The Science Learning Ecosystem

John H. Falk
Institute for Learning Innovation
Oregon State University

ABSTRACT

There is a revolution occurring in how, when, where and even why people learn science. Learning today is continuous and on-demand. Learners of all ages seek science educational experiences from myriad sources and across multiple platforms – while at home, on weekends and even while on vacation. Unlike in the past, most science learning today is *free-choice*, driven primarily by an individual's needs and interests. In fact, research indicates that much of the current disparity in a person's science literacy derives from inequities in access to quality out-of-classroom learning opportunities. Schools remain important components of the new science education ecosystem, but increasingly important are informal educational institutions and resources such as public libraries, museums and national parks.

This material is based upon work supported by the National Science Foundation under Grant Number (DRL-1413783). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Introduction

The nature of science learning is changing worldwide as individuals have unprecedented access to science education opportunities from cradle to grave, 24/7 through an ever-growing network of educational opportunities beyond schooling. These include visits to institutions such as public libraries, museums, zoos, aquariums, science centers, state and national parks and preserves; access of diverse broadcast media such as television, podcasts or film; participation in organized youth programs such as 4H, after-school or summer camps or adult programs like Road Scholar or hobby groups; or in ever increasing numbers utilizing a vast array of digital media such as personal games, the Internet and social networks (Barron, 2006; Falk & Dierking 2002 and 2010; National Research Council, 2009). Over the past decades, dependence on broadcast and print media for science information has declined precipitously while use of digital tools has grown exponentially (NSB, 2015). Because of this ever-expanding availability of organizations and tools for learning, a growing number of individuals have begun to customize and take charge of their own learning. This is particularly the case for adults but also an increasing number of children and youth. Collectively then, the dynamic interactions between individuals and the vast network of science learning providers can be thought of as a complex ecosystem of science learning.

The revolution in 21st century science learning requires a shift in perspective on multiple levels. As part of the ecosystem of science learning, informal educational institutions and resources such as public libraries, museums and national parks must be considered along with schools. Furthermore, learning has increasingly become first and foremost a learner-centered, rather than an institution-centered, phenomenon. The 21st century public library, which is free and accessible to the whole community, must become an important player in the science learning enterprise. Libraries have the capacity to support science learning across the lifespan, starting in the pre-school years and continuing into older age. By collectively supporting patrons of all ages, libraries can help create an ethos of life-long learning in a world that is increasingly driven by free-choice learning. However, the 21st century science learning revolution has not been fully understood nor embraced by the educational establishment.

School-First Paradigm

The scientific research and education communities have long had a goal of advancing the public's understanding of science. The vast majority of the rhetoric, resources and research on this issue in recent years have revolved around the failure of U.S. school-aged children to excel at mathematics and science, particularly as compared with children in other countries. Most policy solutions for this problem involve improving the practices and escalating the investment in schooling, particularly during the pre-college years. This emphasis is based on the widely held assumption that children do most of their learning in school and that therefore the best route to long-term public understanding of science is through successful formal schooling. This "school-first" paradigm is so pervasive that few scientists, educators or policymakers question it, even when the facts increasingly don't seem to support it.

Take for example the performance by U.S. school-aged children on international tests like the quadrennial Trends in International Mathematics and Science Study (TIMMS) and the biannual Programme for International Student Assessment (PISA). For more than two decades, U.S. elementary-aged children perform as well as or better than most children in the world, but the performance of older U.S. children has been mediocre at best. On the most recent TIMMS science exam, U.S. 4th graders were out-performed by only one country in the world, Korea, while U.S. 8th graders were right in the middle of the pack of the 43 participating countries. By 12th grade, U.S. students were among the worst in the world, out-performing only students from Cyprus and South Africa (TIMMS, 2012). On the PISA test, U.S. 8th graders also performed middling, ranking 20th out of the 34 participating countries (PISA, 2012). These results create problems for the "school-first paradigm" for two reasons.

First, why is it that the U.S. performs so well in the early grades but then declines so percipitously in later grades? Most in the U.S. science learning community agree that the quality of school science education in America is better at the secondary level than at the preschool and elementary levels. Recent statistics show that only about 4 percent of U.S. school teachers of kindergarten through second grade (K–2) have undergraduate majors in science or science education and many have taken no college-level science courses at all (Fulp, 2002). However, the quality of science instruction at that level is almost a moot point since it so rarely occurs. Indicative of the situation nationwide, a study of California elementary schools found that eighty percent (80%) of K–5th grade multiple-subject teachers who are responsible for teaching science in their classrooms reported spending 60 minutes or less per week on science; 16% of teachers reported spending no time at all on science (Dorph, et al, 2011). And with increasing emphasis on math and reading high-stakes testing, the time spent on science in the elementary grades continues to decline. Consistent science instruction in U.S. schools only begins at the middle school level, when every student takes at least one or two science courses, usually taught by individuals with some science background. Thus, the only time when U.S. children do well internationally is during the time when effectively no science instruction occurs in school.
The second interesting challenge to the school-first paradigm comes from another set of international comparisons, but this of adults rather than youth. Over the same twenty-year period, U.S. adults have consistently outperformed their international counterparts on science literacy measures, including adults from South Korea and Japan, as well as Western European nations such as Germany and the U.K. In the most recent assessments, U.S. adults were out-performed by only one country, Sweden (NSB, 2015). Although there is still considerable room for improvement in American's understanding of science, our consistent success on these international measures of science literacy is worth taking note of. In particular, if schooling is the primary causative factor affecting how well the public understands science, it is difficult to explain the sudden reversal in fortunes of U.S. performance after the cessation of schooling.

The truth is, these U-shaped results cannot be adequately explained if we assume that schooling alone is responsible for Americans' science learning. We cannot fully explain why young children do well or why the science literacy of the U.S. general public suddenly rebounds after high school. Of course all of these tests, both for school-aged children and adults, are flawed, measuring relative performance based upon a set of standardized questions. For better or worse though these are the tests on which international comparisons are made and they do provide a consistent, if flawed, frame of reference. Although some have argued that taking college-level courses in science is the explanation for adults' success (e.g., Miller, 2010), this is unlikely the full explanation since only 30 percent of U.S. adults ever take one college level science course. We should at least consider other possible explanations, including the fact that the U.S. has the most extensive informal science learning infrastructure in the world (Falk & Dierking, 2010; NSB, 2015).

Free-Choice Science Learning

A growing body of evidence supports the contention that the public learns much if not most of their science in settings and situations outside of school (Falk & Needham, 2013; NRC, 2009; 2015). A 2009 report by the National Research Council describes a range of evidence demonstrating that even everyday experiences such as a walk in the park contribute to people's knowledge and interest in science and the environment as do visits to settings such as national parks, science centers and botanical gardens. Even more common is the science people learn while engaged in efforts to satisfy their own personal need to know. Sometimes the need is a situational and fleeting curiosity. Other times learning is deep and extended, as when individuals learn science to support pursuits such as gardening, cooking, auto repair, birding or star gazing.

More than two decades ago, Lynn Dierking and I coined the term free-choice learning in order to better describe the most important characteristic of this type of learning—the learning people do every day throughout their lives not because they have to but because they want to. Free-choice learning describes the non-linear, self-directed learning that occurs when individuals have primary responsibility for determining the what, when, where, how, why and with whom of learning. Although the term free-choice learning does not define the *where* of learning, currently most free-choice learning occurs outside of the formal education system.

Evidence for the importance of free-choice science learning comes from many sources, but some of the best documented relate to public learning from experiences at science centers. For example, decades of research at the at the California Science Center in Los Angeles have shown that roughly two-thirds of Los Angeles residents have visited the science center since it was renovated in 1998, including residents of all races/ethnicities, neighborhoods, incomes and education levels. A series of random telephone surveys in Los Angeles have shown that a large majority of these former visitors, in fact 95%, self-reported that the experience increased their understanding of science and/or technology, as well as piqued their interest in science and prompted further inquiries after the visit (Falk & Needham, 2011). Consistent with these findings and even more definitive are data from a recent investigation of the role of science centers on public understanding of science. The international study consisted of a random sampling of 11,881 residents of 17 communities with active science centers in 13 countries. Results revealed that individuals who visited science centers had significantly greater science understanding, interest and curiosity, participation in free-choice science leisure activities, and identity relative to science and technology than did individuals who did not visit. Even when potential self-selection biases such as household income, education level and prior interest were taken into consideration, the roughly half of the population of these communities who visited science centers evidenced significantly higher science knowledge and understanding than did the half of the population who did not visit (Falk, et al., in review).

Considerable attention lately has been focused on the role of out-of-school experiences in supporting children and youth's science learning. Data from a variety of sources is accumulating to show that participation in after-school youth programs such as 4H, Girls, Inc. and Boys and Girls Clubs significantly enhance a range of key educational outcomes, including interest and engagement in science-related learning as well as success in school (NRC, 2015). Although the number of young people enrolled in afterschool and summer programs has skyrocketed over the last decade, with currently 1 in 5 children participating in such programs, the supply is currently not meeting the demand, particularly in terms of science programing, with only one-third of the national need being met by existing programs (Afterschool Alliance, 2014). Furthermore, a recent study found that, while most out-of-school programs report providing some kind of science education, only a small portion (%?) are able to provide opportunities for youth to participate in inquiry-based experiences (House, Llorente, Leones & Lundh, 2014). This reality reflects the growing disparity in access to quality free-choice experiences. Research shows that much of the current "performance gap" between high and low income youth can be attributed to summer experiences, or more accurately lack of summer experiences, rather than in-school opportunities (Alexander & Entwisle, 1996; Alexander, Entwisle & Olson, 2007).

Historically, the majority of attention paid to out-of-school science learning, including the majority of the research in this area, has been focused on short-term experiences like visiting a science museum, zoo or aquarium or watching a science television show such as NOVA. Although as shown above, these free-choice science learning experiences are important contributors to the public's science literacy, they represent only the most conspicuous part of the free-choice science learning landscape. Equally important, but much less discussed and studied are education situations that support long-term, more in-depth opportunities for science learning. A wide range of adolescents and adults are engaged in leisure-time activities that involve science, including model rocketry, raising ornamental fish, gardening, rock collecting, birding, scuba diving and star gazing. Hobbyists such as these often possess deep specialized knowledge of science and invest considerable amounts of time and money in equipment, travel, education and training to refine their craft. Equally important are the many events in life, often highly personal, which demand increased understanding of science "right-now." For example, when an individual is diagnosed with leukemia or heart disease, that person and his/her loved ones invest large amounts of time researching websites and medical reports in order to learn as much as possible about the particular disease. Similar behaviors arise when an environmental crisis such as a toxic spill or the imposition of water rationing occur. With an increasingly accessible Internet, opportunities to become informed about such issues are easy and common. According to the research conducted by the Pew Internet & American Life Project (2012), 2006 was the tipping point when the Internet exceeded even broadcast media as the primary source of public science information. During the recent dramas surrounding the deep-water oil spill in the Gulf of Mexico, news websites like CNN and CNBC, information websites like www.theoildrum.com and even the government's own NOAA website were humming with activity as the public tried to get below the superficial headlines of the 6:00 news (Pew Research Center, 2013). Today, more people seek medical advice from online professionals than from face-to-face visits with "live" healthcare professionals (Pew Research Center, 2013).

Hobbyists, many with little formal training, exhibit high levels of knowledge and depth of understanding (Liu & Falk, 2014). Amateur astronomy club members, who lack college-level astronomy training, generally knew more basic astronomy than did undergraduate astronomy majors, according to research conducted by Berendsen (2005). Such hobbyists often have collegial relationships with experts in the field and some even find themselves in the right place at the right time. For example, on March 18-19, 2010, British amateur astronomer Nick Howes was working from his desktop computer in Great Britain using a remote-controlled 2-meter telescope located in Hawaii and operated by the Faulkes Telescope Project (http://www.faulkes-telescope.com/). He dialed up a comet's coordinates he had been observing, calibrated his camera and captured a set of six photos showing an object moving away from the main icy nucleus of the comet. What he captured was the breakup of comet C2007 C3, an observation hailed by the International Astronomical Union as a "major astronomical discovery" (BBC, 2010).

Investigations of everyday science literacy have reinforced that much of what is learned in school actually relates more to learning *for school*, as opposed to learning *for life*. For example, Canadian studies found that members of an activist group working on the environmental revitalization of a local creek and its watershed acted and learned using knowledge derived from a wide variety of resources, virtually none of which required or drew from school-based sources (Roth & Van Eijck, 2010). Other studies have found that the number or level of mathematics courses taken in school poorly correlated, if at all, with mathematical performance in out-of-school, everyday life situations. Even individuals who did not do well or were not formally trained in school mathematics demonstrated the ability to use math successfully in their everyday life (cf., Sriraman & Freiman, 2010). In another example, success in technical and scientific training courses for ship officers was shown to be unrelated to the relevant knowledge required onboard (Emad & Roth, 2008). As observed by Roth and colleagues in their investigation of adults working on a local environmental issue, "there was little that looked like school science, and there was little done in school science that prepared these adults for this or any other similar kinds of problematic situations in life."

Finally, there is a small but compelling set of data that is beginning to emerge showing that the public also gathers in-depth science knowledge outside of school (e.g., Falk & Needham, 2013; HFRP, 2007; Weiss, et al., 2009). For example, research by my colleague Mark Needham and I (2013) found that when multiple sources of science learning were considered together, free-choice learning experiences represented the single greatest contributors to adult science knowledge. Childhood free-choice learning experiences also significantly contributed to adult science knowledge, as did work experiences (as well as gender, income and race/ethnicity). Schooling too was significant but it ranked at the bottom of sources of adult science knowledge.

Conclusions

There is a revolution afoot! We are witnessing a tectonic shift in how, when, where and even why people learn. Just as the information revolution dramatically transformed our nation, this learning revolution too is changing the way people live and compete in the 21st century. Learning today is 24/7, continuous and on-demand. Whether age 5 or 95, learners seek educational experiences from a myriad of sources, while at home, on weekends and even while on vacation. For the past 100 years we've come to believe that the words "*learning*", "*education*" and "*school*" were synonymous – today public education doesn't just happen at school. Today's learners spend only a fraction of their lives in a classroom. In fact, research indicates the achievement gap is less a factor of disparities in classroom learning than inequities in access to enriching experiences in the out-of-school time space. Most learning is *free-choice*, driven by an individual's needs, interests and access to learning opportunities.

Schools remain important components of the new science education ecosystem, but increasingly important are informal educational institutions and resources such as public libraries, museums and national parks. In order to successfully fulfill their role as public science facilitators, institutions such as libraries must not only seek to understand what and how people learn in the 21st century, but also why. They also need to increasingly see themselves as important connectors and integral pieces of this complex ecological system; a system involving multiple players and modalities (cf., Falk, et al., 2015; NRC, 2015; Traphagen & Traill, 2014). These are the challenges and opportunities of the 21st century.

References

Afterschool Alliance (2014). *America After 3 PM: Afterschool Programs in Demand*. Washington, DC: Afterschool Alliance.

Alexander, K.L. & Entwisle, D.R. (1996). Early schooling and educational inequality: Socioeconomic disparities in children's learning. pp. 63-79. In James S. Coleman (Ed.), *Falmer Sociology Series*. London: Falmer Press Ltd.

Alexander, K.L., Entwisle, D.R. & Olson, S.L. (2007). The lasting consequences of the summer learning gap. *American Sociological Review*, 72, 167-180.

Barron. B. (2006). Interest and self-sustained learning as catalysts of development: A learning ecologies perspective. *Human Development*, 49, pp. 193-224.

BBC (2010). Amateur sees comet breaking up from desktop. http://news.bbc.co.uk/2/hi/uk_news/wales/8579963.stm Retrieved 16 April 2015.

Berendsen, M.L. (2005). Conceptual astronomy knowledge among amateur astronomers, *The Astronomy Education Review*, 1(4), 1-18.

Dorph, R., Shields, P., Tiffany-Morales, J., Hartry, A., McCaffrey, T. (2011*) High hopes-few opportunities: The status of elementary science education in California.* Sacramento, CA. The Center for the Future of Teaching and Learning at WestEd.

Emad, G., & Roth, W.-M. (2008). Contradictions in practices of training for and assessment of competency: A case study from the maritime domain. Education and Training, 50, 260 – 272.

Falk, J. H., & Dierking, L.D. (2002). *Lessons without limit: How free-choice learning is transforming education.* Lanham, MD: AltaMira Press.

Falk, J.H. & Dierking, L.D. (2010). The 95% Solution: School is not where most Americans learn most of their science. *American Scientist*, 98, 486-493.

Falk, J.H., Dierking, L.D., Osborne, J., Wenger, M., Dawson, E. & Wong, B. (2015). Analyzing science education in the U.K.: Taking a system-wide approach. *Science Education*, 99(1), 145–173.

Falk, J.H., Dierking, L.D., Swanger, L., Staus, N., Back, M., Barriault, C., Catalao, C., Chambers, C., Chew, L.-L., Dahl, S.A., Falla, S., Gorecki, B., Lau, T.C., Lloyd, A., Martin, J., Santer, J., Singer, S., Solli, A., Trepanier, G., Tyystjärvi, K. & Verheyden, P. (in review). Role of science centers in supporting adult science literacy: An international, cross-institutional study. *Science Education*.

Falk, J.H. & Needham, M. (2011). Measuring the impact of a science center on its community. *Journal of Research in Science Teaching*, 48(1), 1-12.

Falk, J. H., & Needham, M. D. (2013). Factors contributing to adult knowledge of science and technology. *Journal of Research in Science Teaching, 50*(4), 431-452.

Fulp, S. L. (2002). The status of elementary science teaching. Technical Report. Chapel Hill, NC: Horizon Research, Inc.

Harvard Family Research Project. (2007). *Study of predictors of participation in OST activities*. http://www.hfrp.org/out-of-school-time/projects/study-of-predictors-of-participation-in-out-of-school-time-activities Retrieved 16 April 2015.

House, A., Llorente, C., Leones, T., & Lundh, P. (2014). *Navigating the Future of Afterschool Science: Afterschool Science Networks Study Recommendations*. SRI International.

Liu, C-C & Falk, J.H. (2014). Serious fun: Viewing hobbyist activities through a learning lens. *International Journal of Science Education, Part II*, 4(4), 343-355.

Miller, J. D. (2010), Adult science learning in the Internet era. *Curator: The Museum Journal*, 53, 191–208.

National Research Council (2009). *Learning science in informal environments: Places, people and pursuits*. Washington, DC: National Academy Press.

National Research Council (2015). *Successful out-of-school STEM learning*. Washington, DC: National Academy Press.

National Science Board, (2015). *Science and engineering indicators*: 2014. Washington, DC: Government Printing Office.

Pew Research Center. (2012). In changing news landscape, even television is vulnerable. http://www.people-press.org/2012/09/27/in-changing-news-landscape-even-television-is-vulnerable/. Accessed 16 April 2015.

Pew Research Center. 2013. Public's knowledge of science and technology. http://www.people-press.org/2013/04/22/publics-knowledge-of-science-and-technology/. Accessed 16 April 2015.

Programme for International Student Assessment (PISA).(2012). www.pisa.oecd.org/.

Roth, W. & Van Eijck, M. (2010). Fullness of life as minimal unit: Science, technology, engineering, and mathematics (STEM) learning across the life span. *Science Education*, 94(6), 1027-1048.

Sriraman, B. and Freiman, V. (Eds). (2010). *Interdisciplinarity for the 21st century: Proceedings of MACAS3*, Moncton, Canada 2009. Information Age Publishing

Traphagen, K. and Traill, S. (2014). *How Cross-Sector Collaborations are Advancing STEM Learning*. Palo Alto, CA: The Noyce Foundation.

Trends in International Mathematics and Science Study (TIMSS), (2012). http://nces.ed.gov/timss/.

Weiss, H.B., Little, P.M.D., Bouffard, S.M., Deschenes, S.N. and Malone, H.J. (2009). *The federal role in out-of-school learning: After-School, summer learning, and family Involvement as critical learning supports*. Commissioned paper for the Rethinking the Federal Role in Education. Washington, DC: Center on Education Policy.