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INNOVATIVE LEARNING ENVIRONMENTS

Optimising learning: implications of learning sciences research

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This chapter introduces the field of learning sciences, and outlines some of its key findings in recent years. It explains that while the standard model of schooling was designed to prepare students for the industrial age, the global shift to the knowledge economy will require the rethinking of schooling in order to accommodate evolving needs. Several key findings of learning sciences research and how they align with the needs of the knowledge economy are explained.

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OPTIMISING LEARNING
IMPLICATIONS OF LEARNING SCIENCES RESEARCH
BY

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Introduction

Learning sciences is an interdisciplinary field that studies teaching and learning. Learning scientists study learning in a variety of settings – not only the more formal learning of school classrooms, but also the more informal learning that takes place at home, on the job, and among peers. The goal of the learning sciences is to better understand the cognitive and social processes that result in the most effective learning, and to use this knowledge to redesign classrooms and other learning environments so that people learn more deeply and more effectively. The sciences of learning include cognitive science, educational psychology, computer science, anthropology, sociology, information sciences, neurosciences, education, design studies, instructional design, and other fields. In the late 1980s, researchers in these fields who were studying learning realised that they needed to develop new scientific approaches that went beyond what their own discipline could offer, and to collaborate with other disciplines. Learning sciences was born in 1991, when the first international conference was held, and the *Journal of the Learning Sciences* was first published. This new science is called *the learning sciences* because it is an interdisciplinary science; the collaboration among these disciplines has resulted in new ideas, new methodologies, and new ways of thinking about learning. The first comprehensive overview of the field was published in 2006: *The Cambridge Handbook of the Learning Sciences* (Sawyer, 2006b).

Learning sciences researchers are working to design more effective learning environments – including school classrooms, and also informal settings such as science centres or after-school clubs, on-line distance learning, and computer-based tutoring software. These classroom environments combine new curricular materials, new collaborative activities, support for teachers, and innovative educational software. Learning sciences research suggests several alternative models of learning, particularly those that involve deep links between formal schooling and the many other learning institutions available to students – libraries, science centres and history museums, after school clubs, on-line activities that can be accessed from home, and even collaborations between students and working professionals. In this report, I draw on learning sciences findings to identify a set of principles that should guide the development of alternative models of learning.

The standard model of schooling

By the 20th century, all major industrialised countries offered formal schooling to all of their children. These many educational systems took different paths, but eventually converged on essentially the same model of schooling. When this model emerged in the 19th and 20th centuries, scientists did not know very much about how people learn. Even by the 1920s, when schools started to become the large bureaucratic

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institutions that we know today, there still was no sustained study of how people learn. As a result, this model of schooling was based on common-sense assumptions that had never been tested scientifically:

- Knowledge is a collection of *facts* about the world and *procedures* for how to solve problems. Facts are statements like "The earth is tilted on its axis by 23.45 degrees" and procedures are step-by-step instructions like how to do multi-digit addition by carrying to the next column.
- The goal of schooling is to get these facts and procedures into the student's head. People are considered to be educated when they possess a large collection of these facts and procedures.
- Teachers know these facts and procedures, and their job is to transmit them to students.
- Simpler facts and procedures should be learned first, followed by progressively more complex facts and procedures. The definitions of "simplicity" and "complexity" and the proper sequencing of material were determined either by teachers, by textbook authors, or by asking expert adults like mathematicians, scientists, or historians – not by studying how children actually learn.
- The way to determine the success of schooling is to test students to see how many of these facts and procedures they have acquired.

Because this traditional vision of schooling has been taken for granted for so long, it has not been explicitly named until recently. Within the OECD/CERI programme "Alternative Models of Learning" project, this traditional model is referred to as *the standard model*. Learning scientists often refer to the traditional model as *instructionism*, a term coined by Seymour Papert (1993), because it assumes that the core activity of the classroom is instruction by the teacher. Other education researchers have called this a *transmission and acquisition* model of schooling (*e.g.* Rogoff, 1990), because it emphasises that a knowledgeable teacher transmits knowledge, and a learner then acquires that knowledge.

Standard model schools effectively prepared students for the industrialised economy of the early 20th century; schools based on this model have been effective at transmitting a standard body of facts and procedures to students. The goals of standard model schools were to ensure standardization – all students were to memorise and master the same core curriculum – and this model has been reasonably effective at accomplishing these goals. Standard model schools were structured, scheduled, and regimented in a fashion that was explicitly designed by analogy with the industrial-age factory (Callahan, 1962), and this structural alignment facilitated the ease of transition from school student to factory worker.

The shift to the innovation economy

In recent decades, many OECD member countries have experienced a rapid transformation from an industrial to a knowledge economy (Bell, 1976; Drucker, 1993). The knowledge economy is based on "the production and distribution of knowledge and information, rather than the production and distribution of things" (Drucker, 1993, p. 182). In the knowledge economy, knowledge workers are "symbolic analysts" (Reich, 1991) who manipulate symbols rather than machines, and who create conceptual artefacts rather than physical objects (Bereiter, 2002; Drucker, 1993). Several economists have begun to argue that in today's economy, knowledge is an intrinsic part of the economic system – a third factor, added to the traditional two of labour and capital (Florida, 2002; Romer, 1990).

These analysts emphasise the importance of creativity, innovation, and ingenuity in the knowledge economy; some scholars now refer to today's economy as a *creative economy* (Florida, 2002; Howkins, 2001). Florida argued that "we now have an economy powered by human creativity" (2002, pp. 5-6) and that human creativity is "the defining feature of economic life" (p. 21). Florida represents an economic school of thought known as New Growth Theory, which argues that creativity and idea generation are central to today's economy (Cortright, 2001).

By the 1990s, educators had begun to realise that if the economy was no longer an industrial-age factory economy, then our schools were designed for a quickly vanishing world (Bereiter, 2002; Hargreaves, 2003; Sawyer, 2006c). This consensus led major governmental and international bodies to commission reports summarising learning sciences research; these reports include the United States National Research Council's *How People Learn* (Bransford, Brown and Cocking, 2000), the OECD's *Innovation in the Knowledge Economy: Implications for Education and Learning* (2004), and a study of 28 countries conducted by the International Society for Technology in Education, called *Technology, Innovation, and Educational Change: A Global Perspective* (Kozma, 2003).

In the standard model of schooling, the role of educational research is to help schools more effectively transmit facts and procedures to students. But when learning scientists first went into classrooms in the 1970s and 1980s, they discovered that schools were not teaching the deep knowledge that underlies knowledge work. By the 1980s, cognitive scientists had discovered that children retain material better, and are able to generalise it to a broader range of contexts, when they learn deep knowledge rather than surface knowledge, and when they learn how to use that knowledge in real-world social and practical settings. In the late 1980s, these learning scientists began to argue that standard model schools were not aligned with the knowledge economy.

Many of today's schools are not teaching the deep knowledge that underlies innovative activity. But it is not just a matter of asking teachers to teach different curriculum, because the structural configurations of the standard model make it very hard to create learning environments that result in deeper understanding. One of the central underlying themes of the learning sciences is that students learn deeper knowledge when they engage in activities that are similar to the everyday activities of professionals who work in a discipline. This focus on authentic practice is based on a new conception of the expert knowledge that underlies knowledge work in today's economy. In the 1980s and 1990s, scientists began to study science itself, and they began to discover that newcomers become members of a discipline by learning how to participate in all of the practices that are central to professional life in that discipline. Increasingly, cutting-edge work in the sciences is done at the boundaries of disciplines; for this reason, students need to learn the underlying models, mechanisms, and practices that apply across many scientific disciplines, rather than learning in the disconnected and isolated six-week units that are found in many standard model science classrooms – moving from studying the solar system to studying photosynthesis to studying force and motion, without ever learning about connections among these units.

Studies of knowledge workers show that they almost always apply their expertise in complex social settings, with a wide array of technologically advanced tools along with old-fashioned pencil, paper, chalk, and blackboards. These observations have led learning sciences researchers to a *situated* view of knowledge (Greeno, 2006). "Situated" means that knowledge is not just a static mental structure inside the learner's head; instead, knowing is a process that involves the person, the tools and other people in the environment, and the activities in which that knowledge is being applied. This perspective moves beyond a transmission and acquisition conception of learning that is implicit in the standard model; in addition to acquiring content, what happens during learning is that patterns of participation in collaborative activity change over time (Rogoff, 1990, 1998).

In the knowledge economy, memorisation of facts and procedures is not enough for success. Educated graduates need a deep conceptual understanding of complex concepts, and the ability to work with them creatively to generate new ideas, new theories, new products, and new knowledge. They need to be able to critically evaluate what they read, to be able to express themselves clearly both verbally and in writing, and to be able to understand scientific and mathematical thinking. They need to learn integrated and usable knowledge, rather than the sets of compartmentalised and decontextualised facts emphasised by instructionism. They need to be able to take responsibility for their own continuing, lifelong learning. These abilities are important to the economy, to the continued success of participatory democracy, and to living a fulfilling, meaningful life. The standard model of schooling is particularly ill-suited to the education of creative professionals who can develop new knowledge and continually further their own understanding.

Key learning sciences findings

In the three decades that learning sciences research has been under way, several key findings have emerged. These findings align with the needs of the knowledge economy, as identified above.

The importance of deeper conceptual understanding

Scientific studies of knowledge workers demonstrate that expert knowledge includes the facts and procedures that the standard model is designed to transmit to learners. However, these studies also demonstrate that acquiring those facts and procedures is not sufficient to prepare a person to perform as a knowledge worker. Factual and procedural knowledge is only useful when a person knows which situations to apply it in, and exactly how to modify it for each new situation. The standard model of schooling results in a kind of learning which is very difficult to use outside of the classroom. When students gain a deeper conceptual understanding, they learn facts and procedures in a much more useful and profound way that transfers to real-world settings. This deeper conceptual understanding has several components, as described in the following sections.

The cognitive bases of expertise

One of the most surprising discoveries of cognitive science in the 1970s was that everyday behaviour was harder to represent computationally than expert behaviour. Some of the most successful artificial intelligence (AI) programmes simulated expert performance in knowledge-intensive domains like medicine, manufacturing, telecommunications, and finance (Liebowitz, 1998). As a result of these efforts, cognitive science developed a sophisticated understanding of the cognitive bases of expertise. Everyday common-sense behaviour remains beyond the abilities of AI computer programmes, even as expert performance in many knowledge-intensive domains like medicine has been successfully simulated.

A large body of cognitive science research shows that expertise is based on:

- A large and complex set of representational structures.
- A large set of procedures and plans.
- The ability to improvisationally apply and adapt those plans to each situation's unique demands.
- The ability to reflect on one's own cognitive processes while they are occurring.

Problem solving

Cognitive scientists have spent several decades attempting to identify the cognitive bases of problem solving. One of the most persistent theories about problem solving is that it depends on a person having a mental representation of a *problem space* (Newell and Simon, 1972) which contains *beliefs* and *mental representations* – of concepts, specific actions, and the external world. Problem solving is then conceived of as searching through the problem space until the desired *goal state* is reached. Because knowledge work typically requires problem solving, many learning sciences approaches to learning are based on this research. For example, Koedinger and Corbett's cognitive tutors (2006) assume that *production rules* are used to move through the problem space, and Kolodner's *case-based reasoning* (2006) assumes that case lookup and matching algorithms are used.

Thinking

Educators often talk about the importance of higher-order thinking skills, but educational programmes that emphasise thinking skills are often not based on scientific research. Instead, they are based on one or another intuitively-based taxonomy of thinking skills, with almost no scientific justification of why this specific set of skills should be taught in schools (Kuhn, 1990, p. 2). Beginning in the 1980s and 1990s, cognitive psychologists began to study informal reasoning (Voss, Perkins and Segal, 1991) – the good and bad reasoning that people engage in everyday, when faced with real-life problems that do not have simple solutions. They also began to study everyday decision making, discovering a wide range of common thinking errors that most people make (Kahneman, Slovic and Tversky, 1982). Also during this time, developmental psychologists began to identify a range of good and bad thinking strategies and how these strategies develop over the lifespan. They extended Piaget's original insight, showing how children's thinking differs from that of adults – information that is absolutely critical to education based on the learning sciences (*e.g.*, Dunbar and Klahr, 1989).

Focusing on learning in addition to teaching

Before Jean Piaget, most people held to the common-sense belief that children have less knowledge than adults. Piaget argued a radically different theory: although children certainly possess less knowledge than adults, what's even more important to learning is that children's minds contain different knowledge structures than are in adults' minds. In other words, children differ not only in the quantity of knowledge they possess; their knowledge is *qualitatively* different.

By the 1980s, researchers had confirmed this fundamental claim that children think differently from adults. Educational researchers had discovered, for example, that children do not get math problems wrong only because they did not study hard enough or because they forgot what they read in the textbook – they often got the problems wrong because their minds were thinking about the math problems in a different way than educators expected, and math education was not designed to correct these misconceptions. Learning scientists began to identify the cognitive characteristics of children's "naïve math" and "naïve physics", and began to accumulate an important body of knowledge about the typical misconceptions that people have about these content areas (diSessa, 2006; Linn, 2006). This body of research allows designers of learning environments to connect learning to students' prior knowledge and misconceptions.

Constructivism explains why students often do not learn deeply by listening to a teacher, or reading from a textbook. Learning sciences research is revealing the deeper underlying bases of how knowledge construction works. To design effective learning environments, one needs a very good understanding of what children know when they come to the classroom. This requires sophisticated research into children's cognitive development, and the learning sciences draw heavily on psychological studies of cognitive development (*e.g.* Siegler, 1998).

Building on prior knowledge

One of the most important discoveries guiding learning sciences research is that learning always takes place against a backdrop of existing knowledge. Students do not enter the classroom as empty vessels, waiting to be filled; they enter the classroom with half-formed ideas and misconceptions about how the world works – sometimes called "naïve" physics, math, or biology. Many cognitive developmentalists have studied children's theories about the world, and how children's understanding of the world develops through the preschool and early school years. The basic knowledge about cognitive development that has resulted from this research is absolutely critical to reforming schooling so that it is based on the basic sciences of learning.

Standard model schools were developed under the behaviourist assumption that children enter school with empty minds, and the role of school is to fill up those minds with knowledge. Standard model curricula were designed before the learning sciences discovered how children think and what knowledge structures they bring to the classroom.

Reflection

The learning sciences have discovered that when learners externalise and articulate their developing knowledge, they learn more effectively (Bransford, Brown and Cocking, 2000). This is more complex than it might sound, because it is not the case that learners first learn something, and then express it. Instead, the best learning takes place when learners articulate their unformed and still developing understanding, and continue to articulate it throughout the process of learning. Articulating and learning go hand in hand, in a mutually reinforcing feedback loop. In many cases, learners do not actually learn something until they start to articulate it – in other words, while thinking out loud, they learn more rapidly and deeply than studying quietly.

One of the reasons that articulation is so helpful to learning is that it makes possible *reflection* or *metacognition* – thinking about the process of learning and thinking about knowledge. Learning scientists have repeatedly demonstrated the importance of reflection in learning for deeper understanding. Many learning sciences classrooms are designed to foster reflection, and most of them foster reflection by providing students with tools that make it easier for them to articulate their developing understandings. Once students have articulated theirincreasing comprehension , learning environments should support them in reflecting on what they have just articulated. One of the most central topics in learning sciences research is how to support students in educationally beneficial reflection.

Scaffolding learning

One of the most important topics of learning sciences research is how to support students in this ongoing process of articulation and reflection, and which forms of articulation and reflection are the most beneficial to learning. The learning sciences have discovered that articulation is more effective if it is *scaffolded* – channelled so that certain kinds of knowledge are articulated, and in a certain form that is most likely to result in useful reflection. Students need help in articulating their developing understandings; they do not yet know how to think about thinking, and they do not yet know how to talk about thinking.

Scaffolding is the help given to a learner that is tailored to that learner's needs in achieving his or her goals of the moment. The best scaffolding provides this help in a way that contributes to learning. For example, telling someone how to do something, or doing it for them, may help them accomplish their immediate goal; but it is not good scaffolding because the child does not actively participate in constructing that knowledge. In contrast, effective scaffolding provides prompts and hints that help learners to figure it out on their own. Effective learning environments scaffold students' active construction of knowledge in ways similar to the way that scaffolding supports the construction of a building. When construction workers need to reach higher, additional scaffolding is added, and when the building is complete, the scaffolding can be removed. In effective learning environments, scaffolding is gradually added, modified, and removed according to the needs of the learner, and eventually the scaffolding fades away entirely.

Design principles from the Learning Sciences

Research emerging from the learning sciences is still too premature to specify a single, well articulated alternative model of schooling. However, learning sciences findings imply several principles that can be used to guide the development of new models of schooling that are more closely aligned with the innovation economy.

Customised learning

In the standard model, everyone learns the same thing at the same time. Many parallel structures and processes of these schools align to enforce standardisation. However learning sciences findings suggest that each student learns best when they are placed in a learning environment that is sensitive to their pre-existing cognitive structures; and learning sciences research has shown that different learners enter the classroom with different structures. Learning sciences research suggests that more effective learning will occur if each learner receives a customised learning experience.

Educational software gives us the opportunity to provide a customised 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 (see Koedinger and Corbett, 2006 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 "5th grade" reading and "3rd grade" math at the same time. In age-graded classrooms this would be impossible, but in alternative models of schooling 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 socialise 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.

Diverse knowledge sources

The standard model is based on a transmission-and-acquisition approach, where the teacher is assumed to possess all of the knowledge, and classroom activities are designed to facilitate the teacher-to-student transfer of knowledge. In the constructivist and project-based learning suggested by learning sciences research, 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. Learners will acquire knowledge from diverse sources; of course, expert support from the teacher can facilitate these learning processes, but the teacher's involvement will not be one of transmitting knowledge.

Distributed knowledge

In knowledge intensive occupations, people act intelligently by making frequent use of books, papers, and technology. Knowledge work occurs in teams and organisations, 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.

At the same time, learning sciences research is showing that collaborating student groups can accelerate learning (Sawyer, 2006a). Here is a case where learning sciences research supports increased classroom collaboration, and the innovation economy, as well, demands graduates who are highly skilled at creating together in groups (Sawyer, 2007).

Curriculum

Standard model schools typically have highly regimented and articulated curricula. A central question guiding education research must always be: What should be taught in second grade math, or in sixth grade social studies? In the United States in the 1950s and 1960s, practicing scientists became heavily involved in the development of school science curricula (Rudolph, 2002). These new curricula were an improvement on what previously existed. However, learning scientists have discovered that what seems more simple to an adult professional is not necessarily more simple to a learner, and that 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. Even these 1960s textbooks and curricula, developed in collaboration with expert scientists, 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.

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 the standard model, 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, United States 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 United States achievement relative to other countries (Schmidt and McKnight, 1997). In a typical United States classroom, 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 children in the United States (Schmidt and 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.

The role of the teacher

In a knowledge economy school, teachers should also be knowledge workers, with equivalent skills to other knowledge workers such as lawyers, doctors, engineers, managers, and consultants. They should deeply understand the theoretical principles and the latest knowledge about how children learn. They should 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. To align with the innovation economy, teachers will require more autonomy, more creativity, and more content knowledge.

These teachers should be highly trained professionals, comfortable with technology, with a deep pedagogical understanding of the subject matter, able to respond in an improvised manner to the uniquely emerging flow of each classroom (Sawyer, 2004). To foster collaborative and authentic learning, they will lead teams of students – much like a manager of a business or the master in a workshop – rather than controlling students autocratically, as the factory bosses of old.

Assessment

In the knowledge economy, today’s assessments have two critical flaws, both due to the fact that today’s assessments were designed for the standard model of schooling. First, whereas the schools of the future will increasingly result in customised learning, 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 standardisation, at the same time that learning sciences and technology are making it possible for individual students to have customised learning experiences. Customisation combined with diverse knowledge sources enable students to learn different things. Schools will still need to measure learning for accountability purposes, but we do not yet know how to reconcile accountability with customised learning.

Second, today’s standardised tests assess relatively superficial knowledge and do not assess the deep knowledge required by the knowledge society. Standardised tests, almost by their very nature, evaluate decontextualised and compartmentalised knowledge. For example, mathematics tests do not assess model-based reasoning (Lehrer and Schauble, 2006); science tests do not assess whether pre-existing misconceptions have indeed been left behind (diSessa, 2006; Linn, 2006) nor do they assess problem-solving or inquiry skills (Krajcik and Blumenfeld, 2006). As long as schools are evaluated on how well their students do on such tests, it will be difficult for them to leave the standard model 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, 2006; Means, 2006). Several learning sciences researchers are developing new assessments that focus on deeper conceptual understanding.

The learning sciences and alternative models of learning

Following the above discussion, a set of key findings has emerged from learning sciences research:

- The importance of learning deeper conceptual understanding, rather than superficial facts and procedures.
- The importance of learning connected and coherent knowledge, rather than knowledge compartmentalised into distinct subjects and courses.
- The importance of learning authentic knowledge in its context of use, rather than decontextualised classroom exercises.
- The importance of learning in collaboration, rather than in isolation.

These key findings imply that the most effective learning environments will have the following characteristics:

- *Customised learning*. Each child receives a customised learning experience.
- *Availability of diverse knowledge sources*. Learners can acquire knowledge whenever they need it from a variety of sources: books, web sites, and experts around the globe.
- *Collaborative group learning*. Students learn together as they work collaboratively on authentic, inquiry-oriented projects.
- *Assessment for deeper understanding*. Tests should evaluate the students’ deeper conceptual understanding, the extent to which their knowledge is integrated, coherent, and contextualised.

To date, the standard model of schooling does not align with these characteristics. Learning is standardised; knowledge sources are limited to the teacher and the textbook; most learning occurs by a solitary learner; and assessment typically measures the memorisation of superficial facts and procedural knowledge. Some of these characteristics can be implemented within the standard model; for example, existing classrooms could introduce collaborative learning tasks (as many schools are doing today). But some of these characteristics will be extremely difficult to implement within the standard model; for example, the notion of customised learning is inconsistent with the high degree of standardisation associated with the standard model school.

The work of the OECD's Centre for Educational Research and Innovation (CERI) on alternative models of learning needs to explore whether or not there are other models of learning that align more naturally with these learning sciences characteristics. A natural place to start the exploration is to study non-school locations where learning occurs – whether called self-directed learning or informal learning. Many non-school learning environments have existed through history and continue to exist alongside formal schooling. One example that has been widely studied is apprenticeship (Collins, 2006; Rogoff, 1990) – where a young adult who aspires to learn a trade works closely with an older expert. In some disciplines, such as medicine, apprenticeship is a core feature of the learning experience; in medical school, students spend two years in classrooms and then two years in the hospital, working alongside senior physicians. Apprenticeship is a core component of education in craft trades such as carpentry and electrical wiring. A second example of non-school learning that has been widely studied is the huge amount of knowledge that young children acquire, at home, in the years before they begin formal schooling – they learn their first language, and a wide range of physical and social skills.

Many learning scientists are experimenting with new models of learning that blend some features of formal schools with some features of these non-school learning environments. Institutions where self-directed learning is common have been of particular interest; these include museums and public libraries. In recent years, the managers of these institutions have been expanding their educational offerings. Science centres have already taken the lead in this area, developing inquiry-based curricula and conducting teacher professional development, but art and history museums may soon follow suit. Over time, these institutions could evolve into full-fledged learning resource centres, and some segments of the school day might be better spent in these institutions, rather than in traditional schools.

The creative economy is also a learning society, one in which all workers must continue to acquire new knowledge throughout their lives. It is no longer possible to imagine that education ends by a certain age, after which learning is no longer necessary. As a result of these broader economic changes, the boundary between formal schooling and continuing education could begin to break down. The milestones of a high school and a college 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. Many types of knowledge – for example, the trade knowledge that is today acquired through apprenticeship – 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 Internet provides an opportunity for a new kind of learning environment: a sophisticated form of distance learning, where the learners and the teachers may all be in different physical locations, communicating via the network. As of 2005, twenty-two of the United States had established on-line virtual schools; during the 2003-04 school year, the Florida Virtual School became the state's 73rd school district, and now receives per-student funding from the state just like any other district. In the 2004-05 school year, 21 000 students enrolled in at least one of its courses (Borja, 2005). When each student is working at their own computer, there is no longer a compelling social reason to group students by age; students could easily be grouped according to their current level of understanding, allowing the customised learning implicated by the learning sciences.

Conclusion

The standard model of schooling emerged during the industrial age, and it has been effective at generating the kinds of graduates needed by the industrial economy. However, the broad global shift to an innovation economy has revealed some weaknesses with the standard model. The learning sciences offer us a set of research findings that allow us to begin to create new models of learning. Those societies that can effectively develop alternative models of learning that are in accordance with learning sciences principles will be the leaders in the 21^{st} century (OECD, 2000, 2004).

We are at an exciting time in the study of learning. 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. Researchers have just begun to explore what models of schooling might emerge in response to the new research emerging from the learning sciences, and to the computer technology that makes these new learning environments possible. 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. Existing schools should redesign themselves with a foundation in the learning sciences, and should work closely with non-school learning environments – libraries, museums, after-school clubs, on-line virtual schools, and the home – to develop a new model of learning for the future. As our scientific understanding of the processes of learning is increasingly refined, the final step to transform schools must be taken by our whole society: parents and teachers, and the administrators, policy makers, and politicians with whom we entrust our schools.

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