33 The Learning Sciences in the 2020s: Implications for Schools and Beyond

R. Keith Sawyer

This chapter reviews the implications of learning sciences (LS) research for schools, including assessment, curriculum, teaching practice, and systemic transformation. I discuss the role of technology in education – its history, its failings and successes, and how future technology designs can be grounded in LS. I then describe some trends and opportunities in the field of LS research, including the integration of individual and sociocultural research approaches; the ways that LS research can contribute to equity and diversity in learning and in schools; and the sociology and history of LS as a discipline.

Beginning in the 1970s, since the earliest appearances of personal computers, technologists have made predictions about how technology would change schooling in the future. Starting at about that same time, critics of modern schooling have argued that traditional pedagogies reproduce societal inequities, and that new forms of pedagogy are necessary to attain an equitable and just society. In this chapter I discuss these predicted and proposed futures from the perspective of LS, I provide some suggestions for what education might look like when it is grounded in LS, and I discuss how LS itself might evolve.

By the 1990s, a consensus had formed in many countries – among politicians, parents, and the business community – that it was essential to get computers into schools (Cuban, 2001). During the 1990s and 2000s there was a major push to install computers and the Internet in schools. By 2009, in the United States, 97 percent of teachers had one or more computers in their classroom every day and 93 percent of these computers were connected to the Internet (Gray, Thomas, & Lewis, 2010; Parsad & Jones, 2005). By 2020 educational technology had extended beyond the school into the home. In 2020, US schools were providing computers to 61 percent of student households (US Census Bureau, 2020) and 21 percent of US public schools offered at least one course entirely online (National Center on Education Statistics [NCES], 2021). In 2018, 88 percent of US 3- to 18-year-olds had computers at home with internet access (NCES, 2020). In Fall 2018, 34 percent of US undergraduate students participated in online education and 14 percent took their courses exclusively online (NCES, 2020).

However, this substantial societal investment in computer technology has not measurably increased student performance in Organisation for Economic Co-operation and Development (OECD) countries, including the United States (e.g., OECD, 2015). My explanation for this lack of impact is simple:

https://doi.org/10.1017/9781108888295.040 Published online by Cambridge University Press

most educational technology innovations have not been aligned with the science of how people learn. Before educational innovation will have an impact on student learning it must be grounded in LS. What would schooling look like if education were redesigned based on LS? What technologies are the most likely to support a transformation to pedagogy grounded in LS? What new organizational forms and instructional strategies must happen to support schooling grounded in LS?

This chapter was written in 2020–2021 – a very different world from 2006 when this handbook was first published. In 2020 and 2021, a deadly worldwide pandemic – the virus Covid-19 – forced many schools to completely close. In the United States, many schools were closed for a full year. In the United Kingdom, schools were closed for twenty-seven weeks; in France, ten weeks (https://en.unesco.org/covid19/educationresponse#schoolclosures). The pandemic school closures overlapped almost exactly with the writing and editing of this third edition. By April 2020, soon after schools closed, around 1.6 billion learners were affected in 194 countries, which is more than 90 percent of total enrolled learners prior to the closures (OECD, 2020b). Students and teachers were required to stay at home so that they would not encounter others who might have the virus. In many countries, social events were banned and playgrounds were closed; many students only saw their parents and siblings for months. In those countries with the resources to do so, teaching and learning took place on computers and the Internet. Most of the technologies that were used to respond to this sudden change existed in some form even in 2006: tablets, smartphones, internet-connected software, remote and distance learning, online courses, and learning management systems (LMS). In 2006, these were expensive and primitive by today's standards, and they were only available in a small number of institutions and a few countries. But their sophistication and their dissemination has increased dramatically. By 2018, schools in OECD countries had, on average, over 90 percent of their computers connected to the Internet (OECD, 2020a). In 2015, across all OECD countries, over 60 percent of 15-year-olds had access to internet-connected school computers and used them, with Great Britain close to 90 percent (OECD, 2019, p. 42). By 2016, across all OECD countries, over 10 percent of all individuals age 16–24 had attended an online course (OECD, 2017, Figure 6.4.3), 95 percent of young people aged 16–24 had access to the Internet, 84 percent of people had used the Internet in the last twelve months, and 72 percent did so every day (OECD, 2019, pp. 34–35). Remote teaching was the response to Covid-19 closures, and it was only possible because of this widespread availability of computers and the Internet.

At the time of publication of this third edition in 2022, technologies that were only prototypes in 2006 and 2014 had become firmly established in many schools and many countries. Some technologies that were ready to be implemented years ago, but were difficult to implement due to institutional, structural, and political factors, were finally implemented in response to Covid-19 school closures. These technological solutions were rushed and hence not ideal;

they were not equitably distributed across countries or within countries; their effectiveness has been criticized; but they nonetheless warrant examination by learning scientists who hope to design effective learning environments that incorporate these technologies.

It is hard to know how these trends will unfold when the pandemic retreats, but the past provides many lessons for the future. For example, we can expect that technological solutions will not be as successful as originally hoped. By 2010, after the first two decades of attempting to "fix" schools with technology, a growing number of techno-skeptics emerged (see A. Collins & Halverson, 2009). For example, in 2010 the computer pioneer and visionary Alan Kay – who worked at Apple from 1984 to 1997 – said that thirty years of technology in schools had failed (Cult of Mac, 2010). At about the same time, a US government review of ten major software products for teaching algebra, reading, and math found that nine of them did not have statistically significant effects on test scores (Gabriel & Richtel, 2011). More recently, a 2015 OECD study of dozens of countries likewise found "no appreciable improvements in student achievement in the countries that had invested heavily in ICT for education" (ICT = Information and Communication Technologies; OECD, 2015, p. 3).

When researchers began to look more closely at why computers were having so little impact, they discovered that computer use was not based on LS; instead, they were being used as quick add-ons to the existing instructional classroom (Cuban, 2001). A 2010 report from the NCES (Institute for Educational Sciences, 2010) reported that almost 70 percent of teachers said they used computers for drilling students on basic skills. The 2015 OECD report, in explaining the lack of impact of computers on learning, concluded "we have not yet become good enough at the kind of pedagogies that make the most of technology . . . adding 21st-century technologies to 20th-century teaching practices will just dilute the effectiveness of teaching" (OECD, 2015, p. 3). Learning scientists are well aware that computers have generally failed teachers and students; that they are, in Larry Cuban's (2001) famous words, "oversold and underused."

These findings should give pause to LS researchers, who often work at the cutting edge of new technologies in schools. And yet, learning scientists can readily explain why computers have had very little impact on student learning – it is because technology use in schools has rarely been aligned with LS findings. Instead, new technologies such as online instruction have continued to be aligned with *instructionism* (Sawyer, Chapter 1 in this volume), a pedagogy where teachers deliver information to passive students. The pedagogy used in online courses "is a transmission model, relying on video lectures, recommended readings and staged assessment" (Sharples et al., 2013, p. 3) – exactly the opposite of what LS research would advise. Computers will never realize their full potential if they are merely add-ons to the existing instructionist classroom; that is why learning scientists are engaged in the hard work of designing entire learning environments – not just stand-alone computer applications, as previous generations of educational software designers did.

Those countries that can effectively restructure their schools on a learning sciences foundation will be the leaders in the twenty-first century (OECD, 2000, 2004, 2008, 2010, 2013). As long ago as 2003, the issues addressed by the learning sciences were recognized as critical in all twenty-eight of the countries studied by the International Society for Technology in Education (ISTE; Kozma, 2003). The chapters in this handbook describe how to design the learning environments of the future. In this conclusion, I begin by presenting some possible visions of the schools of the future; I compare these with some suggestions that I made in 2006 and 2014, to help provide a long-term picture of how schooling evolves over many years; and I discuss some issues that will face LS as its findings begin to be used to build the learning environments of the future. I conclude by discussing how LS might grow and evolve by the time we see the fourth edition of this handbook.

33.1 Implications of the Learning Sciences: Schools and Beyond

The learning sciences have enormous potential to transform schools so that students learn better and more deeply, are more prepared to function in a creative age, and are able to participate actively in an open, democratic society that works toward equity and social justice. These chapters provide a wealth of research-based evidence for how learning environments should be designed. Note that these chapters generally talk about "learning environments" rather than "schools" or "classrooms"; this is because learning environments include schools and classrooms but also the many informal learning situations that have existed through history and continue to exist alongside formal schooling, and that more recently include computer- and internet-based alternatives to classrooms. A true science of learning has to bring together understandings of all learning environments, drawing on their best features to build the schools of the future. Instead of studying small incremental changes to today's schools, learning scientists ask a more profound question: are today's schools structured in ways that can foster deep learning?

Learning scientists are committed to improving schools, and they believe that school reform should involve working together with teachers, engage in professional development, and integrate new software into classrooms. But LS research, combined with new technologies, might also lead to more radical alternatives that would result in dramatically new organizational forms of schooling. In 2006 – when the first edition of this handbook was published – education futurists predicted several changes that did not happen until the 2020–2021 pandemic made them essential. When the pandemic closed schools for months, many of these 2006 predictions suddenly came true: schools were no longer physical locations where students went each day; students were not grouped by age or grade, but by family and neighborhood; and students learned wherever they could find a good internet connection. The Covid-19 pandemic required schools to close in most countries, resulting in a sudden transition to online learning, at least in wealthy countries with widespread internet connectivity. Although schools, teachers, and families were not prepared for the pandemic shutdown, they had many tools in place that enabled teaching and learning to continue online. Many OECD countries were already using online LMS for students to submit papers and take quizzes and for teachers to send grades to students. Free and easy-to-use video conferencing tools were widely available, including Zoom, Microsoft Teams, and Google Classroom. However, when schools used these technologies to respond to Covid-19 closures, in most places pedagogy become even *more* instructionist. These technologies seemed to make it more difficult than ever to teach using active, research-based pedagogy. And yet, the Covid-19 impact on schooling could have been much worse. Imagine if a pandemic had closed schools in 1970, before the Internet and personal computers. Students would have had no interaction at all with their teachers or schools. Parents and students alike are understandably dissatisfied with online learning, but if schools had closed for a year in 1970, there would have been no teaching, no grading, no structure to a student's day except perhaps for reading books from the local library (imagine waiting lists and hoarding of books), and almost certainly no learning. This is what happened outside of the affluent OECD countries without access to computers or the Internet: schooling stopped completely or it continued in ways that fostered the spread of the virus and resulted in higher mortality rates. In many affluent countries, the technology to enable online education was in place long before the Covid-19 pandemic.

In 2014 – when the second edition of this handbook was published –education futurists predicted a variety of potential transformations in the organizational forms of schooling. One of these predictions was that education would move away from large, centralized buildings to distributed learning centered around online home-based activities along with small neighborhood learning clubs. In response to the pandemic, this actually did happen in many US cities, although only on a small scale and without top-down organization or planning (Shapiro, 2021). Some communities in San Francisco responded to school closures by creating "learning hubs" with programs that operated 8:30am to 5:30pm and with staff available to help students with their schoolwork. Similar learning hubs opened in New York City, Washington, DC, and Chicago. These hubs, like many around the USA, served students across grade levels from primary to secondary schools (North, 2020; Shapiro, 2021). New York City created "regional enrichment centers" that were open longer than the traditional school day and that were for children of emergency medical workers. For complex political and organizational reasons, however, these responses rarely involved public schools or teachers. International students who could no longer leave their home country to return to their overseas campuses joined together in "learning centers" or "study hubs," particularly in Chinese cities for students attending colleges in the USA, Australia, and others (IDP Connect, 2021).

As long ago as the 1970s – when Alan Kay envisioned the *Dynabook*, a portable tablet computer (see Pea & Sharples, Chapter 18 in this volume) – education futurists predicted the demise of physical textbooks. This has come to pass in many advanced countries. Many schools in the USA provide a Google Chromebook free to all students – a low-cost tablet with secure software that can be used for school activities. Other possible transformations predicted in 2014 are not widespread but have happened in some countries. For example, in 2014 I suggested that "teachers" might begin to operate as independent consultants who work from home most of the time. This has been the case in China for many years, where some of the best teachers – whether of English-language instruction or national test preparation – can make a substantial income by going into business on their own (although in 2021 the Chinese government issued new regulations to restrict for-profit education: Shen, Munroe, Zhu, & Westbrook, 2021). If these trends expand internationally, these teachers – perhaps rebranded as "educational consultants" – could occasionally meet with ad-hoc groups of students at local learning clubs. Each meeting would be radically different in nature, depending on the customized activities and curricula developed by the teacher. Teachers, rather than operating alone, might join together to form small businesses that bring together a variety of learning specialists. These changes, based as they are on market competition and funded by payments from parents, will raise issues of equity: only the most affluent families would be able to afford these star teachers. For example, in China, only the affluent have been able to afford expensive after-school education.

In the USA, *homeschooling* is an example of this possible future. In homeschooling, parents choose not to send their children to a public school; instead, one of the parents stays home and teaches their children in a semi-structured "school day." Homeschooling is legal in many countries, and in all fifty US states, although different countries and the fifty different US states regulate homeschooling to differing degrees. In eleven states, parents have complete freedom regarding homeschooling; at the other extreme, 10 percent of states have strict laws regulating it. There were over 1.5 million homeschooled children in the USA in 2016, prior to the 2020–2021 pandemic – that is 3.3 percent of all US students (McQuiggan & Megra, 2017). In the pandemic, with students learning from home, of course all children were homeschooled by definition. Homeschooling predates the Internet, but the Internet has made it much easier by providing curriculum and activities to parents and by enabling local groups of nearby families to collectively provide substitutes for nonacademic activities that traditionally take place in schools, such as affinity clubs (chess, theater, gaming) and team sports. These activities provide opportunities for socialization with same-age peers. Just as with the potential emergence of expensive private teachers, the growth in homeschooling would probably increase society's inequity because only the most affluent families can afford to have one parent stay at home with the children rather than leave for work. Many studies show that homeschooling families skew heavily toward higher-income, college-educated parents (e.g., Admissionsly, 2021). The most financially disadvantaged children are statistically more likely to have parents who both work, or parents who have divorced or separated, leaving only one parent at home. That parent often works full-time and depends on the public school for both education and day care.

In 2014, I quoted futurists who predicted that schools might dramatically modify their schedules by creating a "hybrid" model – half in-person and half online – for example with a three-hour intensive workday in person and then with each student taking home their laptop to complete the remainder of the day at home. In the 2020–2021 pandemic, this became a reality in many schools. Even when schools opened, they could only accommodate half of their usual number of students at a time due to the need for students to remain six feet apart to reduce the chance of virus transmission. In my own city's schools, in Spring 2021 the secondary schools opened only partially – with one-half of students attending in person Monday and Tuesday, the other half attending Thursday and Friday, and both groups working remotely from home three days each week.

Museums and public libraries, over the last several decades, have intentionally transformed themselves into educational institutions (Pierroux, Knutson, & Crowley, Chapter 22 in this volume), and they might continue to play an increasingly larger role in education. Informal educational institutions are contributing to student learning in several ways. For example, many institutions have developed curricula and lesson plans and have made these available to all students over the Internet. Science centers have taken the lead in this area, developing inquiry-based curricula and conducting teacher professional development. A leading example is the San Francisco Exploratorium (www.exploratorium.edu). Many large art museums and history museums have full-time educational staff and are developing activities, curricular units, and summer school programs. They have redesigned their buildings to include classrooms; some have constructed new buildings to house their education offerings. These institutions could continue to expand into territory traditionally occupied by public schools.

Among adults, the boundary between formal schooling and professional education will increasingly blur. Inexpensive tablets and phones allow learning to take place anywhere, anytime. The daily schedule of a junior apprentice to a trade, who may be 16–20 years of age, could involve a daytime internship while they take their classes at night just as many adult students do now. Many types of knowledge are better learned in workplace environments; this kind of learning will be radically transformed by the availability of anywhere, anytime learning. Apprentices, or employees training for new tasks, could take their tablets on the job with them, with software specially designed to provide apprenticeship support while they work. In the USA, career-focused postsecondary education has historically been associated with two-year community colleges that offer "associate degrees." In 2018, about one-third of US undergraduate students were enrolled in one of these two-year colleges (Bauman & Cranney, 2020). Online learning is more important for adult students than for full-time undergraduate students because it is much harder for them to get to campus: they have jobs that fill their schedules, they often have young children, and they do not live on campus near classroom buildings. Online learning has put campus-based models of adult education at risk. The fastest-growing US colleges are those that have aggressively moved into online education – such as the nonprofit Southern New Hampshire University, with only 3,000 on-campus students but over 100,000 online students (Southern New Hampshire University, 2021), and the for-profit Strayer University, founded in 1892 to provide training in secretarial skills including typing and shorthand, which is now a career-focused university that has almost 50,000 students in its online learning programs (Strayer University, 2021).

Education futurists predicted many of these changes decades ago – shortly after the onset of personal computers and the Internet. It has taken several decades, but many of these predictions have come to pass. But these innovations are unevenly distributed among nations, communities, and social classes. As learning scientists, we are concerned that most of these changes have not resulted in learning experiences grounded in LS. The above technologies, organizational reconfigurations, and curricular revisions have, for the most part, reinforced instructionist pedagogy. That has certainly been the experience with the Covid-19 transformation to remote learning – pedagogy has become more instructionist in most cities and countries. Learning outcomes have suffered dramatically, with many commentators saying that 2020–2021 was a "lost year" with students learning almost nothing. After one year of online learning, most students and families preferred to return to in-school, in-person instruction.

For educational institutions to use technology effectively, curriculum and pedagogy must be designed to align with LS findings. Regardless of what schools look like; regardless of how the Internet is used; regardless of whether students are learning in school, at museums, or in homeschooled clusters; children and adults will learn more effectively in learning environments that are redesigned on a foundation in LS.

33.1.1 What Constitutes Evidence of Learning?

In the United States, higher education classes are organized around a "credit hour" model and a nine- or ten-month calendar. In the USA, a credit hour corresponds to the time spent in the classroom each week – excluding time the student is expected to work outside of class. One college class is typically three credits per term, corresponding to three "contact hours" spent in the classroom with the instructor. In the European Union, one ECTS credit (European Credit Transfer and Accumulation System) corresponds to the total number of hours the student is expected to work on a course for the entire term, roughly 25–30 hours of work. This typically adds up to a total of 60 credits for one academic year, corresponding to 1,500–1,800 hours of total workload (European Union, 2015). A student receives those credits, with the grade earned, at the end of the course. A student's transcript – the document providing evidence of successful learning – is likewise organized by term, course, and credit.

Many educational innovations challenge this model – particularly online distance learning. In the USA, many or most of those weekly three contact hours are taken up by professor lectures in a large lecture hall. But when an instructor can easily record a lecture on their computer and post the video on the Internet for students to watch whenever they like, should we count the time watching the video as "contact hours"? Why should the fundamental unit of teaching and learning be so tightly connected to a physical campus and to face-to-face interaction? Even before the Internet, the credit hour was a rather poor measure of how much learning had occurred. Remote learning cries out for another way to measure the amount of learning than the credit hour.

One of the most prominent alternatives to the credit hour model is the proposal to use *badges* as the fundamental unit of learning. Terms like "competency based," "proficiency based," or "credentialing" are used to refer to the practice of granting degrees and certificates based on performance on a final assessment rather than time in the classroom (Selingo, 2013, pp. 112–116). In 2016, five of the fifty US states had advanced policies supporting competency-based education in K-12 education (Brodersen, Yanoski, Mason, Apthorp, & Piscatelli, 2016). An increasing number of US universities offer competency-based courses and degrees. A major problem with many competency-based systems is that, to date, they assess relatively superficial knowledge rather than the deeper understanding advocated by LS and required by today's creative age.

A second prominent alternative is the idea of instituting an "exit exam" as a prerequisite for graduating with a degree. Already in many of the world's countries – including almost all of Asia and Europe – the most important evidence of successful learning at the secondary level is a high-stakes exit exam. In the USA, one's secondary-school grades are certainly important, but in addition many college-bound students take one of the privately developed and privately administered college entrance exams, the ACT or the SAT. Whether a student is evaluated by final GPA or by standardized test scores, these both are considered – perhaps simplistically – to be measures of total amount of learning that has occurred. An issue with this alternative is that performance on summative final assessments correlates highly with socioeconomic status, so that if these scores are used for future access to high-quality schooling and high-paying careers, they can serve to reproduce societal inequities. Many US colleges have made secondary school exit exam scores optional for application out of concern that such tests may reproduce societal inequities, seemingly more so than the use of secondary-school grades, which continue to be almost universally used in college admissions.

The challenge will be to design assessments that are grounded in the latest science of how people learn, and that accurately reflect twenty-first- century skills – creativity, collaboration, and deeper conceptual understanding. Almost all assessments – in particular, automated assessments – only work well for the shallow and superficial knowledge that is taught by instructionism. Unfortunately, if both pedagogy *and* assessment continue to be aligned with instructionism, this synergistic stability will make it very difficult to transition to LS-based pedagogy and to deeper conceptual learning. Assessment design is an active area of research (see Pellegrino, Chapter 12 in this volume), and this research is needed to support a future where schools are based in LS.

33.1.2 Assessment and Accountability

The ultimate goal of learning sciences research is to contribute to the design of learning environments that lead to better student outcomes. Success will need to be measured using some sort of assessment of student learning. This is, of course, a challenge for sociocultural approaches that focus on groups and cultures as their unit of analysis; ultimately, these learning scientists need to translate their findings to an individual level of analysis. However, LS suggests that many of today's standardized tests are flawed, because they focus on the surface knowledge emphasized by instructionism, and do not assess the deep knowledge required by the knowledge society. Standardized tests, almost by their very nature, evaluate decontextualized and compartmentalized knowledge. For example, science tests rarely assess whether preexisting misconceptions have indeed been left behind (diSessa, Chapter 6 in this volume) and rarely assess problem-solving or inquiry skills (Krajcik & Shin, Chapter 4 in this volume). As long as schools are evaluated on how well their students do on such tests, it will be difficult for them to leave instructionist methods behind. One of the key issues facing LS is how to design new kinds of assessment that correspond to the deep knowledge required in today's knowledge society (Pellegrino, Chapter 12 in this volume; Sawyer, 2019).

In classrooms that make day-to-day use of computer software, installed on each student's own personal computer, there is an interesting new opportunity for assessment – the assessment could be built into the software itself using learning analytics and microgenetic analysis (see Baker & Siemens, Chapter 13 in this volume; Pellegrino, Chapter 12 in this volume; Sherin & Chinn, Chapter 11 in this volume). After all, LS has found that learning environments, to be effective, must closely track the student's developing knowledge through a learning trajectory. If that tracking was being done anyway, it would be a rather straightforward extension to make summary versions of it available to teachers. New LS software is exploring how to track deep learning during the learning process, in some cases inferring student learning from such subtle cues as where the learner moves the cursor, where the learner is gazing at the screen, and when they click the mouse buttons – providing an opportunity for assessment during the learning itself, not in a separate multiple-choice quiz (e.g., Gobert, Buckley, & Dede, 2005).

These new forms of assessment represent the cutting edge of LS research. A critical issue for the future is to continue this work, both in the research setting but also in the policy arena – working with developers of standardized tests and working with state boards of education to develop broad-scale standardized tests. Test construction is complex, involving field tests of reliability and validity, for example, and will require learning scientists to work with psychometricians and policy experts.

33.1.3 Curriculum

What should be taught in second-grade math, or in sixth-grade social studies? Learning scientists have discovered that what seems more simple to an adult professional is not necessarily more simple to a learner. The most effective sequencing of activities is not always a sequence from what experts consider to be more simple to more complex. Children arrive at school with naïve theories and misconceptions and, during the school years, children pass through a series of cognitive developmental stages. Instructionist textbooks and curricula were designed before learning scientists began to map out the educational relevance of cognitive development.

In the next ten to twenty years, new curricula for K-12 education will hopefully emerge that are based in LS. Major funding should be directed at identifying the specific sequences of activities and concepts that are most effective in each subject – sometimes referred to as *learning trajectories* or *learning progressions* (Sherin & Chinn, Chapter 11 in this volume; Pellegrino, Chapter 12 in this volume). Developing these new curricula will require many teams of researchers, distributed across all grades and all subjects, to identify the most appropriate sequences of material, and the most effective learning activities, based on research into children's developing cognitive competencies and how children construct their own deep knowledge while engaged in situated practices.

Related to the issue of curriculum is the sensitive topic of *coverage* – how much material, and how many topics, should students learn at each age? In instructionism, the debate about curriculum is almost exclusively a debate about topic coverage – what should be included at each grade, and how much. But research shows that this focus on breadth is misguided. According to the Trends in International Mathematics and Science Study (TIMSS), which compares student achievement in math and science in fifty countries every four years, US science and math curricula contain more content than other countries as a result of their survey approaches to material – but rather than strengthening students' abilities, the survey approach weakens US achievement relative to other countries (Sawyer, 2019, pp. 21–22). Compared to other countries, US science curricula are "a mile wide and an inch deep" (Vogel, 1996, p. 335). Each topic is taught as its own distinct unit and the units are presented in sequence, but learning in one unit is often forgotten as soon as the students turn to the next unit. Studies of the TIMSS data show that children in nations that pursue a more focused, coherent, and deep strategy do better on the mathematics assessment than do US children (Schmidt & McKnight, 1997).

https://doi.org/10.1017/9781108888295.040 Published online by Cambridge University Press

This is consistent with the LS finding that students learn better when they learn deep knowledge that allows them to think and to solve problems with the content that they are learning.

A near-term task facing LS is to identify the content of the curriculum for each subject and each grade and then to design an integrated, coherent, unified curriculum to replace existing textbooks. LS research could be directed toward identifying which deep knowledge should be the outcome of each grade. This has successfully been done in science education, in the US Next Generation Science Standards (NGSS), and yet it has proven difficult to transform science education in ways that lead to these deep learning outcomes. LS-based curricula will contain fewer units and fewer overall line items, with more time spent on each item. This will be a political challenge, because some parents may view it as an attempt to make school easier by reducing the expectations of students. In the USA, politicians and school boards have frequently responded to concerns about the quality of education by adding *more* content requirements to the curriculum – further exacerbating the “mile wide, inch deep” phenomenon. It will take a paradigm change to shift the terms of this policy debate, and learning scientists could make valuable contributions.

33.1.4 The Teachers of the Future

LS focuses on learning and learners. Many education researchers are instead focused on teachers and teaching (Fishman et al., Chapter 31 in this volume), and these readers may observe that the classroom activities described in these chapters seem very challenging for teachers. How are we going to find enough qualified professionals to staff the schools of the future? The teachers of the future will be knowledge workers, with equivalent skills to other knowledge workers such as lawyers, doctors, engineers, managers, and consultants. They will deeply understand the theoretical principles and the latest knowledge about how children learn. They will be deeply familiar with the authentic practices of professional scientists, historians, mathematics, or literary critics. They will have salaries comparable to other knowledge workers; if not, the profession will have difficulty attracting new teachers with the potential to teach for deep knowledge. The classrooms of the future will require more autonomy, more creativity, and more content knowledge (see Sawyer, 2019).

Over a wide variety of international schools, a set of best practices surrounding educational technology is emerging (Kozma, 2003; Sawyer, 2019; Schofield & Davidson, 2002). Instead of instructionism – with the teacher lecturing in a transmission-and-acquisition style – these classrooms engage in authentic and situated problem-based activities. If you looked into such a classroom, you would see the teacher advising students, improvisationally creating structures to scaffold student activities, and monitoring student progress. Effective teachers use *guided improvisation* – they scaffold students through a learning trajectory as they construct their own knowledge in a collaborative process (Sawyer, 2019; Scardamalia & Bereiter, Chapter 19 in this volume). You would see the students actively engaged in projects, managing and guiding their own activities, and collaborating with other students. Through these activities, teachers prepare students to fully participate in a creative world.

33.1.5 Enlisting Stakeholders in Educational Transformation

The research in this handbook can be used by educators to design more effective and innovative learning environments, including school classrooms and also informal settings such as science centers or after-school clubs, online learning, and educational software. Learning scientists are disseminating these findings to a broad audience of stakeholders. Several books published since the 2014 second edition of this handbook have translated LS research for a broader audience of teachers, school leaders, parents, and policy makers. These include (oldest to newest):

- *Make It Stick: The Science of Successful Learning* (Brown, Roediger, & McDaniel, 2014).
- *The ABCs of How We Learn: 26 Scientifically Proven Approaches, How They Work, and When to Use Them* (Schwartz, Tsang, & Blair, 2016).
- *Learn Better* (Boser, 2017).
- *The Creative Classroom: Innovative Teaching for 21st-Century Learners* (Sawyer, 2019).

The publication of so many books written for a broad readership indicates that there is a thirst among the public for solid, trustworthy scientific knowledge about teaching and learning. The task facing all knowledge societies is to translate LS research into educational practice. Perhaps the most solid finding to emerge from LS is that significant change cannot happen by fiddling around at the edges of a system that remains instructionist at the core. Instead, the entire instructionist system will have to be replaced with new learning environments that are based on LS. This will require both structural and cultural change. Learning scientists are an important part of the solution, but many stakeholders must participate in transitions to the schools of the future. Learning scientists will need to work with this broader educational ecosystem to accomplish change.

- Parents, politicians, and school boards must be convinced that change is necessary, both because this pedagogy will look very different from what they experienced as children, and also because it will be expensive. The shift will require an initial and also a continued investment in hardware and software, due to the rapid developments in new technology that have been happening every few years. Pedagogical transformation may require new buildings with as-yet-undetermined architectural designs, such as the neighborhood learning hubs described in Section 33.1.
- Textbooks must be rewritten – whether print or digital – to present knowledge in the developmentally appropriate sequence suggested by LS, and to present

https://doi.org/10.1017/9781108888295.040 Published online by Cambridge University Press

knowledge as a coherent, integrated whole, rather than as a disconnected series of decontextualized facts. Textbooks, conceived of as linearly structured text, may be replaced by gamified and personalized multimedia learning tools. These are much more expensive than writing and producing books.

- The shift to customized, just-in-time learning might result in a radical restructuring of the school day, and may make many features of today's schools obsolete: schools years might no longer be grouped by age, school days might no longer be organized into class periods, standardized tests might no longer be administered en masse to an auditorium of students, perhaps not everyone will graduate high school or start college at the same age. Many of the socially entrenched aspects of schools that are not directly related to education would have to change as a result: organized sports, extracurricular activities, graduation rituals that function as rites of passage.
- The relationship between the institution of school and the rest of society may need to change, as network technologies allow learners to interact with adult professionals outside the school walls, and as classroom activities become increasingly authentic and embedded in real-world practice.
- Standardized tests must be rewritten to assess deep knowledge as well as surface knowledge, and to take into account the fact that due to customization, different learners might learn different subject matter.
- Teacher education programs must prepare teachers for the schools of the future – teachers who are experts in disciplinary content, knowledgeable about the latest research on how people learn, and able to respond creatively to support each student's optimal learning.

All of these changes will be expensive. Building new schools and designing new multimedia gamified learning tools is a major investment. Restructuring the schedule of the school day could lead to obsolete and unused buildings and auditoriums. Many university architecture firms have started to work with learning scientists and now realize that lecturing is an ineffective pedagogy. In the school of the future, large lecture halls built a hundred years ago no longer have a pedagogical justification. Some universities are beginning to invest significant funds in redesigning lecture halls to support active, collaborative learning – replacing chairs bolted down in rows with small tables and rolling chairs to foster group discussion. But to date, these are tentative efforts usually in only one or two spaces (photos of which are usually prominently displayed on a university's website). Very few schools have the resources to completely redesign all of their learning spaces.

There are many other challenges that are likely to raise the cost of schooling. First, assessments of deeper understanding generally cost *fifty* times as much to administer as those used today to assess superficial knowledge (Sawyer, 2019). Second, teachers who develop the advanced pedagogical skills aligned with the chapters in this handbook will warrant substantially higher salaries than those paid today. Third, if schools no longer serve a "day care" function of monitoring children during the day, five days each week – and if their parents still must leave the house to work – other institutions will need to emerge to take care of those children during their remote learning time. Otherwise, the economy could not function because parents could not leave the house to work (except, of course, for the subset of parents with knowledge-economy jobs that can be done from home – further exacerbating social inequity).

Due to all of these necessary changes, a school based on LS will be significantly more expensive to run than the schools we have today. It is unlikely that the transformation can take place with the existing government allocations of resources. To transform schools to a foundation in LS, society as a whole must decide whether to invest the necessary resources. If the existing level of public school funding continues, schools may find it difficult to shift away from instructionist pedagogy. A risk is that private schools that service wealthy families may invest in LS pedagogy, whereas the great majority of students who cannot afford these private schools will continue to experience ineffective instructionist pedagogy due to limited public funds. This could reproduce societal class structure because the wealthy will receive pedagogy that prepares them for the high-paying jobs of the creative age, while those families with fewer resources – as Freire (1968) argued – will not "develop the critical consciousness which would result from their intervention in the world as transformers of that world." Instead, the continuation of the banking concept, of instructionism, "serves the interests of the oppressors" (p. 60). These graduates will not be prepared for the creative age; such a system will track them into low-paying jobs.

LS research must be the foundation of school redesign and of pedagogical innovation. LS research is necessary to create schools that lead to equal education for all students. This handbook was created by a dedicated group of scholars committed to uncovering the mysteries of learning. These researchers have been working since the 1970s, developing the basic sciences of learning – beginning in psychology, cognitive science, sociology, and other disciplinary traditions, and in the 1980s and 1990s, increasingly working closely with educators and in schools. As these scholars continue to work together in a spirit of interdisciplinary collaboration, the end result will be an increasingly detailed understanding of how people learn. Once that understanding is available, the final step to transform schools must be taken by our whole society: parents and teachers, and the administrators and politicians who we entrust with our schools. LS is ready to participate in this essential transformation.

In 2014, two leading learning scientists – Susan A. Yoon and Cindy E. Hmelo-Silver – surveyed 253 ISLS members to ask them what they do and how they would define the field (Yoon & Hmelo-Silver, 2017). They found a substantial crossover between research and practice. Although the majority of Ph.D. graduates from LS degree programs, 63.2 percent, worked at a university – either as a professor, instructor, or postdoctoral fellow – one out of five were working in professional positions either inside and out of the academy. They also interviewed graduates of master's degree programs, and almost all of them were practitioners. Half were educational consultants (20 percent) and K-

https://doi.org/10.1017/9781108888295.040 Published online by Cambridge University Press

12 teachers (over 30 percent); the others worked in industry, IT, or educational leadership. These numbers tell us that LS research is having a broad impact outside of the university setting. Yoon and Hmelo-Silver predicted that LS could increase its real-world influence with more master's degree programs. Their prediction has been realized since they conducted their 2014 interviews: two prominent new master's degree programs in LS in the USA are the "Master of Arts in Learning Engineering" at Boston College (founded by Janet Kolodner in 2019) and the "Master of Arts in Educational Innovation, Technology, and Entrepreneurship (MEITE)" at the University of North Carolina at Chapel Hill (founded by Keith Sawyer in 2016).

33.2 The Future of Learning Sciences Research

With the publication of this third edition it has now been thirty years since the 1991 founding of the learning sciences and fifteen years since the 2006 publication of the first edition. How has the field changed over these decades? How might it evolve in the future? I discuss three possible opportunities moving forward: bringing together studies of both individual and sociocultural learning; drawing on LS research to contribute to equity and diversity in society; and exploring how LS might evolve in partnership with other disciplines that study learning.

33.2.1 Individual Learning and Sociocultural Learning

In Chapter 2 of this volume, Mitch Nathan and I grouped LS research into *elemental* and *systemic* approaches. Elemental approaches focus on individual learning whereas systemic approaches focus on groups and classrooms. Many learning scientists emphasize the importance of learning in groups, in part because most human action outside of schools takes place in rich and complex social and cultural settings. These group processes are generally analyzed using systemic approaches. In contrast, many psychologists take elemental approaches that focus on individual learning and individual knowledge (Dunlosky & Rawson, 2019).

An opportunity for LS is to integrate scientific findings emerging from the elemental and systemic approaches. The field brings together a diverse range of positions on how to accomplish this – cognitive psychologists who focus on the mental structures that underlie knowledge; sociocultural theorists who advocate a blend of cognitive and social pedagogies; and a few socioculturalists who hold that it is not possible to study the learning or knowledge of an individual because one cannot separate the mental structures of any one person from the situated social practices they are embedded in (Esmonde, 2017; Rogoff, 1990). Most learning scientists reside in the center of this debate, believing that a full understanding of learning requires a combination of elemental and systemic approaches. But there is disagreement among learning scientists about where

https://doi.org/10.1017/9781108888295.040 Published online by Cambridge University Press

the emphasis should be placed (for a theoretical account of these tensions, see Sawyer, 2002).

The usefulness of each approach is likely to vary in different learning environments. For example, the individualist approach of cognitive psychology is more useful to explain how a student learns while reading a book alone in the library or while studying for a test in their residence. A sociocultural approach is more useful when analyzing a youngster working together with a parent on a chore, athletes practicing a team sport after school, or relations between learning, power, and identity in different cultural communities (Esmonde, 2017).

Individual learning is always going to be an important goal of schooling. Parents want their children to succeed; employers hire individuals, not social groups; all nations need their citizens to share some unifying knowledge – regardless of their family and community background – such as being able to speak the national language and being able to read a common orthography; students search for employment as individuals; and, with hope, all students will find satisfaction in realizing their personal potential as human beings. Individuals learn some knowledge better in social and collaborative settings than they do in isolation, but schools will continue to be judged on how well individual graduates perform on some form of individualized assessment. LS suggests that today's assessments are misguided in design, in part because they isolate individuals from meaningful contexts. New assessments could include components that evaluate the individual's ability to work in a group, to engage equitably with people from a diversity of backgrounds, or to communicate in complex, rapidly changing environments. But even if new forms of assessment take a sociocultural approach and focus at the group level of analysis, we will still need to assess the individual learning of each member of the group.

33.2.2 Equity, Diversity, and Learning

Since the origin of modern bureaucratic schools in industrialized countries over a hundred years ago, they have served the function of fostering a unified national culture and belief system (Carretero & Perez-Manjarrez, Chapter 26 in this volume). As sociologists argued in the 1950s and 1960s, this *social reproduction* function is necessary for large-scale modern society to maintain its structural form (J. Collins, 2009). Education plays a central role in reproducing the structures of society, including the inequalities of social structure, cultural order, and economic class. A prominent example of the reproduction function is in history education, where the great majority of educational systems worldwide teach *national narratives* that, as Carretero and Perez-Manjarrez (Chapter 26 in this volume) point out, "serve the function of consolidating national identity and building nation-states" (p. 531; also see Nasir et al., Chapter 29 in this volume). As a result, it is difficult to consider "the perspectives of nondominant groups" (p. 531). A deeper understanding of history, which they call *second-order understanding*, is needed to allow learners to critically examine these national narratives, hence developing deeper

https://doi.org/10.1017/9781108888295.040 Published online by Cambridge University Press

conceptual understanding of the social and historical forces that resulted in the emergence of those narratives.

Many education theorists have argued that the homogenizing function of schools should be challenged because it reproduces social structures that enforce hierarchies of class, race, and ethnicity. In 1968, the socialist education theorist Paolo Freire argued that instructionism, which he called the *banking concept* of education, reinforced authoritarian mindsets and oppressive social systems: "In their political activity, the dominant elites utilize the banking concept to encourage passivity in the oppressed" (p. 84). Western neo-Marxists like Louis Althusser argued that institutions including schools "interpellated" individuals to mold them into workers who would submit to inequitable societal structures (1970/1971). To establish societal equality and a democratic society, Freire advocated a pedagogy of inquiry and problem-based learning that he referred to, variously, as "problem-posing," "humanizing," and "co-intentional." At that time, advocates of social justice did not know how to implement these insights in pedagogy. Today, learning scientists have developed pedagogies aligned with Freire's revolutionary proposals: collaborative, constructivist, and problem-based. Social justice and equity require that we redesign schools to be based on LS.

In the United States, many scholars have extended the focus on the reproduction of class structures to a focus on ethnicity and race as additional explanatory factors in educational outcomes, an approach sometimes known as *critical theory*. Scholars who focus on social reproduction have historically studied factors unrelated to classroom pedagogy that are documented to have a significant impact on student learning outcomes: residential segregation, school funding differences, ability-based tracking, demographic characteristics of families, and regional and national policy decisions (e.g., Coleman et al., 1966; Konstantopoulos & Borman, 2011). Critical theorists argue that schools are structured in ways that lead to the reproduction not only of class structures, but also of other inequitable social structures of race, ethnicity, culture, and gender.

However, rarely have these theorists examined exactly how different learning environments educate in ways that reproduce inequity. In the years just before this third edition was published, several critical theorists began to realize that LS is a necessary part of the solution to societal inequity (e.g., Esmonde & Booker, 2017b; C. D. Lee, de Royston, Nasir, & Pea, 2020). Learning scientists have begun to collaborate with these scholars to help them identify how LS research can contribute to an equitable and just society.

In Chapter 1 of this volume, I cited a large body of research showing that there is no evidence that members of any race, culture, or nationality learn differently from any other. And yet, this universality seems to be inconsistent with statistical evidence: in the United States, students from nondominant cultures have lower grades and test scores, they are more likely to be disciplined for their behavior, and they are more likely to drop out of school altogether. Why, when the processes of learning are universal, do national statistics show that students from dominant groups seem to learn more effectively than those

https://doi.org/10.1017/9781108888295.040 Published online by Cambridge University Press

from nondominant groups? LS research provides at least two causal explanations that can contribute to the design of more equitable schools. The first, perhaps most obvious, is that differences in learning outcomes can be explained by differential access to LS-based pedagogy and teachers trained in it. For example, a US National Academy of Sciences report found that for groups traditionally excluded from science and science education, their science instruction in school provides them with only inadequate and intermittent access to high-quality science experiences (National Academies of Sciences, Engineering, and Medicine, 2019). The resolution of this cause of inequity is to make research-based pedagogy available to all students equally. In the future, learning scientists can contribute to equity on this issue by communicating their findings to school leaders, policy makers, and teachers, with the potential of leading to improved pedagogy for all students.

A second way that today's schools can lead to unequal learning experiences is that there may be a mismatch between the language and culture of the school, and the language and culture of students from nondominant groups. Many countries have large communities that speak a language very different from the national language, but schooling tends to occur in only the national language. This gives an advantage to students whose home language is the national language. Although the United States does not recognize an official language, almost all instruction is in English. Other than the USA, in almost all countries there is an official national language and schooling is offered only in the national language.

More subtle are the different ways that the national language is spoken in different communities, which de Royston, Lee, Nasir, and Pea (2020) refer to as "linguistic repertoires … the differing ways of speaking, writing, and reasoning" (p. 10). Speech genres and performative norms of identity and social role vary dramatically across ethnicities and social classes (e.g., Gumperz & Hymes, 1972/1986). The speech styles that are valued in school settings by the teachers and the administrators are almost always the speech styles of the dominant cultural group. Students from other cultural groups who have been socialized into different speech genres and interactional patterns are likely to find it more challenging to succeed without assimilating into those dominant interactional patterns.

In the USA, scholars studying race and inequity have, for example, documented that schools do not recognize or teach the speech styles and genres that are associated with widely known African American orators and that are likely to be familiar to and respected by African American students (Ball, 1995; also see Nasir et al., Chapter 29 in this volume). In contrast, more typically "white" styles of public speaking are rewarded because they align with what the school considers a proper academic style. But when classroom pedagogy is modified to build on the narrative conventions of the African American community, those students generate higher-quality written narratives (C. D. Lee, Spencer, & Harpalani, 2003; Smitherman, 2000). Another research study has found that if word problems use examples from activities that are common in nondominant communities then those students will perform better. For example, Nasir, Hand, and Taylor (2008) demonstrated this to be the case with basketball among African American students.

Another type of mismatch between school and student that could explain lower test scores in nondominant students comes from sociocultural studies (see Chapters 1 and 2 in this volume). In countries with many different cultural groups, the practices and values of schools tend to be aligned with those of the dominant group. The cultural practices and values that are associated with one's home culture are often referred to as *funds* or *repertoires of knowledge* (Nasir et al., Chapter 29 in this volume; also see González, Moll, & Amanti, 2005). For dominant culture students, their repertoires or funds of knowledge – defined as "the strategic and cultural resources … that households contain" (Vélez-Ibáñez & Greenberg, 2005, p. 47) align with the expectations of formal schooling, making it easier for them to succeed in school. In contrast, students from nondominant groups have to struggle to master unfamiliar cultural forms (C. D. Lee et al., 2020). Nasir and Saxe (2003) note that when students face a tension between their ethnic and school identities it results in inequitable learning when compared to dominant-culture students whose ethnic identity is more aligned with the identities projected onto students by school practices. LS can contribute to the amelioration of this cause of inequity by showing how to modify the school's culture and pedagogical practice so that it aligns equally with the home and community cultures of all students – what de Royston et al. (2020) call "culturally sustaining instruction" (p. 10).

In these ways and others, LS has the potential to provide new perspectives on questions of social inequity and societal reproduction that have traditionally been addressed by sociologists and critical theorists. As Esmonde and Booker write, "the learning sciences is uniquely positioned" to analyze interactions between learning and power, equity, and social justice (2017a, p. 4), because critical theorists to date primarily focus on macro variables and hence neglect the science of how people learn. Learning sciences methodologies "excel at the micro- and meso-levels of analysis" (Esmonde, 2017, p. 23), exactly where theories of power, reproduction, and social structure are lacking (see Esmonde & Booker, 2017c, p. 163). Scholars who study the role of ethnicity, social class, and societal reproduction have begun to draw on LS to better understand how learning environments can be designed to foster effective learning for all students. Perhaps the most hopeful finding is that pedagogies based on LS research improve learning outcomes for all students and reduce inequities in education. Multiple studies of US students in STEM classes have found that LS-based pedagogies are effective with all students, but are even *more* effective with underrepresented minorities (URM), hence reducing the achievement gap with their dominant-culture peers (Haak, HilleRisLambers, Pitre, & Freeman, 2011; Theobald et al., 2020).

Studies of learning, race, equity, and social justice have been primarily associated with scholars in the United States. In two recent edited volumes that bring together scholarship on this topic (Esmonde & Booker, 2017b; C. D Lee

https://doi.org/10.1017/9781108888295.040 Published online by Cambridge University Press

et al., 2020), of over seventy contributors, only a handful are based outside of the United States. This US-centric focus may result from its diverse society, its open public sphere, and its receptiveness to nondominant viewpoints. These features of US society enable nondominant groups to advocate publicly and politically for radical changes in schooling, whereas in many countries, such political action is not possible. This is no doubt the case in authoritarian countries, but even in the open democratic countries of Europe, almost all schools are single-language and single-culture and are intentionally designed to acculturate nondominant students into a national culture (Onishi, 2021).

All countries have internal cultural diversity. Many of them, such as China and India, have much greater linguistic and cultural diversity than in the United States. Many countries will no doubt continue to design their schools to socialize all students into dominant cultural norms. For those countries that instead choose to work toward a multicultural society, there is potential that these US research foci will gradually impact scholarship outside the United States.

33.2.3 The Sociology and History of the Learning Sciences

In analyzing LS as a discipline, we can gain valuable perspective from sociologists of science, who have spent decades studying how new fields emerge and grow (Kuhn, 1962; Cole & Zuckerman, 1975; Price, 1963). These scholars would predict that a newly emergent field would change rapidly during its early years and then gradually find a relative stability and continuity. This is true of LS: there were many different conceptions of it in the 1990s, in part reflecting its interdisciplinary origins, and now, conceptions have increasingly converged (V. R. Lee, Ye, & Recker, 2012). LS has reached a point in its history where numerous publications have begun to look back and describe the history of the field, and to analyze what it was then and how it has become what it is today (Evans, Packer, & Sawyer, 2016; Hoadley, 2018; V. R. Lee et al., 2012; Sommerhoff et al., 2018; Yoon & Hmelo-Silver, 2017).

According to the sociologist of science Thomas Kuhn, the emergence of a new scientific field is marked by "the formation of specialized journals, the foundation of specialists' societies, and the claim for a special place in the curriculum" (1962, p. 19). A new field, which Kuhn calls a *paradigm*, is successful when it is "sufficiently unprecedented to attract an enduring group of adherents away from competing modes of scientific activity" and is "sufficiently open-ended to leave all sorts of problems for the redefined group of practitioners to resolve" (p. 10). LS has successfully established these features, warranting a claim to its status as a scientific discipline. For example, the number of graduate programs in LS has increased substantially since the 2006 first edition. The ISLS coordinates the NAPLeS [*sic*] consortium of sixty graduate degree programs in LS at thirty-nine universities. For a history and an analysis of the content of these programs, see Packer and Maddox (2016); Nathan, Rummel, and Hay (2016); and Sommerhoff et al. (2018).

https://doi.org/10.1017/9781108888295.040 Published online by Cambridge University Press

Kuhn theorized that fields followed a fairly linear history from coherence through revolution and then gradually back again to coherence. But this linear view of coherence is not easily applied to LS because many intellectual currents joined to form LS and those different currents retain their own identities. A better explanation for the intellectual history of LS is found in Foucault's theoretical framework for the history of ideas – published in 1969, largely in opposition to Kuhn's theories (Foucault, 1969/1972; Sawyer, 2016). For Foucault, a scientific discipline is not a single unified entity, but rather contains within it many intellectual currents. These currents frequently evolve and sometimes join together in larger currents. In Foucault's theory, fields focus on an *object*, and the object of LS is learning, or perhaps more specifically, a moment or process of learning or a learning outcome. But Foucault notes that no field can study everything about its object, so he next presented an analysis of intellectual *strategies*. A "strategy" is a set of choices made about what subset of the object will be studied. Foucault's prediction is true of LS: it does not incorporate all scientific studies of learning. Here are a few examples of the intellectual boundaries of LS that have resulted from these historical strategies:

- The study of solitary individual learning in isolated settings is generally considered to be cognitive psychology and to not be a part of LS. Note that the contributor list of the 2019 book *The Cambridge Handbook of Cognition and Education* (Dunlosky & Rawson, 2019) has almost no overlap with this handbook's.
- The neurological foundations of learning are not studied by LS, but rather by cognitive neuroscientists. Note that the contributor list of the 2016 *Wiley Handbook on the Cognitive Neuroscience of Learning* (Murphy & Honey, 2016) has no overlap with this handbook's.
- The authors of articles in the *International Journal of Artificial Intelligence in Education* rarely overlap with authors of articles in the *Journal of the Learning Sciences*, although both fields include researchers that incorporate artificial intelligence (AI) technology.
- The journal of *Interactive Learning Environments*, in its "Aims and Scope," has considerable overlap with that of the *Journal of the Learning Sciences*. And yet, the editorial boards of these two journals have no members in common.

One finds a similar lack of overlap between LS and the authors in the journals and handbooks of many other fields that study learning: instructional design, educational psychology, learning technologies, and others. As Foucault would predict, the scope of what LS is today was not completely an intellectual choice but rather has been historically and socioculturally determined. Sociologists of science have found that new fields generally do *boundary work* (Gieryn, 1983) to demarcate how they are different from related fields, and this has happened with LS. "Boundary work" is defined as the activities whereby boundaries between different fields of knowledge are created, criticized, or reinforced.

And yet, in spite of the above demarcations, LS welcomes intellectual collaborations and cross-fertilization. Some boundary work is always necessary to retain a stable intellectual core, but the interdisciplinary spirit of LS prepares it to join hands with all of these other fields. For example, in 2018, the annual learning sciences conference joined together with the annual AI in Education conference in the "London Festival of Learning" – ending a rift between these two fields that began with the 1991 inaugural learning sciences conference (see Sawyer, Chapter 1 in this volume). In the future, these linkages will be enabled by the fact that "learning" is a shared *boundary object* that links all of these fields:

> Boundary objects are objects which are both plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites . . .. They have different meanings in different social worlds but their structure is common enough to more than one world to make them recognizable, a means of translation. The creation and management of boundary objects is a key process in developing and maintaining coherence across intersecting social worlds. (Star & Griesemer, 1989, p. 393)

As a boundary object, "learning" links all of the fields itemized above. In dialectic with boundary work that draws barriers, a boundary object enables interdisciplinary collaborations while allowing each participating field to retain its identity. LS then can serve as a "broker" across these diverse intellectual fields (Yoon & Hmelo-Silver, 2017, p. 183).

Now that LS has attained the stability of a scientific discipline, with the properties that Kuhn associated with normal science, most learning scientists have conceptions of their field which largely overlap even if not entirely coincident (see Hoadley, 2018; Yoon & Hmelo-Silver, 2017). Sociologists of science would predict that the early founders of the field – a fairly small number of loosely organized scholars that sociologist of science Diana Crane (Crane, 1972) called an "invisible college" – would see the field differently from more recent participants. The invisible college consists of the informal structures of power and influence within a discipline that are not written down anywhere and that are rarely talked about explicitly, but which newcomers must come to know through acculturation to be successful in the field. Members of an invisible college often meet face-to-face and they are connected through relatively strong network links such as doctoral thesis advisor–advisee relationships, shared doctoral program cohorts, the association's board of advisors, and the editorial board of its journal. As a discipline grows, the invisible college of founders loses its informal intellectual control over the field as it becomes institutionalized and as a new generation of researchers takes responsibility for leadership of the field. Between the 2006 publication of the first edition of this handbook and the publication of this 2022 third edition, these predictions have come true: many founders have retired and scholars who were their graduate students decades ago are now senior professors leading their own research teams of doctoral students. Their students will soon become the next generation of learning scientists.

The learning sciences is not as stable and fixed as most scientific disciplines. LS has a stability of sorts, but perhaps not enough to be a "normal science" exactly as Kuhn would conceive of one. LS does boundary work, but not aggressively – some learning scientists are primarily affiliated with a nearby discipline such as computer science; others work in collaborative teams with researchers in affiliated disciplines; many learning scientists did not receive their Ph.D. from a learning sciences program; and many learning scientists attend annual conferences for related fields like cognitive psychology, AI, and instructional technology. A normal science requires a stable paradigm, and yet LS blends many paradigms, each of them always evolving. Kuhn observed that in a normal science, participants share an understanding of what is known and what remains unknown; everyone knows what the unanswered questions are and everyone is working on those questions. Kuhn called it a "scientific revolution" when many of the scholars realize that those shared questions cannot be answered using their shared methodologies; they then work to identify and formulate new questions. But LS is a question-seeking field and is constantly finding new problems and new conceptual formulations. Therein lies its power, its creative energy. LS is revolutionary science, always evolving and emerging, and yet retaining a unifying core. Perhaps a better lens is provided by Foucault's archeological theory of the formation and continuation of new disciplines. Foucault argued that stability is elusive; that fields are always changing; and that they are changing due to underlying intellectual and strategic forces that are systemic – forces that no single person is in control of and that are rarely explicitly institutionalized. The learning sciences continually gains energy from tensions and dialectics that perhaps should never be resolved: between scholarly traditions in different countries; between different disciplines, theories, and methodologies; between different edited volumes and handbooks; between basic and applied research; between the individual and the sociocultural; between universal findings and particular instantiations.

References

Admissionsly. (2021). *Homeschooling statistics: Breakdown by the 2021 numbers*. Retrieved from https://admissionsly.com/homeschooling-statistics/

Althusser, L. (1971). Ideology and ideological state apparatuses (Notes towards an investigation). In *Lenin and philosophy, and other essays* (pp. 127–186). London, England: New Left Books. (Original work published in *La Pensee*, 1970).

Ball, A. F. (1995). Community based learning in an urban setting as a model for educational reform. *Applied Behavioral Science Review*, *3*(2), 127–146.

Bauman, K., & Cranney, S. (2020). *School enrollment in the United States: 2018*. Retrieved from www.census.gov/content/dam/Census/library/publications/2020/demo/p20-584.pdf

Boser, U. (2017). *Learn better*. New York, NY: Rodale.

Brodersen, R. M., Yanoski, D., Mason, K., Apthorp, H., & Piscatelli, J. (2016). *Overview of selected state policies and supports related to K-12 competency-based education (REL 2017-249)*. Washington, DC: US Department of Education, Institute of Education Sciences, National Center for Education Evaluation and Regional Assistance, Regional Educational Laboratory Central.

Brown, P. C., Roediger, H. L., & McDaniel, M. A. (2014). *Make it stick: The science of successful learning*. Cambridge, MA: Harvard University Press.

Cole, J. R., & Zuckerman, H. (1975). The emergence of a scientific specialty: The self-exemplifying case of the sociology of science. In L. A. Coser (Ed.), *The idea of social structure* (pp. 139–174). New York, NY: Harcourt, Brace, Jovanovich.

Coleman, J. S., Campbell, E. Q., Hobson, C. J., et al. (1966). *Equality of educational opportunity*. Retrieved from http://garfield.library.upenn.edu/classics1979/A1979HZ27500001.pdf

Collins, A., & Halverson, R. (2009). *Rethinking education in the age of technology: The digital revolution and schooling in America*. New York, NY: Teachers College Press.

Collins, J. (2009). Social reproduction in classrooms and schools. *Annual Review of Anthropology*, *38*, 33–48.

Crane, D. (1972). *Invisible colleges: Diffusion of knowledge in scientific communities*. Chicago, IL: University of Chicago Press.

Cuban, L. (2001). *Oversold and underused: Computers in the classroom*. Cambridge, MA: Harvard University Press.

Cult of Mac. (2010). *Computers in schools are a failure, says computer pioneer Alan Kay*. Retrieved September 17, 2013, from www.cultofmac.com/68757/computers-in-schools-are-a-failure-apple-fellow-alan-kay/

Dunlosky, J., & Rawson, K. A. (Eds.). (2019). *The Cambridge handbook of cognition and education*. New York, NY: Cambridge University Press.

Esmonde, I. (2017). Power and sociocultural theories of learning. In I. Esmonde & A. N. Booker (Eds.), *Power and privilege in the learning sciences: Critical and sociocultural theories of learning* (pp. 6–27). New York, NY: Routledge.

Esmonde, I., & Booker, A. N. (2017a). Introduction. In I. Esmonde & A. N. Booker (Eds.), *Power and privilege in the learning sciences: Critical and sociocultural theories of learning* (pp. 1–5). New York, NY: Routledge.

Esmonde, I., & Booker, A. N. (Eds.). (2017b). *Power and privilege in the learning sciences: Critical and sociocultural theories of learning*. New York, NY: Routledge.

Esmonde, I., & Booker, A. N. (2017c). Toward critical sociocultural theories of learning. In I. Esmonde & A. N. Booker (Eds.), *Power and privilege in the learning sciences: Critical and sociocultural theories of learning* (pp. 162–174). New York, NY: Routledge.

European Union. (2015). *ECTS users' guide*. Retrieved from https://ec.europa.eu/assets/eac/education/ects/users-guide/docs/ects-users-guide_en.pdf

Evans, M. A., Packer, M. J., & Sawyer, R. K. (Eds.). (2016). *Reflections on the learning sciences*. New York, NY: Cambridge University Press.

Foucault, M. (1972). *The archeology of knowledge and the discourse on language*. New York, NY: Pantheon Books. (Originally published as *L'Archèologie du Savoir* [Paris, France: Editions Gallimard, 1969]).

Freire, P. (1968). *Pedagogy of the oppressed*. New York, NY: Continuum.
Gabriel, T., & Richtel, M. (2011, October 9). Inflating the software report card: School-technology companies ignore some results. *The New York Times*, pp. A1, A22.
Gieren, T. F. (1983). Boundary-work and the demarcation of science from non-science: Strains and interests in professional ideologies of science. *American Sociological Review*, *48*(6), 781–795.
Gobert, J., Buckley, B. C., & Dede, C. J. (2005). *Logging students' learning with hypermodels in BioLogica and Dynamica*. Paper presented at the American Educational Research Association, Montreal, Canada.
González, N., Moll, L. C., & Amanti, C. (Eds.). (2005). *Funds of knowledge: Theorizing practices in households and classrooms*. Mahwah, NJ: Lawrence Erlbaum Associates.
Gray, L., Thomas, N., & Lewis, L. (2010). *Teachers' use of educational technology in U.S. public schools: 2009* (NCES 2010-040). Retrieved from https://nces.ed.gov/pubs2010/2010040.pdf
Gumperz, J. J., & Hymes, D. (Eds.). (1986). *Directions in sociolinguistics: The ethnography of communication*. New York, NY: Basil Blackwell. (Original work published 1972).
Haak, D. C., HilleRisLambers, J., Pitre, E., & Freeman, S. (2011). Increased structure and active learning reduce the achievement gap in introductory biology. *Science*, *332*, 1213–1216.
Hoadley, C. (2018). A short history of the learning sciences. In F. Fischer, C. E. Hmelo-Silver, S. R. Goldman, & P. Reimann (Eds.), *The international handbook of the learning sciences* (pp. 11–23). New York, NY: Routledge.
IDP Connect. (2021, February 17). *Are Australian university pop up study hubs in China here to stay?* Retrieved from www.idp-connect.com/newspage/apac-editors-choice/australian-university-pop-up-study-hubs-in-china-here-to-stay/
Institute of Education Sciences. (2010). *Teachers' use of educational technology in U.S. public schools: 2009*. Retrieved from https://nces.ed.gov/pubs2010/2010040.pdf
Konstantopoulos, S., & Borman, G. D. (2011). Family background and school effects on student achievement: A multilevel analysis of the Coleman data. *Teachers College Record*, *113*(1), 97–132.
Kozma, R. B. (Ed.). (2003). *Technology, innovation, and educational change: A global perspective*. Eugene, OR: International Society for Technology in Education.
Kuhn, T. S. (1962). *The structure of scientific revolutions*. Cambridge, MA: MIT Press.
Lee, C. D., de Royston, M. M., Nasir, N. S., & Pea, R. (Eds.). (2020). *Handbook of the cultural foundations of learning*. New York, NY: Routledge.
Lee, C. D., Spencer, M. B., & Harpalani, V. (2003). Every shut eye ain't sleep: Studying how people live culturally. *Educational Researcher*, *32*(5), 6–13.
Lee, V. R., Ye, L., & Recker, M. (2012). *What a long strange trip it's been: A comparison of authors, abstracts, and references in the 1991 and 2010 ICLS proceedings*. Paper presented at the International Conference of the Learning Sciences, Sydney, NSW, Australia.
McQuiggan, M., & Megra, M. (2017). *Parent and family involvement in education: Results from the national household education surveys program of 2016* (NCES 2017-102). Retrieved from http://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2017102

Murphy, R. A., & Honey, R. C. (Eds.). (2016). *The Wiley handbook on the cognitive neuroscience*, Chichester, England: Wiley Blackwell.

Nasir, N. S., Hand, V., & Taylor, E. V. (2008). Culture and mathematics in school: Boundaries between "cultural" and "domain" knowledge in the mathematics classroom and beyond. *Review of Research in Education*, *32*(1), 187–240.

Nasir, N. S., & Saxe, G. B. (2003). Ethnic and academic identities: A cultural practice perspective on emerging tensions and their management in the lives of minority students. *Educational Researcher*, *32*(5), 14–18.

National Academies of Sciences, Engineering, and Medicine. (2019). *Science and engineering for grades 6-12: Investigation and design at the center*. Washington, DC: The National Academies Press.

National Center for Education Statistics. (2020). *Annual report: The condition of education*. Retrieved from https://nces.ed.gov/pubs2020/2020144.pdf

National Center for Education Statistics. (2021). *National teacher and principal survey (NTPS)*. Retrieved from https://nces.ed.gov/surveys/ntps/tables/ntps1718_2019082303_s12n.asp

Nathan, M. J., Rummel, N., & Hay, K. E. (2016). Growing the learning sciences: Brand or big tent? In M. A. Evans, M. Packer, & R. K. Sawyer (Eds.), *Reflections on the learning sciences* (pp. 191–209). New York, NY: Cambridge University Press.

North, A. (2020, October 27). *The remote learning center trend, explained*. Retrieved from www.vox.com/21523961/covid-school-remote-learning-center-distance

OECD. (2000). *Knowledge management in the learning society*. Paris, France: OECD Publications.

OECD. (2004). *Innovation in the knowledge economy: Implications for education and learning*. Paris, France: OECD Publications.

OECD. (2008). *Innovating to learn, learning to innovate*. Paris, France: OECD.

OECD. (2010). *The nature of learning: Using research to inspire practice*. Paris, France: OECD.

OECD. (2013). *Innovative learning environments*. Paris, France: OECD.

OECD. (2015). *Students, computers and learning: Making the connection*. Paris, France: OECD Publishing.

OECD. (2017). *OECD science, technology and industry scorecard 2017: The digital transformation*. Paris, France: OECD Publishing.

OECD. (2019). *How's life in the digital age? Opportunities and risks of the digital transformation for people's well-being*. Paris, France: OECD Publishing.

OECD. (2020a). *PISA 2018 results: Vol. V. Effective policies, successful schools*. Paris, France: PISA, OECD Publishing.

OECD. (2020b). *Strengthening online learning when schools are closed: The role of families and teachers in supporting students during the COVID-19 crisis*. Paris, France: OECD Publishing.

Onishi, N. (2021, February 9). Will American ideas tear France apart? Some of its leaders think so. *The New York Times*. Retrieved from www.nytimes.com/2021/02/09/world/europe/france-threat-american-universities.html

Packer, M. J., & Maddox, C. (2016). Mapping the territory of the learning sciences. In M. A. Evans, M. J. Packer, & R. K. Sawyer (Eds.), *Reflections on the learning sciences* (pp. 126–154). New York, NY: Cambridge University Press.

Parsad, B., & Jones, J. (2005). *Internet access in U.S. public schools and classrooms: 1994–2003* (NCES 2005-015). Retrieved from https://nces.ed.gov/pubs2005/2005015.pdf

Price, D. (1963). *Little science, big science*. New York, NY: Columbia University Press.

Rogoff, B. (1990). *Apprenticeship in thinking: Cognitive development in social context*. New York, NY: Oxford University Press.

de Royston, M. M., Lee, C., Nasir, N. S., & Pea, R. (2020). Rethinking schools, rethinking learning. *Phi Delta Kappan*, *102*(3), 8–13.

Sawyer, R. K. (2002). Unresolved tensions in sociocultural theory: Analogies with contemporary sociological debates. *Culture & Psychology*, *8*(3), 283–305.

Sawyer, R. K. (2016). A Foucauldian analysis of the learning sciences: Past, present, and future. In M. A. Evans, M. Packer, & R. K. Sawyer (Eds.), *Reflections on the learning sciences* (pp. 259–280). New York, NY: Cambridge University Press.

Sawyer, R. K. (2019). *The creative classroom: Innovative teaching for 21st-century learners*. New York, NY: Teachers College Press.

Schmidt, W. A., & McKnight, C. C. (1997). *A splintered vision: An investigation of U.S. science and mathematics education*. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Schofield, J. W., & Davidson, A. L. (2002). *Bringing the Internet to school: Lessons from an urban district*. San Francisco, CA: Jossey-Bass.

Schwartz, D. L., Tsang, J. M., & Blair, K. P. (2016). *The ABCs of how we learn: 26 scientifically proven approaches, how they work, and when to use them*. New York, NY: Norton.

Selingo, J. J. (2013). *College (un) bound: The future of higher education and what it means for students*. New York, NY: Houghton Mifflin Harcourt.

Shapiro, E. (2021, March 21). "Always an afterthought": Schools closed, but not child care facilities. *The New York Times*, p. Y4.

Shen, S., Munroe, T., Zhu, J., & Westbrook, T. (2021, July 23). *China bars for-profit tutoring in core school subjects*. Reuters. Retrieved from www.reuters.com/world/china/china-bars-for-profit-tutoring-core-school-subjects-document-2021-07-23/

Sharples, M., McAndrew, P., Weller, M., et al. (2013). *Innovating pedagogy 2013: Open University innovation report 2*. Milton Keynes, England: The Open University.

Smitherman, G. (2000). African American student writers in the NAEP, 1969–1988/89 and "The Blacker the berry, the sweeter the juice". In G. Smitherman (Ed.), *Talkin that talk: Language, culture and education in African America* (pp. 163–194). New York, NY: Routledge.

Sommerhoff, D., Szameitat, A., Vogel, F., Chernikova, O., Loderer, K., & Fischer, F. (2018). What do we teach when we teach the learning sciences? A document analysis of 75 graduate programs. *Journal of the Learning Sciences*, *27*(2), 319–351.

Southern New Hampshire University. (2021). *About SNHU: Expanding the boundaries of higher education*. Retrieved from www.snhu.edu/about-us

Star, S. L., & Griesemer, J. R. (1989). Institutional ecology, "translations" and boundary objects: Amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907–1939. *Social Studies of Science*, *19*(3), 387–420.

Strayer University. (2021). *Strayer University fact sheet*. Retrieved from www.strayer.edu/content/dam/strayer/pdf/Strayer_University_Fact_Sheet.pdf

Theobald, E. J., Hill, M. J., Tran, E., et. al. (2020). Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math. *Proceedings of the National Academy of Sciences (PNAS)*, *117*(12), 6476–6483.

US Census Bureau. (2020). *Household pulse survey*. Retrieved from www.census.gov/data/tables/2020/demo/hhp/hhp20.html

Vélez-Ibáñez, C., & Greenberg, J. (2005). Formation and transformation of funds of knowledge. In N. González, L. C. Moll, & C. Amanti (Eds.), *Funds of knowledge: Theorizing practices in households and classrooms* (pp. 47–69). Mahwah, NJ: Lawrence Erlbaum Associates.

Vogel, G. (1996). Global review faults U.S. curricula. *Science*, *274*(5286), 335.

Yoon, S. A., & Hmelo-Silver, C. E. (2017). What do learning scientists do? A survey of the ISLS membership. *Journal of the Learning Sciences*, *26*(2), 167–183.