Opportunities for Integration

Opportunity 1: Incorporate text to help children develop and deepen explanations and to situate reading in conceptually coherent, meaningful pursuits of understanding and solutions.

Text—broadly defined to include a range of materials and genres—can be an important resource for helping children extend and deepen understanding developed as they explore empirical systems and engage with data. In addition, the data needed to support some scientific explanations is not possible or accessible within elementary classroom work. For example, consider the difficulty studying the solar system or directly observing organisms' different strategies and behaviors in tropical rainforests, temperate forests, and the Arctic.

There is evidence that this approach can support literacy learning and reading comprehension as well (Cervetti, Wright, and Hwang, 2016). For example, fourth grade children reading a set of conceptually coherent text sets demonstrate greater understanding, vocabulary knowledge, and learn more from a new text on a related topic than learners engaged in similar instruction with a variety of unconnected texts (Cervetti, Wright, and Hwang, 2016). Further, children benefit from support to understand the features of informational and multimodal text and to learn to navigate these forms of text effectively (Jian, 2016; Prain and Waldrip, 2006). Duke (personal communication, August 27, 2020) points out that science and engineering texts have particular informational text features that other areas of study do not. Therefore, using text to deepen understanding and explanations explored through firsthand investigation with data is a productive context for building children's comprehension and their motivation for reading to find out, and children's use of text features in the service of developing understanding. Literacy learning benefits from motivation, opportunity to build background knowledge, and conceptual coherence. Science learning benefits from incorporating understanding of text features and ways to help children learn to navigate expository text. Providing text to help children deepen their explanations after engaging in investigation, design, and sensemaking supports ongoing sensemaking without usurping it (as providing expository text prior to investigation or design might do). Opportunity 2, below, describes additional designs and uses of text.

Multimodal text (including representations, videos, photographs, interactive diagrams, and simulations) can play an important role in supporting children's learning. These forms of text can be approached as something children connect to phenomena and problems and learn to engage with critically (Dalton and Palincsar, 2013; DeFrance, 2008, Easley, 2020, Henderson, Klemes, and Eshet, 2000; Varelas and Pappas, 2006, Varelas and Pappas, 2013; Wilson and Bradbury, 2016). Texts can also facilitate connections across home and school (Shymansky, Yore, and Hand, 2000; StricklerEppard, Czerniak, and Kaderavek, 2019).

National Academies of Sciences, Engineering, and Medicine 2021. Science and Engineering in Preschool Through Elementary Grades: The Brilliance of Children and the Strengths of Educators. Washington, DC: The National Academies Press. https://doi.org/10.17226/26215.

Opportunities for Integration

Opportunity 2: Incorporate text describing doing and using science and engineering to provide expansive views of science and engineering and help children develop identities and interests.

Text can also be an important resource for helping children develop an understanding of the connections of science and engineering to their lives, including constructing images of the practices that scientists and engineers engage in, developing understanding of who is and can be a scientist and engineer, and understanding the problems that science and engineering have relevance for. In classroom studies that have supported teachers to use text, children developed broader and more nuanced understanding of who does science, where science is done, and what activities scientists engage in, and the nature of scientific understanding—for example as tentative and social (Farland, 2006; TuckerRaymond et al, 2007).

Studies that analyzed the content of science texts designed for young readers have demonstrated that teachers and curriculum designers must choose text carefully and then support engagement with text to develop expansive views of what science and engineering are and who does science and engineering (Ford, 2006; Kelly, 2018; Rivera and Oliveira, 2021). Texts are more likely to represent science knowledge than the doing of science and to present knowledge as facts (Ford, 2006; May et al., 2020), emphasize experiment or observation over other methods of science knowledge development (Ford, 2006), and represent scientists as white and/or male (Kelly, 2018; May et al., 2020). They vary widely in their reference to science practice and science knowledge development, with biographies and other books that emphasize the "lived lives of scientists" through fictional accounts of science work, descriptions of the history of science ideas, and descriptions of contemporary science problem solving more likely to provide descriptions of science practice (Kelly, 2018; May et al., 2020).

Integration may also generate new genres of text. Palincsar and Magnusson (2001) conducted a program of research that culminated in the development and study of an innovative genre of text—one written as a scientist's notebook—that was specifically designed to support children and teachers to approach science text as an inquiry. A hybrid of exposition, narration, description, and argumentation, the notebooks included multiple ways of representing data, including tables, figures, and diagrams. The authors' quasiexperimental study found that both the traditional texts and these "notebook texts" supported learning, but that the children found the notebook texts more enjoyable. Subsequent observational research revealed the ways teachers used notebook texts to help children more effectively represent data from their own firsthand investigations, assume a more critical stance toward texts, and acquire vocabulary.

National Academies of Sciences, Engineering, and Medicine 2021. Science and Engineering in Preschool Through Elementary Grades: The Brilliance of Children and the Strengths of Educators. Washington, DC: The National Academies Press. https://doi.org/10.17226/26215.

Opportunities for Integration

Opportunity 3: Support children in producing texts and inscriptions to represent their reasoning for themselves, the classroom community, and the wider community

Children's ongoing work to document and share their thinking, observations, designs, and findings in science and engineering is a natural fit for developing multimodal composition strategies (which support literacy). Similarly, recent research has found multiple benefits to young children engaging in multimodal composition (e.g., drawing, creating models) to document science observations, including deepening thinking and learning with data (supporting science and engineering).

Thus, first, supporting learners in engaging in multimodal composition supports their learning. Traditional definitions of literacy often consider the four primary modalities of literacy to be reading, writing, speaking, and listening (National Governors Association, 2010). However, many literacy scholars have encouraged expanding the modality of "writing" to include multimodal composition, including using drawing or other imagebased media (e.g., images, symbols, audio, graphical displays, and/or animation) to represent ideas (Dalton, 2012; Dalton and Palincsar, 2013; Siegel, 2006), which is similar to what professional scientists do Krajcik et al., 2021; Lemke, 2004; Suárez, 2020).

In preschool through elementary school, science journals or notebooks provide young children opportunities to observe closely and to represent their observations of objects and phenomena (Brenneman and Louro, 2008; Romance and Vitale, 2001). Engineering programs similarly involve children maintaining some variety of engineering journal or notebook, either hand drawn (Cunningham et al., 2020; Douglas et al., 2018; English and King, 2017; Hertel, Cunningham, and Kelly, 2017; King and English, 2016) or digital (Wendell, Andrews, and Paugh, 2019). Children are often guided with prompts, graphic organizers, suggested headings, or other supports, and reflective prompts support children's learning of key understanding and development of vocabulary (Rouse and Rouse, 2019).

Second, supporting learners in writing explanations and supporting claims with evidence engages and develops science and engineering concepts and also literacy skills relevant to writing persuasive text and supporting claims. Research on written explanations of learners in Grades 3–5 suggest that writing explanations and descriptions of engineering designs supports improved understanding of engineering and science models and ideas (Chambliss, Christenson, and Parker, 2003; Rouse and Rouse, 2019; Songer and Gotwals, 2012) and improvement in learners' explanations and understanding of evidence (McNeill, 2011; Yang and Wang, 2014). This research indicates the need for a coherent and dual focus on the science/engineering and literacy practices. For example, a teacher might engage children in developing explanations in contexts where there is more than one plausible explanation and so they must generate their own explanation/rationale (Zangori and Forbes, 2014), supporting children to both connect and distinguish everyday and scientific argumentation (McNeill, 2011) and providing supports, including models and peer feedback, for particular linguistic features of scientific explanations (Chambliss, Christenson, and Parker, 2003; McNeill, 2011; Seah, 2016).

National Academies of Sciences, Engineering, and Medicine 2021. Science and Engineering in Preschool Through Elementary Grades: The Brilliance of Children and the Strengths of Educators. Washington, DC: The National Academies Press. https://doi.org/10.17226/26215.

Other uses and genres of text can also be beneficial. Numerous studies have documented the role of drawing—both observational records and engaging in developing and revising models—in supporting children's learning in science (e.g., diSessa et al., 1991; Fox and Lee, 2013; Samarapungavan et al, 2017). Science and engineering can be a context where children write persuasive texts to convince community members of the importance of problems and propose solutions (Calabrese Barton and Tan, 2010; Davis and Schaeffer, 2019). Finally, some work explores imaginative narrativebased writing, theater, poetry, and art as a context for children to deepen and explore science and engineering (Danish and Enyedy, 2006; Gallas, 1995; Varelas et al., 2010).

National Academies of Sciences, Engineering, and Medicine 2021. Science and Engineering in Preschool Through Elementary Grades: The Brilliance of Children and the Strengths of Educators. Washington, DC: The National Academies Press. https://doi.org/10.17226/26215.

References

Brenneman, K., and Louro, I.F. (2008). Science journals in the preschool classroom. *Early Childhood Education Journal*, 36(2), 113–119.

Calabrese Barton, A., and Tan, E. (2010). We be burnin'! Agency, identity, and science learning. *Journal of the Learning Sciences*, 19(2), 187–229.

Cervetti, G.N., Wright, T.S., and Hwang, H. (2016). Conceptual coherence, comprehension,and vocabulary acquisition: A knowledge effect? Reading & Writing, 29, 761–779.

Chambliss, M.J., Christenson, L.A., and Parker, C. (2003). Fourth graders composing scientific explanations about the effects of pollutants: Writing to understand. Written Communication, 20(4), 426–454.

Chambliss, M.J., Christenson, L.A., and Parker, C. (2003). Fourth graders composing scientific explanations about the effects of pollutants: Writing to understand. Written Communication, 20(4), 426–454.

Cunningham, C.M., Lachapelle, C.P., Brennan, R.T., Kelly, G.J., Tunis, C.S.A., and Gentry, C.A. (2020). The impact of engineering curriculum design principles on elementary students' engineering and science learning. Journal of Research in Science Teaching, 57(3), 423–453.

Dalton, B. (2012). Multimodal composition and the common core state standards. The Reading Teacher, 66(4), 333–339.

Dalton, B., and Palincsar, A.S. (2013). Investigating text–reader interactions in the context of supported eText. In R. Azevedo and V. Aleven (Eds.), International Handbook of Metacognition and Learning Technologies (pp. 533–544). New York: Springer.

Dalton, B., and Palincsar, A.S. (2013). Investigating text–reader interactions in the context of supported eText. In R. Azevedo and V. Aleven (Eds.), International Handbook of Metacognition and Learning Technologies (pp. 533–544). New York: Springer.

Danish, J.A., and Enyedy, N. (2006). Unpacking the mediation of invented representations. In S. Barab, K. Hay, and D. Hickey (Eds.), Proceedings of the 7th International Conference on Learning Sciences (pp. 113–119). Bloomington, IN: International Society of the Learning Sciences.

Davis, N.R., and Schaeffer, J. (2019). Troubling troubled waters in elementary science education: Politics, ethics, & black children's conceptions of water [justice] in the era of Flint. Cognition and Instruction, 37(3), 367–389.

DeFrance, N.L. (2008). Struggling Readers Learning with GraphicRich Digital Science Text: Effects of a Highlight and Animate Feature and Manipulable Graphics. Unpublished doctoral dissertation, University of Michigan, Ann Arbor.

diSessa, A., Hammer, D., Sherin, B., and Kolpakowski, T. (1991). Inventing graphing: Metarepresentational expertise in children. Journal of Mathematical Behavior, 10, 117–160.

Douglas, K.A., Moore, T.J., Johnston, A.C., and Merzdorf, H.E. (2018). Informed designers? Students' reflections on their engineering design process. International Journal of Education in Mathematics, Science and Technology, 6, 443–459.

Easley, K.M. (2020). Simulations and Sensemaking in Elementary ProjectBased Science. Unpublished doctoral dissertation, University of Michigan, Ann Arbor.

National Academies of Sciences, Engineering, and Medicine 2021. Science and Engineering in Preschool Through Elementary Grades: The Brilliance of Children and the Strengths of Educators. Washington, DC: The National Academies Press. https://doi.org/10.17226/26215.

English, L.D., and King, D.T. (2017). Engineering education with fourthgrade students: Introducing designbased problem solving. International Journal of Engineering Education, 33(1), 346–360.
Farland, D. (2006). The effect of historical, nonfiction trade books on elementary students' perceptions of scientists. Journal of Elementary Science Education, 18(2), 31–48.
Ford, D.J. (2006). Representations of science within children's trade books. Journal of Research in Science Teaching, 43, 214–235.
Fox, J.E., and Lee, J. (2013). When children draw vs when children don't: Exploring the effects of observational drawing in science. Creative Education, 4(7), 11–14.
Gallas, K. (1995). Talking Their Way into Science: Hearing Children's Questions and Theories, Responding with Curricula. New York: Teachers College Press.
Henderson, L., Klemes, J., and Eshet, Y. (2000). Just playing a game? Educational simulation software and cognitive outcomes. Journal of Educational Computing Research, 22(1), 105–129.
Hertel, J.D., Cunningham, C.M., and Kelly, G.J. (2017). The roles of engineering notebooks in shaping elementary engineering student discourse and practice. International Journal of Science Education, 39(9), 1194–1217.
Jian, Y.C. (2016). Fourth graders' cognitive processes and learning strategies for reading illustrated biology texts: Eye movement measurements. Reading Research Quarterly, 51(1), 93–109.
Kelly, L.B. (2018). An analysis of awardwinning science trade books for children: Who are the scientists, and what is science? Journal of Research in Science Teaching, 55(8), 1188–1210.
King, D., and English, L.D. (2016). Engineering design in the primary school: Applying STEM concepts to build an optical instrument. International Journal of Science Education, 38(18), 2762–2794.
Krajcik, J., Schneider, B., Miller, E., Chen, I.C., Bradford, L., Bartz, K., Barker, Q., Palinscar, A., PeekBrown, D., and Codere, S. (2021). Assessing the Effect of ProjectBased Learning on Science Learning in Elementary Schools (Technical Report). Michigan State University. Available: https://mlpbl.open3d.science/sites/default/files/MLPBLtechnicalreport.pdf.
Lemke, J.L. (2004). The literacies of science. In W. Saul (Ed.), Crossing Borders in Literacy and Science Instruction: Perspectives on Theory and Practice (pp. 33–47). Arlington, VA: NSTA Press.
May, L., Crisp, T., Bingham, G.E., Schwartz, R.S., Pickens, M.T., and Woodbridge, K. (2020). The durable, dynamic nature of genre and science: A purposedriven typology of science trade books. Reading Research Quarterly, 55(3), 399–418.
McNeill, K.L. (2011). Elementary students' views of explanation, argumentation, and evidence, and their abilities to construct arguments over the school year. Journal of Research in Science Teaching, 48(7), 793–823.
National Governors Association Center for Best Practices, Council of Chief State School Officers. (2010). Common Core State Standards for English Language Arts. Available: http://www.corestandards.org/ELALiteracy/.

Palincsar, A.S., and Magnusson, S.J. (2001). The interplay of firsthand and textbased investigations to model and support the development of scientific knowledge and reasoning. In S. Carver and D. Klahr (Eds.), Cognition and Instruction: TwentyFive Years of Progress (pp. 151–194). Mahwah, NJ: Lawrence Erlbaum Associates.
Prain, V., and Waldrip, B. (2006). An exploratory study of teachers' and students' use of multimodal representations of concepts in primary science. International Journal of Science Education, 28(15), 1843–1866.
Rivera, S., and Oliveira, A. (2021). "Why would Benjamin Franklin want to know if lightning was electricity?" Elementary teachers and students making sense of the nature of science during interactive readalouds. Cultural Studies of Science Education, 16, 47–69.
Romance, N.R., and Vitale, M.R. (2001). Implementing an indepth expanded science model in elementary schools: Multiyear findings, research issues, and policy implications. International Journal of Science Education, 23(4), 373–404.
Rouse, A.G., and Rouse, R. (2019). Third graders' use of writing to facilitate learning of engineering concepts. Journal of Research in Science Teaching, 56(10), 1406–1430.
Samarapungavan, A., Bryan, L., and Wills, J. (2017). Second graders' emerging particle models of matter in the context of learning through model-based inquiry. Journal of Research in Science Teaching, 54(8), 988–1023.
Seah, L.H. (2016). Understanding the conceptual and language challenges encountered by grade 4 students when writing scientific explanations. Research in Science Education, 46(3), 413–437.
Shymansky, J.A., Yore, L.D., and Hand, B.M. (2000). Empowering families in handson science programs. School Science and Mathematics, 100(1), 48–58.
Siegel, M. (2006). Rereading the signs: Multimodal transformations in the field of literacy education. Language Arts, 84(1), 65–77.
Songer, N.B., and Gotwals, A.W. (2012). Guiding explanation construction by children at the entry points of learning progressions. Journal of Research in Science Teaching, 49(2), 141–165.
StricklerEppard, L., Czerniak, C.M., and Kaderavek, J. (2019). Families' capacity to engage in science inquiry at home through structured activities. Early Childhood Education Journal, 47(6), 653–664.
Su.rez, E. (2020). "Estoy Explorando Science": Emergent bilingual students problematizing electrical phenomena through translanguaging. Science Education, 104(5), 791–826.
TuckerRaymond, E., Varelas, M., Pappas, C.C., Korzh, A., and Wentland, A. (2007). "They probably aren't named Rachel": Young children's scientist identities as emergent multimodal narratives. Cultural Studies of Science Education, 1(3), 559–592.
Varelas, M., and Pappas, C.C. (2006). Intertextuality in readalouds of integrated scienceliteracy units in urban primary classrooms: Opportunities for the development of thought and language. Cognition and Instruction, 42, 211–259.
Varelas, M., and Pappas, C.C. (Eds.). (2013). Children's Ways with Science and Literacy: Integrated Multimodal Enactments in Urban Elementary Classrooms. Routledge.
Varelas, M., Pappas, C.C., TuckerRaymond, E., Kane, J., Hankes, J., Ortiz, I., KeblaweShamah, N. (2010). Drama activities as ideational resources for primarygrade children in urban science classrooms. Journal of Research in Science Teaching, 47(3), 302–325.

Wendell, K.B., Andrews, C.J., and Paugh, P. (2019). Supporting knowledge construction in elementary engineering design. Science Education, 103(4), 952–978.
Wilson, R.E., and Bradbury, L.U. (2016). The pedagogical potential of drawing and writing in a primary science multimodal unit. International Journal of Science Education, 38(17), 2621–2641.
Yang, H.T., and Wang, K.H. (2014). A teaching model for scaffolding 4th grade students' scientific explanation writing. Research in Science Education, 44(4), 531–548.
Zangori, L., and Forbes, C.T. (2014). Scientific practices in elementary classrooms: Thirdgrade students' scientific explanations for seed structure and function. Science Education, 98(4), 614–639.