CHAPTER 34

Conclusion

The Schools of the Future

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The schools of today were largely designed in the nineteenth and twentieth centuries to provide workers for the industrial economy. 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 our schools were designed for a quickly vanishing world (Bereiter, 2003; Hargreaves, 2003; Sawyer, in press). Leading thinkers in business, politics, and education are now in consensus that schools have to be redesigned for the new economy, and that the learning sciences are pointing the way to this new kind of school — a school that teaches the deep knowledge required in a knowledge society. This consensus led major governmental and international bodies to commission reports summarizing learning sciences research; these reports include the U.S. National Research Council’s How People Learn (Bransford, Brown, & Cocking, 2000), the OECD’s Innovation in the Knowledge Economy: Implications for Education and Learning (2004), and a study of twenty-eight countries conducted by the International Society for Technology in Education, called Technology, Innovation, and Educational Change: A Global Perspective (Kozma, 2003).

Those societies that can effectively restructure their schools on the learning sciences will be the leaders in the twenty-first century (OECD, 2000, 2004). The issues addressed by the learning sciences have been recognized as critical in all twenty-eight 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 for a society to make this transition successfully. For example, the Ministry of Education in Finland has created a vision of the Finnish Information Society that stresses collaborative teaching and learning, networking, and teamwork (Ministry of Education, Finland, 1999). Singapore’s “Master Plan for IT in Education” integrates computers into all aspects of education, with the goals of helping students...
to think flexibly, creatively, and collaboratively—a vision known as "Thinking Schools, Learning Nation" (Ministry of Education, Singapore, 2002). Unlike most other countries, the U.S. educational system is not centralized under federal government control and it is not possible to implement a new vision nationwide; but various influential national entities are taking action. The National Research Council funded the preparation of How People Learn in 1999, and the National Science Foundation announced competitions in 2003 and 2005, each totaling about $20,000,000, to create a network of Science of Learning Centers to extend learning sciences research; many of the U.S. authors of this handbook conduct research that is now funded by these grants.

The NRC, ISTE, and OECD reports helped to build a consensus around the learning sciences, but they were necessarily preliminary. They did not provide specific details about how learning sciences research could be used to build the schools of the future. This handbook begins the important work recommended by these reports; the chapters collected here describe the building blocks of the schools 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 schools of the future. 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 its findings begin to be used to build the schools 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. Although these chapters don’t tell us what schools will look like, they take the first step in that direction by telling us how learning environments should be designed. It’s telling that these chapters talk about “learning environments” rather than “schools” or “classrooms.” 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. A true science of learning has to bring together understandings of both informal and formal learning environments, drawing on the best features of all known learning environments to build the schools of the future (Bransford et al., this volume). 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; Confrey, 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 fading industrial economy. Roger Schank (1990) and Seymour Papert (1980) have 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. 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. As of 2005, twenty-two states had established online virtual schools; during the 2003–2004 school year, the state’s school receives just like a school year enrolled in 2005).

Imagining activities that lead high-band would be curricular who won occasional the project that those each type would involve it in a different activity: contracts, invented lesson plans, work at centers, project work. Object of mate the activity, we ident students with different think creatively non-graded
year, the Florida Virtual School became the state's seventy-third school district, and now receives per-student funding from the state just like any other district. In the 2004-2005 school year, twenty-one thousand students enrolled in at least one of its courses (Borja, 2005).

Imagine a nation of online 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 multifaceted, 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 twenty-five students each. Well-designed software could sense each learner's unique learning style and developmental level, and tailor the presentation of material appropriately (see Koedinger & Corbett, this volume, for an example). 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 "fifth grade" reading and "third 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.

In 1980, Seymour Papert famously predicted that when the total twelve-year cost of personal computers was $1000 per student, they would begin to transform education (Papert, 1980, p. 17); this prediction is finally on the horizon. In 2005, the MIT Media Lab launched a new research initiative with the goal of releasing a $100 laptop computer for students by 2007; a prototype was unveiled in November, 2005 (http://laptop.media.mit.edu, accessed November 22, 2005). In 2005, Advanced Micro Devices Inc. released a $200 "personal internet communicator" to bring networked computing to classrooms in the third world. When a laptop computer becomes available for $100, it can store all of a student's textbooks and curriculum materials; as the technology is gradually refined and improved, paper textbooks may eventually become obsolete.

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, tutoring centers like Sylvan Learning Centers 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 all weekend 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 ten or twenty 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.

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 property tax revenue stream. They could participate 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 taken the lead in this area, developing inquiry-based curricula and conducting teacher professional development, but 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. The $100 computer and the inexpensive handheld allow for learning to take place anywhere, anytime; sixteen-year-olds could work their part-time jobs during the day and take their classes at night, just like adults 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 laptops or handhelds 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 and vouchers become widespread. 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, online virtual schools, and at home.

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. The first was in the 1950s, when B. F. Skinner claimed that his “teaching machines” made the teacher “out of date” (1954/1968, p. 22). Then, 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. 6). Nonetheless, two decades later, Larry Cuban famously documented the failure of computers and the Internet to improve U.S. schools in his 2001 book Over-sold and Underused. How is the software

Curric
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 learner centered (Quintana, Shin, Norris, & Soloway, this volume), unlike most of the software currently in use in classrooms, which is generic productivity software like Microsoft Office, and is not designed for learning. One example of the potential is Virginia Tech’s Math Emporium, a former five-and-dime store that has been outfitted with five hundred personal computers, each running specially designed software to teach calculus, linear algebra, and other subjects (http://www.emporium.vt.edu, accessed August 6, 2005). The emporium is open twenty-four hours a day, is accessible from off-site via the Internet, and has professor and graduate student help on staff fourteen hours a day. It serves nearly seven thousand math students each year, at less than half the cost of the lecture courses it replaced, and with higher student math scores and student satisfaction.

Learning scientists work closely in schools; part of the reason that the design research methodology (Barab, this volume; Confrey, 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. For example, the chapter by Cobb and McClain demonstrates a short unit that teaches children the key features of using a coordinate system to represent distributions. But of course, that is only one tiny piece of what we want students to learn from twelve years of math instruction. 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.

Federal agencies and private foundations will need to coordinate their efforts to make sure that each subject and each grade level is being studied, and to avoid duplication of effort. For example, rather than fund five large centers studying tenth grade biology, funding should be spread across five different grades or five different subjects. In their funding of education research, the NSF and the Department of Education have traditionally been field-driven – responding to the important ideas emerging from a loose national network of scholars. But they are both becoming more focused, guiding the nation’s research efforts to ensure that all grades and subject areas are covered.

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 mathematics and science in fifty countries every four years, U.S. science and math curricula contain much more content than other countries as a result of their survey approach 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 United States, politicians and school boards have frequently responded to concerns about education by adding content requirements to the curricu-

lum — 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, mathematicians, 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.

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). 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.

**Scaling Up**

Learning scientists generally believe that learning cannot be studied apart from its contexts. But this results in a difficult problem: if learning is always unique to a specific context, then how can research ever result in sustainable products that can be disseminated and adopted in a wide range of schools? A design experiment transforms one learning environment or classroom, or sometimes an entire school, with a huge investment of highly paid university researchers and assistants. But systemic change can only occur if a design experiment results in curricula and software that can be transferred to many other schools with a relatively minor additional investment.

As a body of research knowledge accumulates, the learning sciences will eventually result in new curriculum materials, software products, teacher professional development courses, and assessments focused on deep knowledge and authentic reasoning abilities. A few of the more established learning sciences laboratories have already developed widely used curricula that are summarized in this handbook: Krajcik’s project-based learning, Linn’s knowledge integration, Kolodner’s Learning By Design, and Koedinger’s cognitive tutors.

**Speed Bumps in the Road to the Future**

It is too early to predict exactly what the schools of the future will look like. Two things are certain: first, that schools will eventually have to change to meet the needs of the modern knowledge society; and second, that schools are complex institutions that have proven to be amazingly resistant to change. 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 a forthcoming book, Collins and Halverson (in preparation) identify several entrenched features of today’s public schools that might make them resist the necessary changes emerging from the learning sciences:

- **Uniform learning versus 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 versus 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 e-mail 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 versus 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 versus distributed knowledge.** In the real world, people act
Intelligent 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 Individual and Group Knowledge

Learning scientists emphasize the importance of learning in groups, in part because most knowledge work takes place in complexly organized teams. But this leads to a tension between group work and individual learning. Many psychologists focus on individual learning and assume that all knowledge is individual knowledge. 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. But some 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).

The learning sciences combine a diverse range of positions on this issue, from cognitive psychologists who focus on the mental structures that underlie knowledge, to sociologists 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 individual cognitive analysis and social interactional analysis — the synthesis that Greeno (this volume) refers to as "situative." 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

In today's high-stakes testing environment, learning sciences researchers need to demonstrate that their methods result in better student outcomes. The learning sciences suggest that today's standardized tests are deeply flawed, because they assess only 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, mathematics tests do not assess model-based reasoning (Lehrer & Schauble, this volume); science tests do not assess whether preexisting misconceptions have indeed been left behind (diSessa, this volume; Linn, this volume) nor do they assess problem-solving or inquiry skills (Krajcik & Blumenfeld, 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 (Carver, this volume, Means, this volume). Several learning sciences researchers...
are developing new assessments that focus on deeper conceptual understanding. For example, Lehrer and Schauble (this volume) have 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. After all, the learning sciences have 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 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. Many educators and politicians have recently applied the medical model of research to education (Shavelson & Towne, 2002). But the medical model does not imply that all research consists of controlled experiments. Medical research proceeds in roughly five phases:

- **Preclinical:** basic scientific research. A wide range of methodologies is used.
- **Phase 1:** Feasibility. How to administer the treatment; how much is appropriate. Again, a wide range of methodologies is used.
- **Phase 2:** Initial efficacy. How well does it work? Quasi-experimental methodologies are typically used.
- **Phase 3:** Randomized controlled experiment. 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. Anderson and Koedinger’s cognitive tutors (Koedinger & Corbett, this volume) have entered Phase 3 but their research has been under way for over twenty years (Cherniavsky, 2005). 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 afterwards, 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. Several such examples were presented in a special issue of the *Journal of the Learning Sciences* edited by Barab and Kirschner (2001). Roth created a database that organizes text, photos, written notes, and copies of student work; Barab et al. developed a graphing tool to represent the classroom's network of activity; Kulikowich and Young developed a computer interface that generated time-stamped records of each student's problem-solving process. Many researchers now use the Transana tool for transcribing and analyzing digital video data (freeware downloadable from http://www.transana.org, accessed August 6, 2005). New tools for digital video ethnomethodology are being developed (Goldman et al., in press).

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 tapes, 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 round. Because it requires such a massive human effort, learning sciences work 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 those universities. The NSF recognized this in 2003 and 2005 by creating a few large Science of Learning Centers. This trend will continue, and the learning sciences, to a certain extent, will become more like "big science."

To create the schools of the future, we will need more research sites, and the government will have to increase its 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. These 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.

### The Goals of Education and the Nature of Knowledge

The shift away from the industrial economy makes the facts and procedures emphasized by instructionism insufficient. In addition, students need deep knowledge: the ability to think and reason, the ability to use knowledge in the authentic practices of the deep sciences and to make applications of their knowledge.
of their everyday lives, and the ability to deeply understand the scientific and technological systems that are increasingly important in society. The theory of knowledge that forms the basis of the learning sciences is taken from the cognitive sciences and from studies of knowledge work, and involves theories of representation, knowledge structures, expert practices, concepts, and understanding.

Most of the chapters in this handbook focus on math and science learning. Learning scientists may have focused on science and math simply because there is more government funding for such research (Kolodner, personal communication). But this raises an important question: Does the same kind of knowledge underlie subjects like history, literature, and the arts? Learning sciences researchers tend to believe that the general principles emerging from their work in math and science classrooms are relevant to all content areas (e.g., Bransford, Brown, & Cocking, 2000). But we have not yet done the research to determine whether this is true. After all, knowledge in science and math shares characteristics that are not likely to hold true of softer disciplines: it is rigorously articulated, it has attained a high degree of consensus, and detailed representational formalisms exist to represent such knowledge. Disciplinary knowledge in history, art, and literary criticism is different, and it may turn out that these forms of knowledge are learned in fundamentally different ways than science and math.

**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 learning sciences community should actively engage with these groups to grow the field:

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 training systems for corporations and “integrated learning systems” for schools.

The large community of cognitive psychologists and cognitive neuroscientists who are studying basic brain functions that are related to learning. One of the most significant research topics in cognitive psychology is memory, and memory research has obvious potential implications for education (e.g., Roediger & Karpicke, in press). The large community of educational psychologists who 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 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.

**Education: The Hardest Science**

We usually refer to natural sciences like physics and biology as the “hard” sciences, and social sciences like psychology, education, and sociology as the “soft” sciences. But the biologist Edmund Wilson pointed out that in fact, the social sciences are much harder than the natural sciences, because the systems they study are infinitely more complex (1968). The social systems studied by learning scientists are some of the most complex systems in the modern world — they contain students, teachers, administrators, parents, and politicians, networked in complex overlapping patterns; they contain complex products like textbooks, worksheets, experimental apparatuses, maps, and
classroom posters; they contain assessments and criteria for success like grades and standardized tests; and they contain education researchers, trying to ensure that the whole system is grounded in the sciences of learning. Given this complexity, it should not be surprising that only a few decades of research have not completely revealed the deepest secrets of how learning works. But we have started down the road and the schools of the future are slowly taking shape.

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 even reconceived as laptop-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 will make many features of today’s schools obsolete: schools years will no longer be grouped by age, school days will no longer be organized into class periods, standardized tests will no longer be administered en masse to an auditorium of students, 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 will 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 instead of 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.

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 (Bransford et al., this volume). 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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References


