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Noah Weeth Feinstein *et al.*

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The Education Task Force of the Illinois Business Roundtable has concluded that "the business community, in partnership with political and education leaders, must play a significant leadership role in education reform (*9*)." Recognizing that "education improvement is a marathon and not a hundred-yard dash" and that "education reform needs to be a collaborative, not adversarial, effort," we have helped to create the Career Pathways Program, where businesses are working with the Illinois State Board of Education to bring practical, experience-based curricula into the classroom that can help ensure that students are either job ready or college ready when they graduate from high school (*10*).

Nationally, academic and business leaders have come together in efforts to create effective learning environments outside of the classroom experience. For example, FIRST robotics competitions were founded on the premise that students can succeed when they compete, not just in a simulated game environment, but in the real world where there are winners and losers (*11*). These types of activities need to become part of formal schooling, not merely optional add-ons.

In summary, what can business do? First, be a strong advocate for exposing students to more hands-on problem-solving activities in the classroom. Second, help to provide scarce resources by increasing sponsorship of programs that engage students in such activities. Third, create more internship opportunities that allow students to be exposed to real-world work environments and directly learn what jobs are about. Fourth, support initiatives to question, and limit, the television, computers, and electronic games that can divert students' time and attention away from other world experiences needed for future success. We believe that professional success today and in the future is more likely for those who have practical experience, work well with others, build strong relationships, and are able to think and do, not just look up things on the Internet.

References

1. *New York Times*, "A Sea of Job Seekers, but Some Companies Are Not Getting Any Bids," 23 June 2012.
2. *A Nation at Risk: The Imperative for Educational Reform* (National Commission on Excellence in Education, Washington, DC, 1983).
3. www.bls.gov/opub/mlr/2008/11/art4full.pdf
4. www3.moe.edu.sg/bluesky/tllm.htm
5. Common Core, www.corestandards.org/
6. NGSS, www.nextgenscience.org/
7. E. K. Stage, H. Asturias, T. Cheuk, P. A. Daro, S. B. Hampton, *Science* **340**, 276 (2013).
8. J. W. Pellegrino, *Science* **340**, 320 (2013).
9. The Education Task Force of the Illinois Business Roundtable, www.illinoisbusinessroundtable.com/education2011.htm
10. The Career Pathways Program, www.illinoisworknet.com
11. FIRST Robotics, www.usfirst.org/

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REVIEW

Outside the Pipeline: Reimagining Science Education for Nonscientists

Noah Weeth Feinstein,[1]* Sue Allen,[2] Edgar Jenkins[3]

Educational policy increasingly emphasizes knowledge and skills for the preprofessional "science pipeline" rather than helping students use science in daily life. We synthesize research on public engagement with science to develop a research-based plan for cultivating competent outsiders: nonscientists who can access and make sense of science relevant to their lives. Schools should help students access and interpret the science they need in response to specific practical problems, judge the credibility of scientific claims based on both evidence and institutional cues, and cultivate deep amateur involvement in science.

For half a century, the world's wealthiest countries have asked their education systems to teach science to all students, including those who will not go on to scientific careers (*1*). Under slogans such as "science literacy" and "science for all," schools have attempted to prepare all students to make sense of science in daily life. With the exception of modest and isolated gains in conceptual knowledge (*2*), it is not clear that these campaigns have enhanced people's ability to function in a world where conflicting health advice clutters the Internet, research is filtered through political screens, and the media strips context from scientific claims.

These results should provoke renewed interest in the relationship between science education and public engagement with science and the pursuit of more fruitful forms of science literacy. Instead, many scientists and policy-makers are turning their attention away from the role of science in daily life and advocating a greater focus on the so-called "pipeline": preprofessional education that delivers science-ready students to colleges and universities (*3*). Even crusaders for science literacy take for granted that scientific training—of the same sort that prepares students for scientific practice—will help nonscientists navigate fields as diverse as personal health, politics, the economy, leisure, and employment (*1*, *4*, *5*). There is little empirical evidence to support this assumption. On the other hand, a growing number of studies show untrained citizens engaging with science in adaptive ways (*6*). These citizens, whom Feinstein refers to as "competent outsiders" (*7*), identify relevant pieces of science and understand their local or personal implications without relying on school-based knowledge of particular scientific methods or concepts (*6*, *8*).

How can education help more people act like competent outsiders? We synthesize evidence to develop a research-based plan for cultivating competent outsiders: nonscientists who can access and interpret the science most relevant to their lives. We reconsider established goals of science education in light of three central findings about public engagement with science and discuss implications for research and practice.

How People Interact with Science

Research shows that different groups interpret science differently (*6*, *9*–*12*). An Alzheimer's advocacy group, biotech investment firm, and religious coalition may all be interested in stem cell research, but different motivations underlie their interest and shape their engagement. Social, cultural, and demographic differences influence how people engage with science, both in school (*13*) and out (*6*, *11*). For example, communications researchers have identified six demographically distinct groups of Americans who respond to news about climate change in predictable, group-specific ways (*11*). Local knowledge and experience, such as the history of tension between rural residents and a nuclear power plant (*14*), can play an important role. There are many different "publics" for science, each with different concerns and resources for making sense of the world.

To complicate matters, science is not a single, uniform thing. Science education places particular value on experimentation, but some fields rely on observational data or simulations, whereas others are devoted to theoretical inquiry. Even closely related fields can diverge on important matters, such as the validity of research methods or the nature of acceptable evidence (*15*). Nonscientists typically interact with specific manifestations of science rather than "science" as a whole (*6*, *12*, *16*). Although scientists may agree on abstract principles (such as hypothesis-testing) and

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methodological heuristics (such as model-building), the science of climate modeling is very different from the science of clinical trials, and understanding the family resemblance between them may not help a layperson make sense of evidence.

This leads to perhaps the most important finding: Although some people are interested in science for its own sake, many engage with science in response to situation-specific needs and tend to be interested in science only insofar as it helps them solve their problems (*6*–*10*, *12*). Thus, a mother seeking therapies for her autistic son may explore research literature, but she is not attempting to understand that literature from a scientist's perspective. Instead, she labors to integrate what she learns with her knowledge of local services and her first-hand understanding of her child (*16*). Context shapes the process of engagement, and scientific principles take on different significance in different contexts, where they are laden with social and ethical implications (*8*, *10*, *12*). The challenges of daily life are what cognitive scientists call ill-structured problems, defined in personal and practical terms. Scientific understanding may contribute to the solution, but will rarely be the entire solution. It is important to be realistic about the sort of understanding people seek—and need—to make decisions (*17*).

Reconsidering the Goals of Science Education

These findings about public engagement with science strain the credibility of established approaches to science education. Scientists, educators, and policy-makers claim that science education is useful (*1*–*3*, *5*), but what use is it to know a canonical collection of facts or an allegedly generic scientific method if people engage with specific pieces of science in highly contextualized ways? Can education prepare students for the deep idiosyncrasy of daily life? Evidence on public engagement indicates that students should still know science, think scientifically, and appreciate science—but it may be necessary to reconsider the established interpretation of these goals and the strategies used to achieve them.

Knowing Science: From Knowing the Textbook to Accessing the Science You Need

No set of scientific concepts and principles, no matter how carefully chosen, will be sufficient preparation for future engagement with science. This is a consequence of the unpredictable path of scientific progress, shifting social and political demands on scientific knowledge, and the variety of contexts and motives that drive public engagement. Even if it were possible to predict the future of science, one could never anticipate how science will ripple through the diverse future lives of students (*4*, *9*, *12*). Yet prior knowledge is only one piece of the sense-making apparatus that people use in their encounters with science. When reading a scientific article, a person draws on prior knowledge to interpret the text, but she does not stop when she is unfamiliar with a concept or uncertain of implications; she looks up the concept online, cross-references a second article, discusses the matter with friends, and seeks out complementary expertise (*6*, *16*, *18*). People employ social and material resources to solve problems and answer questions, and encounters with science are an impetus for new learning as well as tests of prior knowledge.

Resources alone do not guarantee fruitful engagement with science: The same literature that reveals impressive sense-making ability among laypeople also reveals failures, frustrations, and uneven competence (*6*, *12*, *16*). Science education should prepare more students to access and interpret scientific knowledge at the time and in the context of need. Public engagement with science is not simply the application of scientific knowledge; it requires translating a daily problem into scientific terms and reconstructing the scientific answer amid the constraints of daily life (*6*, *12*, *16*). A rural resident worried about pesticide contamination must learn to express his concerns in questions that science can answer: What pesticides, at what doses, are most harmful? Are there reliable tests for pesticides in my children's air or water? These questions lead to answers that must then be translated back into local reality: Who will help me test my water? What can I do to mitigate the risks? The decision-making process incorporates both scientific and nonscientific information.

One promising approach for preparing students to succeed in such circumstances is Problem-Based Learning (PBL), which confronts students with ill-structured challenges, asking them to extend their existing knowledge and develop concrete solutions (*19*). PBL can produce durable knowledge gains and foster metacognitive skills that underlie self-directed learning, although researchers have yet to identify which features of PBL contribute most to learning (*19*, *20*). Developed in medical schools, PBL needs further validation in kindergarten through grade 12 (K-12) settings, but it shares features with other promising pedagogies specific to K-12, such as Science-Technology-Society (STS) and Place-Based Education (*21*, *22*). All of these mimic public engagement with science by making the problem a focus for learning, allowing students to develop complex questions and test the adequacy of their answers, and, in many cases, using authentic social and practical problems that cannot be defined in purely scientific terms.

Fundamental problems of research and practice must be addressed before these pedagogies can be used to greatest effect. Little is known about using them together, or over time, to help students recognize when and how science is relevant. Students frequently struggle to apply what they have learned in one specific context to another; on the other hand, teaching generic problem-solving skills appears to have limited value (*23*, *24*). Finding the right level of specificity, and honing strategies to connect multiple learning episodes, are problems of longstanding interest to researchers and educators (*23*, *25*). Educators and researchers should work together to adapt problem-focused pedagogies for a broad range of audiences, develop appropriate assessments, and—critically—find the most productive balance between these strategies and other means of presenting disciplinary science content.

Thinking Scientifically: From Practicing Science to Judging Scientific Claims

"Thinking scientifically" has been interpreted in many ways, from the trial-and-error experimentalism of early progressives to the scientific method dogma of the post-war era and the more flexible (if also more vague) idealism of scientific inquiry (*1*, *5*). In the United States, the forthcoming Next Generation Science Standards decompose scientific inquiry into distinct but interconnected "scientific practices" such as modeling, argumentation from evidence, and communication of results. This is an important step forward. It rejects the empirically dubious notion of a single scientific method, offers greater specificity than most inquiry frameworks, and better represents the collaborative and iterative aspects of scientific work (*5*).

Yet the scientific practices approach still emphasizes the scientist's "insider" perspective, neglecting cues that help outsiders make informed judgments. Nonscientists rarely need to replicate the iterative processes of systematic research, and literature suggests that it is difficult to transfer principles of research design, learned in disciplinary contexts, to the highly variable circumstances of daily life (*23*, *24*). On the other hand, nonscientists do need to judge the trustworthiness and local validity of putatively scientific claims. Studies show that competent outsiders make sophisticated judgments about the credibility of scientific claims based on cues like professional reputation, publication venue, institutional affiliation, and potential conflicts of interest, even when they do not understand technical nuances of experimental design or laboratory technique (*6*, *8*, *10*). In one classic sociological study, local knowledge and historical context, combined with direct observation of scientists in the field, helped farmers make sophisticated counterarguments to government-sponsored studies when their grazing lands were contaminated by radioactive fallout (*14*). Studies have emphasized the importance of trust, reputational networks, and heuristic reasoning in judgment and decision-making (*10*, *26*).

Science education could do far more to help people judge scientific claims based on the information available to them. This is important given the decline in dedicated science journalism at for-profit news organizations; increasingly, citizens are turning to the Internet, with its variable quality and political motivations, for science news (*10*). Lessons that focus on scientific argumentation and communication are part of the solution because they help students understand how scientists evaluate evidence and how research is packaged for presentation to various audiences (*5*, *27*). Yet even this shortchanges the histories, institutions, and norms that contribute to the reliability of scientific knowledge. Competent outsiders appreciate the socio-political nuances of "how science really works," including scientific credentials, the role of peer review in research funding and publication, and the differing perspectives of the many types of research organizations (*8*, *10*). They can navigate the changing world of popular science media, recognizing signs of source bias and understanding the difference between journalistic and scientific accounts of research (*10*).

This material can be dry and inaccessible when presented out of context, but promising pedagogies offer platforms for examining scientific credibility in realistic contexts. In Socio-Scientific Issue Discussions (SSID), students engage in structured conversation about a science-inflected social problem, with the goal of uncovering epistemic and ethical nuances at the interface of science and daily life (*28*). Other strategies focus on the creation and interpretation of science texts, ranging from research articles to popular science journalism (*29*, *30*). These pedagogies must be refined to reveal the social and institutional structures of science. Although both address the credibility and usefulness of different sources, and both provide apt venues for exploring issues of institutional trust, work is needed to develop a systematic and developmentally appropriate set of scaffolds for learning about topics such as peer review and conflicts of interest.

Appreciating Science: From Positive Feelings to Deep and Durable Involvement

Most adults in high-income countries express mild but consistent interest in scientific topics (*31*), but formal education may have little to do with this: A substantial fraction of students in those same countries lose interest in science as they progress through school (*32*). Schools may lag behind informal learning environments in their ability to inspire and develop students' interest in science (*33*). Older, top-down mechanisms for public engagement are being joined by science cafes, participatory science games, and maker spaces (community-oriented places that foster collaboration and resource-sharing in small-scale design and fabrication projects). Children and adults may connect with science through "citizen science" and "professional-amateur" communities dedicated to phenology, astronomy, and even molecular biology (*18*). People who interact with science through these platforms do so for widely varying reasons connected to personal interest and social identity (*18*, *33*). In this rich and dynamic context, how and why should schools continue to foster appreciation of science?

Research suggests that deep, personal interest in some field of science provides motivation for future interactions, even with science in unrelated fields. Students who pursue their own science-related interests have a stronger sense of their ability to learn science in the future (*33*) and are less likely to lose interest over time (*34*). Their involvement in personally or socially meaningful science-related activities can lead to learning experiences that resemble project-based learning and socio-scientific issue discussions (*35*). When students find a particular scientific topic compelling, they seek experiences that prepare them for future encounters with science. Knowledgeable amateurs can become powerful resources for their communities (*9*, *18*, *33*).

Schools wishing to develop deep and durable involvement in science should embrace the diversity of student interests—a challenge for educational systems accustomed to pushing everyone toward the same goal. Three pathways hold promise. First, educators can use the flexibility provided by project- and place-based pedagogies to help students identify and develop individual interests and expertise. Second, schools can pursue partnerships with museums, which excel at sparking curiosity, and with afterschool clubs and community organizations, which provide flexible spaces for ongoing exploration (*33*). Third, educators can integrate science-based games and citizen science engines like FoldIt and GalaxyZoo into their curricula. Researchers should develop efficient ways to track the development of lasting student interests and identify productive ways to integrate informal experiences and game-based technologies into schools and classrooms (*33*).

Implications

On the way to becoming competent outsiders, students should learn to (i) access and interpret science in the context of complex, real-world problems; (ii) judge the credibility of scientific claims based on both social and epistemic cues; and (iii) cultivate deep and durable involvement in science, even when it takes them away from the formal curriculum. In practice, this means moving strategies such as PBL, SSID, and interest-driven student exploration from the pedagogical margins to the center. Allotting more time and resources to these strategies will result in a better balance between preprofessional science education and science education for nonscientists; given that PBL is used in a range of academically rigorous contexts, it may pay dividends for future scientists as well.

These strategies are works in progress. Too few studies investigate the challenges of moving from practical problems to scientific questions and integrating science back into practical solutions. Too few studies identify skills needed to reverse-engineer a robust and coherent knowledge structure using real-world resources. Educational research on scientific epistemology neglects the diverse circumstances in which people encounter scientific claims, as well as the social and institutional knowledge that contributes to evaluating those claims. Research on deep and durable involvement in science is in its infancy; although there are portraits of success in games-based learning and informal science education, practice outstrips research. There is an urgent need to understand how and why these settings succeed (and fail) to transform attitudes, motivation, and identities.

Educators should not wait for these questions to be answered. Useful research requires real-world cases to study, and it is educators who will do much of the work of adapting project-based learning and other strategies to diverse K-12 settings. Predictable challenges loom: School schedules, parent expectations, and high-stakes testing militate against pedagogies that sacrifice short-term knowledge gains for complex skills, increased motivation, and a narrower but longer-lasting body of knowledge. Teachers and administrators should work together to clear space for pilot programs that test and demonstrate the value of these approaches. It may be most effective to deploy them as solutions to other widely acknowledged problems. For example, STS education produces motivational gains among students who are less likely to enroll in science courses (*21*), whereas PBL has found early champions in gifted education, with students who may have exhausted their local course offerings (*19*). Pilot programs conducted in these contexts can serve as beachheads for broader adoption.

Scientists may be allies or adversaries in reform. Some have played a decisive role in pedagogical and curricular progress, whereas others have defended the battlements for the established facts-and-principles approach (*1*). The scientific pipeline dominates educational discourse today, but it is those outside the pipeline who would benefit most from reform. Serving their needs requires a different sort of activism, and new attention to evidence about how, when, and why people interact with science.

Grand Challenges

Help students explore the personal relevance of science and integrate scientific knowledge into complex practical solutions. Teaching science in this way requires a focus on authentic problems that often cannot be defined in purely scientific terms.

Develop students' understanding of the social and institutional basis of scientific credibility. Science education should empower students to make reasonable judgments about the trustworthiness and local validity of scientific claims, even when they don't have deep background knowledge or access to expertise.

Enable students to build on their own enduring, science-related interests. Schooling that fosters the development of idiosyncratic interests, habitual curiosity, and lifelong science-related hobbies will strengthen students' motivation and confidence in future learning experiences.

References and Notes

1. G. DeBoer, *A History of Ideas in Science Education* (Teachers College Press, New York, 1991).
2. J. Miller, *Curator* **53**, 191 (2010).
3. *Rising Above the Gathering Storm* (National Academies, Washington, DC, 2007).
4. S. Miller, *Public Underst. Sci.* **10**, 115 (2001).
5. National Research Council, *A Framework for Science Education* (National Academies Press, Washington, DC, 2012).
6. B. Irwin, Wynne, Eds. *Misunderstanding Science?* (Cambridge Univ. Press, Cambridge, 1996).
7. N. Feinstein, *Sci. Educ.* **95**, 168 (2011).
8. J. Ryder, *Stud. Sci. Educ.* **36**, 1 (2001).
9. W.-M. Roth, A. Calabrese Barton, *Rethinking Scientific Literacy* (Routledge Falmer, New York, 2004).
10. T. Bubela *et al.*, *Nat. Biotechnol.* **27**, 514 (2009).
11. A. Leiserowitz, E. Maibach, C. Roser-Renouf, J. Hmielowski, "Global Warming's Six Americas, March 2012 & November 2011" (Yale Project on Climate Change Communication, Yale Univ. and George Mason Univ., New Haven, CT, 2012); http://environment.yale.edu/climate/files/Six-Americas-March-2012.pdf.
12. D. Layton, E. Jenkins, S. Macgill, A. Davey, *Inarticulate Science?* (Studies in Education Ltd, Driffield, UK, 1993).
13. O. Lee, C. A. Buxton, *Diversity and Equity in Science Education* (Teachers College Press, New York, 2010).
14. B. Wynne, *Public Underst. Sci.* **1**, 281 (1992).
15. P. Galison, *Image and Logic* (Univ. Chicago Press, Chicago, 1997).
16. N. W. Feinstein, *Public Underst. Sci.* **2012**, 0963662512455296 (2012).
17. R. Fernandes, H. A. Simon, *Policy Sci.* **32**, 225 (1999).
18. R. Bonney *et al.*, *Public Participation in Scientific Research: Defining the Field and Assessing Its Potential for Informal Science Education* (Center for Advancement of Informal Science Education, Washington, DC, 2009; http://caise.insci.org/uploads/docs/PPSR%20report%20FINAL.pdf).
19. C. E. Hmelo-Silver; Hmelo-Silver, *Educ. Psychol. Rev.* **16**, 235 (2004).
20. C. Wirkala, D. Kuhn, *Am. Educ. Res. J.* **48**, 1157 (2011).
21. J. Bennett, F. Lubben, S. Hogarth, *Sci. Educ.* **91**, 347 (2007).
22. S. Semken, C. B. Freeman, *Sci. Educ.* **92**, 1042 (2006).
23. J. D. Bransford, A. L. Brown, R. R. Cocking, Eds., *How People Learn* (National Academies Press, Washington, DC, 2000).
24. D. Schwartz, J. D. Bransford, D. Sears, in *Transfer of Learning from a Modern Multidisciplinary Perspective*, J. Mestre, Ed. (Information Age, Charlotte, 2005), pp. 1–51.
25. R. L. Goldstone, S. B. Day, *Educ. Psychol.* **47**, 149 (2012).
26. D. Kahnemann, *Thinking, Fast and Slow* (Farrar, Straus, and Giroux, New York, 2011).
27. J. Osborne, *Science* **328**, 463 (2010).
28. T. D. Sadler, D. L. Ziedler, *J. Res. Sci. Teach.* **46**, 909 (2009).
29. J. S. Krajcik, L. M. Sutherland, *Science* **328**, 456 (2010).
30. S. P. Norris, L. Phillips, *Sci. Educ.* **87**, 224 (2003).
31. National Science Board, *Science and Engineering Indicators 2012* (National Science Foundation, Arlington, VA, 2012).
32. J. Osborne, S. Simon, S. Collins, *Int. J. Sci. Educ.* **25**, 1049 (2003).
33. National Research Council, *Learning Science in Informal Environments* (National Academies Press, Washington, DC, 2007).
34. D. Vedder-Weiss, D. Fortus, *J. Res. Sci. Teach.* **49**, 1057 (2012).
35. J. H. Falk, M. Storksdieck, L. D. Dierking, *Public Underst. Sci.* **16**, 455 (2007).

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REVIEW

Generating Improvement Through Research and Development in Education Systems

M. Suzanne Donovan

To effectively address problems in education, research must be shaped around a problem of practice. Reorienting research and development in this way must overcome three obstacles. First, the incentive system for university researchers must be changed to reward research on problems of practice. Second, the contexts must be created that will allow the complexity of problems of practice to be understood and addressed by interdisciplinary teams of researchers, practitioners, and education designers. And third, meaningful experimentation must become acceptable in school systems in order to develop a better understanding of how to effectively stimulate and support the desired changes.

The connection between research and practice in the field of education has been weak (*1*). The "knowing-doing gap" is lamented in other fields as well, including business management (*2*) and medicine (*3*). But it is difficult to find a parallel in education to the design of digital devices by technology companies that have fundamentally changed how we go about our daily lives, or the application of biomedical research to save lives in extreme circumstances.

How might we make use of research knowledge to pursue new possibilities and design new tools and processes to improve education? The fact that other sectors have made major strides in some regards, yet struggle to reliably incorporate verified improvements into practice, highlights two distinct challenges. One is a design challenge: When research informs designs that solve a problem from the point of view of the users, barriers to change disintegrate (*4*). Doctors, for example, use magnetic resonance imaging because it allows them to see what they otherwise cannot without risky or invasive procedures. And people have changed routine behavior enthusiastically when given access to technological innovations such as smartphones and Internet search engines. But when an innovation requires that people change their behavior to achieve goals others have set—to get hospital physicians to wash their hands or to use checklists that reduce errors (*5*), or to motivate teachers to engage students in classroom discourse rather than to teach through lectures (*6*)—it is an implementation challenge (*7*). The challenges are interrelated: Greater success at designing for the user implies fewer implementation barriers. If it is made easier for doctors to disinfect their hands, they are more likely to do so. But school systems and hospitals are intended to serve the goals of others, making improvements in practice desirable whether or not the user embraces the change. Research and development (R&D) will therefore need to address both design and implementation challenges.

While the task is far from simple, its components can be described in the most basic terms. They are (i) identifying the right problem, (ii) developing effective solutions, and (iii) getting effective solutions to spread.

Identifying the Right Problem

Scientific research can be driven either by theory or by problems of practice. Research that contributes to both falls into "Pasteur's quadrant" (*8*). The National Institutes of Health and the National Science Foundation support programs of "translational research" intended to make advances in research knowledge usable for practice (*9*, *10*). The term "translational" suggests that the required knowledge is in hand. It needs only to be put into the language of practice.

Rarely do problems of education practitioners map neatly onto areas of scientific research, however. Even in the case of pasteurization, translation would be a mischaracterization. Pasteur's scientific breakthrough came with a commission to work on a practical problem: the spoiling of wine (*11*). The problem-solving research did not end with the realization that bacteria cause the spoiling, nor with the evidence that heat could be used to destroy bacteria. The heating process changes the end product—whether wine or milk—affecting taste, appearance, and digestibility (*12*). It took decades of work on the time and temperature of heating and cooling to develop the process of pasteurization that revolutionized the delivery of milk (*13*). The translation metaphor conceals the way in which research that solves problems of practice is shaped and

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