014). Quantitative reasoning learning progression: The matrix. *Numeracy*, 7(2), 1.

Mayes, R. & Myers, J. (2014). Quantitative reasoning: changing practice in science and mathematics. In *Quantitative Reasoning in the Context of Energy and Environment* (pp. 1–35). Sense Publishers.

Mullis, I. V. S., Martin M. O., Loveless T. (2015). *20 Years of TIMSS: International Trends in Mathematics and Science Achievement, Curriculum, and Instruction*. TIMSS & PIRLS International Study Center.

National Governors Association Center for Best Practices. (2010). *Council of chief state school officers, "Common Core State Standards Mathematics"*. Washington, D.C.

National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* National Academies Press.

NGSS Lead States. (2013). *Next generation science standards: For states, by states.* The National Academies Press.

OECD. (2023). *PISA 2022 Results (Volume I): The state of learning and equity in education*. OECD Publishing.

Piel, F. B., Adamkiewicz, T. V., Amendah, D., Williams, T. N., Gupta, S., & Grosse, S. D. (2016). Observed and expected frequencies of structural hemoglobin variants in newborn screening surveys in Africa and the Middle East: deviations from Hardy-Weinberg equilibrium. *Genetics in Medicine*, *18*(3), 265.

Prinster, A. J., Hoskins, J. L., & Strode, P. K. (2019). Pitfall traps and diversity indices: Using quantitative reasoning to test edge effect theory. *The American Biology Teacher* 81:231–238.

Rosenberg, J. M., Schultheis, E. H., Kjelvik, M. K., Reedy, A., & Sultana, O. (2022). Big data, big changes? The technologies and sources of data used in science classrooms. *British Journal of Educational Technology*, *53*(5), 1179–1201.

Scheaffer R. 2008. Scientifically based research in quantitative literacy: Guidelines for building a knowledge base. *Numeracy*, *1*(1), 3.

Schultheis, E. H., & Kjelvik, M. K. (2015). Data nuggets: Bringing real data into the classroom to unearth students' quantitative & inquiry skills. *The American Biology Teacher, 77*, 19–29.

Schultheis, E. H., & Kjelvik, M. K. (2020). Using messy, authentic data to promote data literacy & reveal the nature of science. *The American Biology Teacher, 82*, 439–446.

Schultheis, E. H., Kjelvik, M. K., Snowden, J., Mead, L., & Stuhlsatz, M. A. M. (2022). Effects of Data Nuggets on Student Interest in STEM Careers, Self-efficacy in Data Tasks, and Ability to Construct Scientific Explanations. *International Journal of Science and Mathematics Education,* 21, 1339–1362.

Stage, E. K., Asturias H., Cheuk T., Daro P. A., & Hampton S.B. (2013). Opportunities and challenges in next generation standards. *Science*, *340*, 276–277.

Steen, L. A. (2004). *Achieving quantitative literacy: An urgent challenge for higher education*. Mathematical Association of America.

Strode, P. K. (2015). Hypothesis generation in biology: A science teaching challenge & potential solution. *The American Biology Teacher* 77:17–23.

Uzpen, B., Houseal, A. K., Slater, T. F., & Nuhfer, E. B. (2019). Scientific and quantitative literacy: a comparative study between STEM and non-STEM undergraduates taking physics. *European Journal of Physics*, *40*(3), 035701.

Wilkins, J. L. M. (2000). Special issue article: Preparing for the 21st century: The status of quantitative literacy in the United States. *School Science and Mathematics*, *100*(8), 405–418.

Wilson S. M. 2013. Professional development for science teachers. *Science*, *340*, 310–313.

PAUL K. STRODE (paul.strode@bvsd.org) is a biology and science research teacher at Fairview High School in Boulder, Colorado, USA. LOUISE MEAD (lsmead@msu.edu) is the graduate program director in the Department of Integrative Biology at Michigan State University in East Lansing, Michigan, USA. MOLLY A. M. STUHLSATZ (mstuhlsatz@bscs.org) and AUDREY MOHAN (amohan@bscs.org) are both senior research scientists at BSCS Science Learning in Colorado Springs, Colorado, USA. MELISSA K. KJELVIK (kjelvikm@msu.edu) is a senior research specialist at Michigan State University in East Lansing, Michigan, USA. ELIZABETH H. SCHULTHEIS (schulth5@msu.edu) is education and outreach coordinator at the Kellogg Biological Research Station at Michigan State University in East Lansing, Michigan, USA. ALEXA R. WARWICK (awarwick@msu.edu) is an assistant professor in the Department of Fisheries and Wildlife at Michigan State University in East Lansing, Michigan, USA. JULIE MORRIS (julie.a.morris@du.edu) is a full teaching professor in the Department of Biological Sciences at the University of Denver in Denver, Colorado, USA. ROBERT MAYES (mayes@georgiasouthern.edu) is an emeritus full professor at Georgia Southern University in Stateboro, Georgia, USA.