The future of learning:

Grounding educational innovation in the learning sciences

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The education landscape has changed dramatically since 2006, when the first edition of this handbook was published. In 2006, the following innovations did not yet exist; today, each of them is poised to have a significant impact on education:

- ***Tablet computers***, like **Apple's iPad** and **Microsoft's Surface**. In 2012, Apple released **iBooks Author**, a free textbook authoring app for instructors to develop their own customized textbooks.
- Although ***smartphones*** were well-established among businesspeople in 2006 (then-popular devices included the **BlackBerry** and **Palm Treo**), their market penetration has grown dramatically since the 2007 release of the iPhone, especially among school-age children.
- ***The App store***—Owners of smartphones including **Apple's iPhone**, and phones running **Google's Android** and **Microsoft's**

Windows Phone, can easily download free or very cheap applications, choosing from hundreds of thousands available.

- ***Inexpensive e-readers***, like the **Kindle** and the **Nook**, have sold well, and are connected to online stores that allow books to be downloaded easily and quickly.

Furthermore, since 2006, the following Internet-based educational innovations have been widely disseminated, widely used, and widely discussed:

- ***Massive open online courses (MOOCs)***. MOOCs are college courses, delivered on the Internet, that are open to anyone and are designed to support tens of thousands of students. The products used for such courses include **Udacity**, **Coursera**, **EdX**, **Semester Online**, and **FutureLearn** (founded by the UK's Open University). MOOCs have gained legitimacy because America's top research universities are involved. Coursera delivers courses offered by Brown, Caltech, Princeton, Stanford, and many other schools; EdX delivers courses offered by MIT, Harvard, and others; Semester Online delivers courses offered by Northwestern, Emory, Washington University in St. Louis, the University of North Carolina at Chapel Hill, and others. In 2014, Google released **MOOC.org**, an open-source platform that any university can use.
- ***Learning Management Systems (LMS)***. LMS are now used by most colleges to support their on-campus courses with full-time students. LMS provide online discussion forums, electronic

delivery of readings and assignments, and electronic return of graded assignments. The market leader is **Blackboard**; others include **Moodle** and **Sakai**. Newcomers like **Piazza** and **Classroom Salon** are increasingly integrating social networking features long associated with sites like **Facebook** (Kaufer, Gunewardena, Tan, & Cheek, 2011)**.**

- ***The flipped classroom***. The **Khan Academy**, which began as a series of YouTube instructional videos, popularized the notion of the "flipped classroom," where students watch videotaped lectures at home, and then use class time for peer collaboration and hands-on, interactive learning. **iTunes U** offers full courses from MIT and Stanford (www.mit.edu/itunesu). Instructors can create courses for the iPad using iTunes U Course Manager.
- ***Online college degrees***. The University of North Carolina at Chapel Hill began offering an online MBA degree in 2011, **MBA@UNC**; this has been extremely successful. In May of 2013, **Georgia Tech** announced the first online master's degree in computer science, at one-fourth the cost of their traditional on-campus degree.

These innovations contrast sharply with the schools of today, which were largely designed in the nineteenth and twentieth centuries to provide workers for the industrial economy. And the potential is that these innovations might be more effective than traditional schools, which are based in a pedagogical approach sometimes called *instructionism*—with teachers delivering information to passive, attentive students. In particular, it seems that instructionism is largely ineffective at helping learners acquire the skills and knowledge needed in the 21st century (Sawyer introduction, this volume).

The world has changed dramatically since modern schools took shape around 100 years ago. In the 1970s, economists and other social scientists began to realize that the world's economies were shifting from an industrial economy to a knowledge economy (Bell, 1973; Drucker, 1993; Toffler, 1980). By the 1990s, educators had begun to realize that if the economy was no longer the 1920s-era factory economy, then traditional schools—instructionist, standardized, focused on memorization and rote learning—were designed for a vanishing world (Bereiter, 2002; Hargreaves, 2003; Sawyer, 2006). In the first decade of the 21st century, it became increasingly clear that the world had entered an *innovation age*. Today, it is widely accepted that companies and countries alike now have to continually innovate, to create *new* knowledge—not simply to master existing knowledge.

Leading thinkers in business, politics, and education are now in consensus that schools, and other learning environments, have to be redesigned to educate for innovation. In May 2013, in language typical of such reports, education consultants Michael Barber, Katelyn Donnelly, and Saad Rivzi wrote "Our belief is that deep, radical and urgent transformation is required in higher education much as it is in school systems" (p. 3). These arguments have expanded beyond consulting firms and policy circles to reach the general public; for example, a *New York Times Magazine* cover dated September 15, 2013, had this headline: "The

All-Out, All-Ages Overhaul of School Is Happening Now" (*The New York Times*, 2013).

Everyone seems to agree that education in the 21st century is in need of transformational innovation. But what sort of innovation? And what will the innovation process look like—how do we get there from here? Most policy makers and media stories tend to focus on two drivers of educational innovation:

1. ***The application of market models to the education sector***. Advocates of market models argue that introducing competition and increasing customer choice will drive innovation. Advocates of market competition argue that today's public schools have a monopoly on the delivery of education, and in general, monopolies reduce effectiveness and innovation. Because public schools have a guaranteed revenue stream in government taxes, they are not forced to compete on quality and cost.
2. ***The increasing involvement of the private sector in education***. Many influential business leaders have given high-profile public talks arguing that schools are failing to graduate workers for the 21st century economy. The list of CEOs, companies, and business organizations calling for change is long—Bill Gates of Microsoft; Louis V. Gerstner, the former CEO of IBM (Gerstner, 2008); Lockheed and Intel (Chaker, 2008); the U.S. Chamber of Commerce and the National Association of Manufacturers (Hagerty, 2011). Two of the most influential recent education reforms in the U.S. had strong private sector involvement: the Common Core standards, now adopted by 45 of the 50 states (with

> early involvement by CEOs and senior executives at Intel, Prudential Financial, Battelle, and IBM), and the 21st century skills movement (long sponsored by the Partnership for 21st Century Skills, with its founding organization including AOL Time Warner, Apple, Cisco, Dell, and Microsoft). Many of these same successful business leaders have also funded the push toward market reforms in schools, including the Bill and Melinda Gates Foundation, the Walton Family Foundation, the Eli and Edythe Broad Foundation, and the Michael and Susan Dell Foundation (Ravitch, 2010).

But to date, these potential drivers of educational innovation have not resulted in schools that are more solidly grounded in the learning sciences—the participatory, project-based, constructivist, and collaborative pedagogies suggested by the chapters in this handbook. In many cases, just the opposite has occurred: introducing competition and private sector models into schools has resulted in even more old-fashioned, traditional forms of teaching and learning—instructionism on steroids. To take one example: successful market competition requires a quantified measure of quality and success; consequently, the United States has invested in outcome measures of learning—the famous "high stakes testing" associated with the No Child Left Behind (NCLB) legislation. (Most other countries already had high-stakes national examinations.) And yet, the relatively recent U.S. focus on these high stakes assessments has, for the most part, resulted in a reversion to instructionist pedagogy. (This is consistent with international experience; in most countries with high-stakes national examinations, instructionism is deeply rooted.) To take another example, one of the most widely touted educational innovations, the MOOC, for the most part use "a transmission model, relying on video lectures, recommended readings and staged assessment" (Sharples et al., 2013, p. 3)—exactly the opposite of what learning sciences research would advise.

After several years of attempting to "fix" schools with technology, a growing number of techno-skeptics have emerged (see Collins & Halverson, 2009). For example, in 2010 the computer pioneer and visionary Alan Kay said that 30 years of technology in schools had failed (Cult of Mac, 2010). In 2012, Peter J. Stokes said "The whole MOOC thing is mass psychosis, people just throwing spaghetti against the wall to see what sticks"; he is executive director for postsecondary innovation at Northeastern University's College of Professional Studies (Carlson & Blumenstyk, 2012, pp. A4-A5). A U.S. 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).

If we are to be successful in creating the schools of the future, educational innovation and technology must be grounded in the learning sciences. The learning sciences are showing us how to design the learning environments of the future—learning environments that teach the deep knowledge and adaptive expertise required in an innovation age. Major governmental and international bodies have commissioned reports summarizing learning sciences research; these reports began with the influential U.S. National Research Council's *How People Learn* (Bransford, Brown, & Cocking, 2000). Since the 2006 publication of the first edition of this handbook, the OECD has published many excellent reviews of this research, including *Innovative Learning Environments* (2013), *The Nature of Learning: Using Research to Inspire Practice* (2010), and *Innovating to Learn, Learning to Innovate* (2008).

Those societies that can effectively restructure their schools on the learning sciences will be the leaders in the 21st century (OECD, 2000, 2004, 2008, 2010, 2013). The issues addressed by the learning sciences have been recognized as critical in all 28 of the countries studied by the ISTE (Kozma, 2003). The leaders of these countries agree that the world economy has changed to an innovation- and knowledge-based economy, and that education must change as well for a society to make this transition successfully. This handbook continues the important work recommended by these reports; the chapters collected here describe how to design the learning environments of the future. If you closely read all of these chapters, various visions of the schools of the future begin to take shape—but the outlines remain fuzzy. The key issue facing the learning sciences in the next ten to twenty years will be to outline an increasingly specific vision for the future of learning. In this conclusion, I begin by presenting some possible visions of the schools of the future. I then discuss some unresolved issues that will face the learning sciences as their findings begin to be used to build the learning environments of the future.

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 the knowledge economy, and are able to participate actively in an open, democratic society. 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 also include the new 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 really the right schools for the knowledge society?

Most learning sciences researchers are committed to improving schools, and they believe that school reform should involve working together with teachers, engaging in professional development, and integrating new software into classrooms. A new research methodology developed by learning scientists—the design experiment—is conducted in classrooms, and requires that researchers work closely with teachers as they participate in curriculum development, teacher professional development, and assessment (Barab, this volume).

But learning sciences research might also lead to more radical alternatives that would make schools as we know them obsolete, leaving today's big high schools as empty as the shuttered steel factories of the faded industrial economy. Two of the most influential founders of the learning scientists, Roger Schank (1999) and Seymour Papert (1980), argued that computer technology is so radically transformative that schools as we know them will have to fade away before the full benefits can be realized. The recent technological developments I described earlier seem to finally make this possible. Everything is subject to change: schools may not be physical locations where everyone goes, students may not be grouped by age or grade, students could learn anywhere at any time. I made this same statement in my conclusion to the 2006 first edition, when it may have seemed shocking; now, in 2013, such visions have become the conventional wisdom. I already mentioned the September 2013 *New York Times Magazine* cover "The All-Out, All-Ages Overhaul of School is Happening Now"; the cover photograph behind this text shows a shuttered and abandoned red brick school building. In May 2013, Andy Kessler proposed a de-schooled future for Chicago Public Schools in *The Wall Street Journal*, in response to a study showing that under 8 percent of school graduates were ready for college:

> Why not forget the [Chicago] teachers and issue all 404,151 [Chicago students] an iPad or an Android tablet? At the cost of $161 million, that's less than 10% of the expense of paying teachers' salaries. Add online software, tutors and a $2,000 graduation bonus, and you still don't come close to the cost of teachers. You can't possibly do worse than a 7.9% college readiness level (Kessler, 2013).

As of 2013, 27 states had established online virtual schools; 31 states and Washington, DC have statewide full-time online schools. These schools generally receive per-student funding from the state just like any other district (although typically at a lower amount than an in-school student). In the 2009-2010 school year, an estimated 1,816,400 U.S. students were enrolled in distance learning courses, and 200,000 full-time students were enrolled in full-time online schools (International Association for K-12 Online Learning, 2013). In 2012, Florida became the first U.S. state to offer full-time and part-time online options to all students in grades K-12.

Imagine a nation of on-line home-based activities organized around small neighborhood learning clubs, all connected through high-bandwidth Internet software. There would be no textbooks, few lectures, and no curriculum as we know it today. "Teachers" would operate as independent consultants who work from home most of the time, and occasionally meet with ad-hoc groups of students at a learning club. Each meeting would be radically different in nature, depending on the project-based and self-directed learning that those students were engaged in. In fact, each type of learning session might involve a different learning specialist. The teaching profession could become multi-tiered, with master teachers developing curriculum in collaboration with software developers and acting as consultants to schools, and learning centers staffed by a variety of independent contractors whose job no longer involves lesson preparation or grading, but instead involves mostly assisting students as they work at the computer or gather data in the field (Stallard & Cocker, 2001).

Educational software gives us the opportunity to provide a customized learning experience to each student to a degree not possible when one teacher is responsible for six classrooms of 25 students each. Well-designed software could sense each learner's unique learning style and developmental level, and tailor the presentation of material appropriately—by using learning analytics (see Baker and Siemens, this volume). **Knewton's** adaptive learning offerings are now in K-12 schools and in universities (Selingo, 2013, pp. 73-85; Webley, 2013). Some students could take longer to master a subject, while others would be faster, because the computer can provide information to each student at his or her own pace. And each student could learn each subject at different rates; for example, learning what we think of today as "5th grade" reading and "3rd grade" math at the same time. In age-graded classrooms this would be impossible, but in the schools of the future there may be no educational need to age-grade classrooms, no need to hold back the more advanced children or to leave behind those who need more help, and no reason for a child to learn all subjects at the same rate. Of course, age-graded classrooms also serve to socialize children, providing opportunities to make friends, to form peer groups, and to participate in team sports. If learning and schooling were no longer age-graded, other institutions would have to emerge to provide these opportunities.

Conservative critics of schools see the future emerging through an open market system of competition, in which local property tax dollars can be used by parents to choose from a wide range of learning environments. To take just one hypothetical possibility, for-profit tutoring centers (like Sylvan Learning Centers in the U.S.) might begin to offer a three-hour intensive workday, structured around tutors and individualized educational software, with each student taking home his or her laptop to complete the remainder of the day at home. Because each tutor could schedule two three-hour shifts in one day, class size could be halved with no increase in cost. Because curriculum and software would be designed centrally, and the software does the grading automatically, these future tutors could actually leave their work at the office—unlike today's teachers, who stay up late every night and spend their weekends preparing lesson plans and grading. For those parents who need an all-day option for their children due to their work schedule, for-profit charter schools could proliferate, each based on a slightly different curriculum or a slightly different software package. Particularly skilled teachers could develop reputations that would allow them to create their own "start-up schools," taking 10 or 20 students into their home for some or all of the school day—the best of them providing serious competition for today's elite private schools, and earning as much as other knowledge workers such as lawyers, doctors, and executives. In 2010, one of Korea's best-known English language teachers earned four million dollars (Ripley, 2013, pp. 167-174).

Museums and public libraries might play an increasingly larger role in education. They could receive increased funding to support their evolution into learning resource centers, perhaps even receiving a portion of the government's tax revenue stream. They could contribute to student learning in several ways: for example, by developing curriculum and lesson plans and making these available to students anywhere over the Internet, and by providing physical learning environments as they redesign their buildings to support schooling. Science centers have already taken the lead in this area, developing inquiry-based curricula and conducting teacher professional development, and art and history museums may soon follow suit.

The boundary between formal schooling and continuing education will increasingly blur. The milestone of a high school diploma could gradually decrease in importance, as the nature of learning in school begins to look more and more like on-the-job apprenticeship and adult distance education. Inexpensive tablets and phones allow learning to take place anywhere, anytime; 16 year olds could work their part-time jobs during the day and 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, as new employees take their tablets or smartphones on the job with them, with software specially designed to provide apprenticeship support in the workplace. Professional schools could be radically affected; new forms of portable just-in-time learning could increasingly put their campus-based educational models at risk.

The above scenarios are all hypothetical; it isn't yet clear how schools will change in response to the new research emerging from the learning sciences, and to the computer technology that makes these new learning environments possible. But if schools do not redesign themselves on a foundation in the learning sciences, alternative learning environments that do so could gradually draw more and more students—particularly if charter schools, vouchers, and online learning become widespread. The learning scientists Allan Collins and Richard Halverson predict that schools will fail to change, and that alternative learning environments will emerge and gradually begin to dominate (Collins & Halverson, 2009). And even if schools do not face competition from charters and vouchers, learning will increasingly take place both inside and outside the school walls—in libraries, museums, after-school clubs, on-line virtual schools, Internet-based courses, modules, and certifications, and at home.

What constitutes evidence of learning?

Today's schools are organized around a "credit hour" model and a nine-month calendar. For example, at the university level, a "course" is defined as three hours a week, in a room with a professor, for one term (in the U.S., the nine-month year has either two terms of approximately fifteen weeks each—called *semesters*—or three terms of approximately ten weeks each, called *quarters*). A student receives three credit hours with a passing grade at the end of the course. A student's transcript—the document providing evidence of successful learning—is likewise organized by term and credit hour. Primary and secondary school follow similar frameworks.

Many educational innovations challenge this model—particularly online distance learning. Why, their advocates ask, should the fundamental unit of teaching and learning be so tightly connected to a physical campus and to face-to-face interaction? After all, they argue, the credit hour is a rather poor measure of what learning has occurred. Instead, they propose, why not measure learning outcomes directly, with a culminating examination?

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" or "proficiency based" 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). By some measures, 34 states are moving towards competency education (Carnegie Foundation, 2013). The online Western Governor University does not use grades and credit hours, but instead is solely assessment driven (Kamenetz, 2010, p. 101).

A second prominent alternative is the idea of instituting an "exit exam" for universities, as a replacement for the school transcript and the grade point average (GPA). One prominent example is the Collegiate Learning Assessment (CLA), released in the U.S. in 2013. 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 single high-stakes exit exam. A student's grades in courses are far less important. In the U.S., one's high school grades remain important, but in addition all college-bound students take one of the privately developed and privately administered college entrance exams, the ACT or the SAT.

The challenge will be to design badges and other assessments to be grounded in the latest science of how people learn, and to accurately reflect 21st century skills—creativity, collaboration, and deeper conceptual understanding. Assessment design is an active area of research (see Pellegrino, this volume), and is poised for dramatic developments in the near future.

Computers and the schools of the future

Learning scientists build learning environments that are based on scientific principles. As we've seen throughout this handbook, carefully designed computer software can play a critical role in these learning environments. However, learning scientists know that for fifty years, reformers have been claiming that computers will change schools—and these predictions have never come to pass. Perhaps the first such high-profile prediction was in the 1950s, when the legendary behaviorist B.F. Skinner claimed that his "teaching machines" made the teacher "out of date" (1954/1968, p. 22). (Criticisms of computer-based learning had already appeared in 1951, with Isaac Asimov's classic science fiction short story, "The Fun They Had," critiquing a future where children are educated at home by a robot.) Decades later, starting from the dramatically different theoretical framework of constructivism, Seymour Papert's 1980 book *Mindstorms* argued that giving every child a computer would allow students to actively construct their own learning, leaving teachers with an uncertain role: "schools as we know them today will have no place in the future" (p. 9). Behaviorists and constructivists don't agree about much, but in this case they agreed on the power of computers to transform schools. But both Skinner's and Papert's predictions have been wrong. In 2001, Larry Cuban famously documented the failure of computers and the Internet to improve U.S. schools in his book *Oversold and Underused*. This disappointing history provides a sobering counter-narrative to technological visionaries who today argue that the Internet will transform schooling. How is the software being developed by learning scientists any different?

The fundamental differences are that learning scientists begin by first developing a foundation in the basic sciences of learning, their computer software is designed with the participation of practicing teachers, and is grounded in how people learn. Learning scientists work closely with schools and also with informal learning environments like science centers; part of the reason that the design research methodology (Barab, this volume) is so central to research practice is that this methodology allows computers and programs to be embedded in a complex and integrated curriculum. Learning scientists realize that computers will never realize their full potential if they are merely add-ons to the existing instructionist classroom; that's why they 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.

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 emerge that are based in the learning sciences. 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" (e.g., Daro, Mosher, & Corcoran, 2011). Developing these new curricula will require an army 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 about 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 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 50 countries every four years, U.S. science and math curricula contain much more content than other countries as a result of their survey approaches to material—but rather than strengthening students' abilities, this survey approach weakens U.S. achievement relative to other countries (Schmidt & McKnight, 1997). Compared to other countries, U.S. 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 new knowledge is often forgotten as soon as the students turn to the next topic. Studies of the TIMSS data show that children in nations that pursue a more focused, coherent, and deep strategy do substantially better on the mathematics assessment than do U.S. children (Schmidt & McKnight, 1997). This is consistent with the learning sciences 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 the learning sciences 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. Learning sciences research could be directed toward identifying which deep knowledge should be the outcome of each grade. These curricula are likely to contain fewer units and fewer overall line items, with more time spent on each item. This will be a political challenge, because some will view it as removing material from the curriculum, "dumbing down" or reducing expectations of students. In the U.S., politicians and school boards have frequently responded to concerns about education by adding content requirements to the curriculum—contributing to 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.

The teachers of the future

The learning sciences focus on learning and learners. Many education researchers are instead focused on teachers and teaching, 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 to receive salaries comparable to other knowledge workers, or else 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, 2011).

Over a wide variety of international schools, a set of best practices surrounding educational technology is emerging (Kozma, 2003; 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'd see the teacher advising students, creating structures to scaffold student activities, and monitoring student progress. You'd see the students actively engaged in projects, managing and guiding their own activities, collaborating with other students, and occasionally asking the teacher for help.

The teachers of the future will be highly trained professionals, comfortable with technology, with a deep pedagogical understanding of the subject matter, able to respond improvisationally to the uniquely emerging flow of each classroom (Sawyer, 2004, 2011). They will lead teams of students, much like a manager of a business or the master in a workshop, preparing students to fully participate in the knowledge society.

Speed bumps in the road to the future

It is too early to predict exactly what the learning environments of the future will look like. Three things now seem certain: first, that learning environments will eventually have to change to meet the needs of the modern knowledge society; second, that schools are complex institutions that have proven to be quite resistant to change; and third, that alternative learning environments, many enabled by new technologies, are rapidly emerging to challenge schools. The road from instructionism to the schools of the future will be long and unpredictable, but some of the speed bumps can be predicted.

Incompatibilities between schools and the learning sciences

In an influential book, the learning scientists Allan Collins and Richard Halverson (2009) identified several entrenched features of today's public schools that might make them resist the necessary changes emerging from the learning sciences:

Uniform learning vs. customization. Schools are based on the assumption that everyone learns the same thing at the same time. Courses are structured so that everyone reads the same pages of the text at the same time, and everyone takes the same test on the same day. But in the schools of the future, each learner will receive a customized learning experience.

Teacher as expert vs. diverse knowledge sources. In the constructivist and project-based learning advocated by the learning sciences, students gain expertise from a variety of sources—from the Internet, at the library, or through email exchange with a working professional—and the teacher will no longer be the only source of expertise in the classroom. But today's schools are based on the notion that teachers are all-knowing experts, and their job is to transmit their expertise to the students.

Standardized assessment vs. individualized assessment. Today's assessments require that every student learn the same thing at the same time. The standards movement and the resulting high-stakes testing are increasing standardization, at the same time that learning sciences and technology are making it possible for individual students to have customized learning experiences. Customization combined with diverse knowledge sources enable students to learn different things. Schools will still need to measure learning for accountability purposes, but we don't yet know how to reconcile accountability with customized learning.

Knowledge in the head vs. distributed knowledge. In the real world, people act intelligently by making frequent use of books, papers, and technology. And in most professions, knowledge work occurs in teams and organizations, so that several times every hour, a person is interacting with others. But in today's schools, there is a belief that a student only knows something when that student can do it on his or her own, without any use of outside resources. There is a mismatch between today's school culture and the situated knowledge required in the knowledge society.

Connecting elemental and systemic approaches

In Chapter 2, Mitch Nathan and I grouped learning sciences research into *elemental* and *systemic* approaches. Elemental approaches focus on individual learning, and systemic approaches focus on groups and classrooms. Many learning scientists emphasize the importance of learning in groups, in part because most knowledge work takes place in complexly organized teams. These group processes are generally analyzed using systemic approaches. In contrast, many psychologists focus on individual learning and assume that all knowledge is individual knowledge. These individual cognitive processes are analyzed using elemental approaches. For these researchers, the basic science of learning must be the science of how individuals learn, and social context is only of secondary importance—as a potential influence on these basically mental processes. Many learning scientists reject this individualist view, and argue that all knowledge is in some sense group knowledge, because it is always used in social and cultural contexts (e.g., Rogoff, 1998).

A challenge facing learning sciences is how to integrate the scientific findings emerging from the elemental and systemic approaches, to develop a "unified grand theory" of teaching and learning. The learning sciences combine a diverse range of positions on how to accomplish this, from cognitive psychologists who focus on the mental structures that underlie knowledge, to socioculturalists who believe that it may be impossible to identify the mental structures corresponding to situated social practice. 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 the emphasis should be placed, and how important it is to focus on individual learning.

Individual learning is always going to be an important goal of schooling. 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. The learning sciences strongly suggest 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 manage diversity of backgrounds, or to communicate in complex, rapidly changing environments. But although new forms of assessment may place individuals in groups, we will still need to tease out the individual learning of each group participant.

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 must be measured using assessments of student learning. However, the learning sciences suggest 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 do not assess whether pre-existing misconceptions have indeed been left behind (diSessa, this volume) nor do they assess problem-solving or inquiry skills (Krajcik & Shin, 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 the learning sciences is how to design new kinds of assessment that correspond to the deep knowledge required in today's knowledge society (Pellegrino, this volume). Several learning sciences researchers are developing new assessments that focus on deeper conceptual understanding. For example, Lehrer and Schauble (2006) developed a test of model-based reasoning—a form of deeper understanding that is emphasized in their curriculum, but that does not appear on traditional standardized mathematics tests. The VNOS (Views of the Nature of Science) questionnaire assesses deeper understanding of scientific practice rather than content knowledge (Lederman et al., 2002).

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 (see Baker & Siemens, this volume; Pellegrino, this volume). After all, the learning sciences has found that effective educational software has to closely track the student's developing knowledge structures to be effective; since that tracking is being done anyway, it would be a rather straightforward extension to make summary versions of it available to teachers. New learning sciences 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 and clicks the mouse—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 learning sciences 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.

New methodologies

Experimental studies that randomly assign students to either a new educational intervention or a traditional classroom remain the gold standard for evaluating what works best to improve learning. This method is known as the randomized controlled trial (RCT) and is commonly used in medicine to evaluate new drugs and treatments. Many educators and politicians have recently applied this medical model of research to education (Shavelson & Towne, 2002). But medical research does not consist only of RCTs. Medical research proceeds in roughly five phases:

Preclinical: basic scientific research. A wide range of methodologies are used.

Phase 1: Feasibility. How to administer the treatment; how much is appropriate. Again, a wide range of methodologies are used.

Phase 2: Initial efficacy. How well does it work? Quasi-experimental methodologies are typically used.

Phase 3: Randomized controlled trial (RCT). The gold standard, the controlled experiment is necessary to prove efficacy of the treatment.

Phase 4: Continuing evaluation and follow-on research.

The learning sciences are still in the Preclinical and Phase 1 stages of research, with a few of the more well-established efforts entering Phase 2. Experimental studies are not sufficient to create the schools of the future, for several reasons (cf. Raudenbush, 2005):

1. Learning sciences researchers are still in a preclinical phase of identifying the goals of schools: the cognitive and social outcomes that we expect our students to attain. Experimental methodologies alone cannot help us to rigorously and clearly identify the knowledge that we want students to learn.
2. Experimental methodologies are premature at the preclinical and first phases, when learning scientists are still developing the learning environments of the future. At these early phases, hybrid methodologies and design experiments are more appropriate. Conducting experimental research is expensive, and it wouldn't be practical to do an experiment at every iterative stage of a design experiment. Once well-conceived and solidly researched new curricula

are in place, then experimental methodologies can appropriately be used to compare them.

3. Experimental methodologies identify causal relations between inputs and outcomes, but they cannot explain the causal mechanisms that result in those relations—the step-by-step processes of learning—and as a result, these methodologies are not able to provide specific and detailed suggestions for how to improve curricula and student performance.

A typical learning sciences research project involves at least a year in the classroom; sometimes a year or more in advance to design new software and learner-centered interfaces; and a year or more afterward, to analyze the huge volumes of videotape data, interviews, and assessments gathered from the classroom. Many learning scientists have developed new technological tools to help with analyzing large masses of complex data (Baker & Siemens, this volume), and new tools for digital video ethnography are being developed (Goldman, Zahn, & Derry, this volume).

The studies reported in this handbook typically took at least three years to complete—and the research behind each chapter has resulted in many books, scientific articles, and research reports. This is complex, difficult, and expensive work. It's almost impossible for any one scholar to do alone; most learning sciences research is conducted by collaborative teams of researchers—software developers, teacher educators, research assistants to hold the video cameras and transcribe the recordings, and scholars to sift through the data, each using different methodologies, to try to understand the learning processes that occurred, and how the learning environment could be improved for the next iteration. Because learning sciences research requires such a massive human effort, it has tended to occur at a small number of universities where there is a critical mass of faculty and graduate students, and has tended to cluster around collaborative projects supported by large NSF grants at a small number of universities. The U.S. National Science Foundation recognized this in 2003 and 2005 by creating a few large Science of Learning Centers.

To create the learning environments of the future, we will need more research sites, and governments will have to increase their funding dramatically. Fortunately, a necessary first step is occurring: training the next generation of scholars in doctoral programs to prepare them to take faculty positions and start their own research projects. The number of graduate programs in the learning sciences has increased substantially since the 2006 first edition; the ISLS now coordinates the NAPLES consortium of graduate learning sciences programs, with 23 members (as of September 2013). These master's and doctoral students are being trained in interdisciplinary learning sciences programs; they are learning to draw on a wide range of theoretical frameworks and research methodologies, and learning to combine the basic sciences of learning with hands-on issues like classroom organization, curriculum and software design, teacher education, and assessment.

Building the community

The learning sciences approach is relatively new—the name was coined in 1989, and the research tradition extends only back to the 1970s. There are several groups of scholars engaged in learning sciences research who do not necessarily use that term for their research:

The large community of *educational technologists* and *instructional system designers* who develop computer software for instructional purposes. This community includes university researchers but also for-profit software companies developing a range of educational technologies for corporations and schools.

The large community of *cognitive psychologists* and *cognitive neuroscientists* who are studying basic brain functions that are related to learning.

The large community of *educational psychologists* that are studying a wide range of psychological functions related to learning. A subset of this group that will be particularly important to bring into the learning sciences will be assessment researchers, both in universities and at institutions like the Educational Testing Service (the developer of many widely used tests in the U.S., including the SAT, AP, and GRE).

The task facing society today is to design the schools of the future, and that is a massive undertaking that will involve many different communities of practice.

The Path To Educational Innovation

In the next ten to twenty years, the task facing all knowledge societies will be to translate learning sciences research into educational practice. Perhaps the most solid finding to emerge from the learning sciences is that significant change can't be done 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 the learning sciences. Many tasks have to be accomplished:

Parents, politicians, and school boards must be convinced that change is necessary. The shift will require an initial investment in computers, software, and network infrastructure—perhaps even new buildings with as-yet-undetermined architectural designs—but once the shift is in place the annual costs will not necessarily be any more than current expenditures on textbooks and curricular materials.

Textbooks must be rewritten (or perhaps reconceived as laptop- or tablet-based software packages), to present knowledge in the developmentally appropriate sequence suggested by the learning sciences, and to present knowledge as a coherent, integrated whole, rather than as a disconnected series of decontextualized facts.

The shift to customized, just-in-time learning will 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, class parties 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.

We are at an exciting time in the study of learning. 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. Since the 1990s, the brain research of cognitive neuroscience has made rapid progress that may soon allow it to join with the learning sciences. 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. And 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.

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