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1 Introduction

The New Science of Learning

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The learning sciences is an interdisciplinary field that studies teaching and learning. Learning scientists study a variety of settings, including not only the formal learning of school classrooms, but also the 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 realized that they needed to develop new scientific approaches that went beyond what their own disciplines could offer and to collaborate with other disciplines. The field of learning sciences was born in 1991, when the first international conference was held and the *Journal of the Learning Sciences* was first published.

By the 20th century, all major industrialized countries offered formal schooling to all of their children. When these schools took shape during the 19th and 20th centuries, scientists didn't know very much about how people learn. Even by the 1920s, when schools began to grow into the large bureaucratic institutions that we know today, there was still no sustained study of how people learn. As a result, the schools we have today were designed around commonsense 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 instructions on how to do multi-digit addition by carrying to the next column.
- The goal of schooling is to get these facts and procedures into students' heads. People are considered 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 by teachers, by textbook authors, or by 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.

This traditional vision of schooling is known as *instructionism* (Papert, 1993). Instructionism prepared students for the industrialized economy of the early 20th century. But the world today is much more technologically complex and economically competitive, and instructionism is increasingly failing to educate our students to participate in this new kind of society. Economists and organizational theorists have reached a consensus that today we are living in a knowledge economy, an economy that is built on knowledge work (Bereiter, 2002; Drucker, 1993). In the knowledge economy, memorization 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 compartmentalized and decontextualized facts emphasized 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. Instructionism is particularly ill suited to the education of creative professionals who can develop new knowledge and continually further their own understanding; instructionism is an anachronism in the modern innovation economy.

In the 1970s, a new science of learning was born – based on research emerging from psychology, computer science, philosophy, sociology, and other scientific disciplines. As they closely studied children's learning, scientists discovered that instructionism was deeply flawed. By the 1990s, after about 20 years of research, learning scientists had reached a consensus on the following basic facts about learning – a consensus that was published by the United States National Research Council (see Bransford, Brown, & Cocking, 2000):

- *The importance of deeper conceptual understanding*. Scientific studies of knowledge workers demonstrate that expert knowledge does include facts and procedures, but simply acquiring those facts and procedures does not prepare a person for performance 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. Instructionism results in a kind of learning that 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.

- *Focusing on learning in addition to teaching*. Students cannot learn deeper conceptual understanding simply from better instruction. Students can only learn this by actively participating in their own learning. The new science of learning focuses on student learning processes, as well as instructional techniques.
- *Creating learning environments*. The job of schools is to help students learn the full range of knowledge required for expert adult performance: facts and procedures, of course, but also the deeper conceptual understanding that will allow them to reason about real-world problems. Learning sciences research has identified the key features of those learning environments that help students learn deeper conceptual understanding.
- *The importance of building on a learner's prior knowledge*. Learners are not empty vessels waiting to be filled. They come to the classroom with preconceptions about how the world works; some of them are basically correct, and some of them are misconceptions. The best way for children to learn is in an environment that builds on their existing knowledge; if teaching does not engage their prior knowledge, students often learn information just well enough to pass their tests, and then revert to their misconceptions outside of the classroom.
- *The importance of reflection*. Students learn better when they express their developing knowledge – either through conversation or by creating papers, reports, or other artifacts – and then receive opportunities to reflectively analyze their state of knowledge.

This handbook is an introduction to this new science of learning and to how researchers are using this science to lay the groundwork for the schools of the future. This new science is called *the learning sciences* because it is an interdisciplinary science: it brings together researchers in psychology, education, computer science, and anthropology, among others, and the collaboration among these disciplines has resulted in new ideas, new methodologies, and new ways of thinking about learning. Many people – parents, teachers, policy makers, and even many educational researchers – are not aware of the important discoveries emerging from the learning sciences. Without knowing about the new science of learning, many people continue to assume that schools should be based on instructionism. Parents and policy makers remember being taught that way and are often uncomfortable when their children have different educational experiences. Many teachers have spent entire careers mastering the skills required to manage an instructionist classroom, and they understandably have trouble envisioning a different kind of school. The purpose of this handbook is to build on the new science of learning by showing various stakeholders how to design innovative learning environments and classrooms.

- For *teachers*, reading about the new science of learning can help you be more effective in your classrooms.
- For *parents*, reading about the new science of learning can help you become an informed consumer of schools. The learning sciences explains why and when instructionism fails and which alternative learning environments are based in contemporary science.
- For *administrators*, reading about the new science of learning can help you lead your school into the 21st century.
- For *policy makers*, reading about the new science of learning can help you understand the problems with today's curricula, teacher education programs, and standardized tests, and understand how to form a vision for the future.
- For *education entrepreneurs*, reading about the new science of learning can help you ground your innovations in how people learn and design more effective learning environments.
- For *professionals*, reading about the new science of learning can help you understand why the general public is so poorly informed about science, technology, international relations, economics, and other knowledge-based disciplines.
- And finally, for *education researchers*, reading about the new science of learning can help you learn how your own studies relate to the learning sciences and to see how you can participate in building the schools of the future.

The Goals of Education

The traditional role of educational research has been to tell educators how to achieve their curriculum objectives, but not to help set those objectives. But when learning scientists went into classrooms, they discovered that many schools were not teaching the deep knowledge that underlies intelligent performance. By the 1980s, cognitive scientists had discovered that children retain material better – and are able to generalize and apply 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 (see Table 1.1).

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. Authentic practices are the keystone of many recent educational standards documents in the United States. In the subject of history, for example, reforms call for learning history by doing historical inquiry rather than by memorizing dates and sequences of events: working with primary data sources and using the methods of historical analysis and argumentation that historians use (National Center for History in the Schools, 1996). In the subject of science,

Table 1.1. *Deep learning versus traditional classroom practices*

Learning knowledge deeply (findings from cognitive science)	Traditional classroom practices (instructionism)
Deep learning requires that learners relate new ideas and concepts to previous knowledge and experience.	Learners treat course material as unrelated to what they already know.
Deep learning requires that learners integrate their knowledge into interrelated conceptual systems.	Learners treat course material as disconnected bits of knowledge.
Deep learning requires that learners look for patterns and underlying principles.	Learners memorize facts and carry out procedures without understanding how or why.
Deep learning requires that learners evaluate new ideas and relate them to conclusions.	Learners have difficulty making sense of new ideas that are different from what they encountered in the textbook.
Deep learning requires that learners understand the process of dialogue through which knowledge is created, and that they examine the logic of an argument critically.	Learners treat facts and procedures as static knowledge handed down from an all-knowing authority.
Deep learning requires that learners reflect on their own understanding and their own process of learning.	Learners memorize without reflecting on the purpose or on their own learning strategies.

the National Science Education Standards calls for students to engage in the authentic practices of scientific inquiry: constructing explanations and preparing arguments to communicate and justify those explanations (National Research Council, 1996, p. 105).

To better understand how to engage students in authentic practices, many learning sciences reforms are based on studies of professional practice.

- Professionals engage in a process of inquiry, in which they start with a driving question and then use discipline-specific methods to propose hypothetical answers to the question and to gather and evaluate evidence for and against competing hypotheses.
- Professionals use complex representations to communicate with each other during collaboration.
- Scientists and mathematicians work with concrete, visual models, so students should too.

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 discovered 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. And increasingly, cutting-edge work in the sciences is being 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 units that are found in instructionist science classrooms – moving from studying the solar system to studying photosynthesis to studying force and motion, without ever learning about the connections between these topics.

Studies of knowledge workers show that they almost always apply their expertise in complex social settings, using 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 *situativity* view of knowledge (Greeno & Engeström, Chapter 7, this volume). Situativity 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. The situativity perspective moves us beyond a transmission and acquisition conception of learning; in addition to acquiring content, what happens during learning is that patterns of participation in collaborative activity change over time (Rogoff, 1990, 1998). This combined research has led the learning sciences to focus on how children learn in groups and from collaboration (as discussed in the chapters in Part 4).

Of course, students are not capable of doing exactly the same things as highly trained professionals; when learning scientists talk about engaging students in authentic practices, they are referring to developmentally appropriate versions of the situated and meaningful practices of experts. One of the most important goals of learning sciences research is to identify exactly what practices are appropriate for students to engage in and learn and how to design age-appropriate learning environments without losing the authenticity of professional practice.

The Nature of Expert Knowledge

Should we reduce auto emissions because of global warming? Should we avoid growing and eating genetically modified organisms (GMOs)? Should we allow stem cell research to proceed? Are market-based mechanisms capable of helping to address pressing social problems? Today's public debates about such controversial issues show a glaring lack of knowledge about scientific practice. The U.S. National Science Education Standards observes that "Americans are confronted increasingly with questions in their lives that require scientific information and scientific ways of thinking for informed decision making" (National Research Council, 1996, p. 11).

By the early 1900s, major industrial countries had realized the important role that science and engineering played in their rapid growth, and many scholars began to analyze the nature of scientific knowledge. In the first half of the 20th century, philosophers came to a consensus on the nature of scientific knowledge: scientific knowledge consisted of statements about the world and of logical operations that could be applied to those statements. This consensus was known as *logical empiricism* (McGuire, 1992; Suppe, 1974). Logical empiricism combined with behaviorism and traditional classroom practice to form the instructionist approach to education: disciplinary knowledge consisted of facts and procedures, and teaching was thought of as transmitting the facts and procedures to students.

In the 1960s, sociologists, psychologists, and anthropologists began to study how scientists actually did their work, and they increasingly discovered that scientific knowledge was not simply a body of statements and logical operations. In this new view, scientific knowledge is an understanding about how to go about doing science, combined with deep knowledge of models and explanatory principles connected into an integrated conceptual framework (Songer & Kali, Chapter 28, this volume). Learning scientists often refer to logical empiricism, and to this expanded view of scientific knowledge, as distinct *epistemologies* of science. This newer epistemology holds that the practice of science involves experimentation, trial and error, hypothesis testing, debate, and argumentation. And science is not a solo endeavor; it involves frequent encounters with peers in the scientific community. Scientists frequently talk about evaluating other scientists' claims and think about how best to support and present their claims to others.

In this new view, scientific knowledge is situated, practiced, and collaboratively generated. The traditional science classroom, with its lectures and step-by-step lab exercises, completely leaves out these elements of science. But this kind of knowledge would be extremely useful to members of the general public as they read reports of an experimental drug in the daily paper, as they discuss the potential risks of upcoming surgeries with their doctors, or as they evaluate the health risks of new construction near their neighborhoods.

This new view of expert knowledge has extended beyond science to other forms of knowledge work. For example, literacy scholars have discovered that advanced literacy involves much more than knowing which sounds correspond to which letters; literacy involves knowing how to participate in a complex set of literate practices – like reading a recipe, scanning the classifieds for a specific product, or writing an e-mail to a colleague (Smagorinsky & Mayer, Chapter 30, this volume). Social science educators have discovered that historians are experts because they know how to engage in the complex practices of historical inquiry and argumentation (Carretero & Lee, Chapter 29, this volume).

Processes Involved in Learning

The learning sciences are centrally concerned with exactly what is going on in a learning environment and exactly how it is contributing to improved student performance. The learning environment includes the people in the environment (teachers, learners, and others), the computers in the environment and the roles they play, the architecture and layout of the room and the physical objects in it, and the social and cultural environment. Key questions include: How does learning happen? How do different learning environments contribute to learning, and can we improve the design of learning environments to enhance learning? Some researchers work on specific components of the learning environment – software design, the roles that teachers should play, or the specific activities each student performs. Others examine the entire learning environment as a system and focus on more holistic questions: How much support for the student should come from the teacher, the computer software, or from other students? How can we create a culture where learners feel like a "learning community"? How can we design materials and activities that keep students motivated and sustain their engagement? Chapter 2, "Foundations of the Learning Sciences," further explores this synergistic contrast between *elemental* and *systemic* approaches in the learning sciences.

How Does Learning Happen?: The Transition from Novice to Expert Performance

One of the legacies of early cognitive science research was its close study of knowledge work. Many artificial intelligence researchers interviewed and observed experts, with the goal of replicating that expert knowledge in a computer program. Before it was possible to simulate expertise in a program, these researchers had to describe in elaborate detail the exact nature of the knowledge underlying that expertise. When these researchers turned their attention to education, they had to consider a new twist: How do experts acquire their expertise? What mental stages do learners go through as they move from novice to expert? These questions were the purview of cognitive development research, which combined developmental psychology and cognitive psychology. Cognitive development has been an important foundation for the learning sciences.

Because learning scientists focus on the expert knowledge underlying knowledge work, they study how novices think and what misconceptions they have; then, they design curricula that leverage those misconceptions appropriately so that learners end up at the expert conception in the most efficient way (diSessa, Chapter 5, this volume).

How Does Learning Happen?: Using 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 don't enter the classroom as empty vessels; 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.

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

Promoting Better Learning: Scaffolding

The learning sciences are based on a foundation of constructivism. The learning sciences have convincingly demonstrated that when children actively participate in constructing their own knowledge, they gain a deeper understanding, more generalizable knowledge, and greater motivation. Learning sciences research has resulted in very specific findings about what support the learning environment must provide for learners to effectively construct their own knowledge.

To describe the support that promotes deep learning, learning scientists use the term *scaffolding*. *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 (see Reiser & Tabak, Chapter 3, this volume). 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.

Promoting Better Learning: Externalization and Articulation

The learning sciences have discovered that when learners externalize and articulate their developing knowledge, they learn more effectively (Bransford, Brown, & Cocking, 2000). This is more complex than it might sound, because it's 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 don't actually learn something until they start to articulate it – in other words, while thinking out loud, they learn more rapidly and deeply than while studying quietly.

This fascinating phenomenon was first studied in the 1920s by Russian psychologist Lev Vygotsky. In the 1970s, when educational psychologists began to notice the same phenomenon, Vygotsky's writings were increasingly translated into English and other languages, and Vygotsky is now considered one of the foundational theorists of the learning sciences (see Nathan & Sawyer, Chapter 2, this volume). Vygotsky's explanation for the educational value of articulation is based on a theory of mental development; he argued that all knowledge began as visible social interaction, and then was gradually internalized by the learner to form thought. Learning scientists have widely debated the exact nature of this internalization process, but, regardless of the specifics of one or another explanation, the learning sciences are unified in their belief that collaboration and conversation among learners is critical because it allows learners to benefit from the power of articulation.

One of the most important topics of learning sciences research is how to support students in this ongoing process of articulation, and which forms of articulation are the most beneficial to learning. The learning sciences have discovered that articulation is more effective if it is scaffolded – channeled 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 don't yet know how to think about thinking, and they don't yet know how to talk about thinking. The chapters in Part 4, "Learning Together," describe several examples of learning environments that scaffold effective learning interactions.

Promoting Better Learning: Reflection

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 (see Winne & Azevedo, Chapter 4, this volume). 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 their developing understandings, learning environments should support them in reflecting on what they have just articulated. One of the most central topics