1 An Introduction to the Learning Sciences

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The learning sciences (LS) is an interdisciplinary field that studies teaching and learning. Learning scientists study a variety of settings: not only school classrooms, but also the more unstructured learning that takes place at home, in communities and families, on the job, with peers, and while using apps on computers, smartphones, and web browsers. The goal of LS 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 name "learning sciences" is pluralized with an "s" because the field is interdisciplinary: it draws on cognitive science, educational psychology, computer science, anthropology, sociology, information sciences, education, design studies, instructional design, and other fields. In the 1980s and 1990s, researchers who were studying learning from these various perspectives realized that they needed to develop new scientific approaches that went beyond what their own discipline could offer, and they began to collaborate with other disciplines. The collaboration among disciplines has resulted in new ideas, new methodologies, and new ways of thinking about learning. LS was born in 1991, when the first academic conference was held and the *Journal of the Learning Sciences* was first published. The conference and the journal grew in size and influence during the 1990s. In 2002, the professional society was formed, the International Society of the Learning Sciences (ISLS). In 2006 the first edition of this handbook was published, followed by the second edition in 2014, and this third edition in 2022.

By the twentieth century, all major industrialized countries offered formal schooling to all of their children. When these schools took shape in the nineteenth and twentieth centuries, scientists did not know very much about how people learn. Even by the 1920s, when schools became the large bureaucratic institutions that we know today, there still was 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 how to do multidigit addition by carrying to the next column.

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- 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.
- Simple 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 is 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.

In the 1960s, this traditional vision of schooling was critically analyzed by the Brazilian education theorist Paolo Freire, who metaphorically called it the "banking" concept of education – because knowledge is "deposited" in the learner's head like money in a bank account (Freire, 1968). Learning scientists often refer to this traditional pedagogy as *instructionism* following a similar critique of it by Seymour Papert, the pioneering constructionist theorist and the creator of the Logo programming language for children (Papert, 1993). Instructionism was designed to prepare students for the industrialized economy of the early twentieth century by ensuring they would become compliant and efficient workers (see Chapter 33, Conclusion). In 1900, about 95 percent of jobs were low-skilled and required workers to follow simple procedures that were designed by others. By 2020, in advanced economies, less than 10 percent of jobs were like this. Many working-class factory jobs have been taken over by computers and robots (Sawyer, 2019). A century ago, in a world without communication technology – without phones and the Internet – it was not easy to find someone else who knew the information you needed; you had to know it yourself. Memorizing information was a large part of being educated. With today's Internet, everything that can be memorized is a quick search away. Instructionism fails to educate students to participate in this new kind of society.

Economists and organizational theorists have reached a consensus that today we are living in a creative age, an economy which is built on knowledge work (Bereiter, 2002; Drucker, 1993). In the creative age, 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 to engage with diverse populations within their country and internationally. 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, life-long learning. They need to develop creativity, because uncreative tasks can be automated. As Freire (1968) put it, “knowledge emerges only through invention and re-invention, through the restless, impatient, continuing, hopeful inquiry men pursue in the world, with the world, and with each other” (p. 57). These abilities are important to the economy, to the continued success of participatory democracy, and to living a fulfilling, meaningful life (Partnership for 21st Century Skills, 2015; Sawyer, 2019; Trilling & Fadel, 2009).

Beginning in the 1980s, a new science of learning was born – based in research emerging from psychology, computer science, philosophy, sociology, and other scientific disciplines. As scientists closely studied children’s learning and adult learning, both inside and outside of school, they discovered that instructionism was deeply flawed. By the 1990s, after about twenty years of research, learning scientists had reached a consensus on the following basic facts about learning (Sawyer, 2019):

- **The importance of deeper conceptual understanding:** Expert knowledge includes facts and procedures, but simply acquiring those facts and procedures does not prepare a person to use that knowledge creatively. Factual and procedural knowledge is only useful when a person knows which situations to apply it in and how to modify it for each new situation. Instructionism results in a kind of learning that is 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.
- **Connected learning:** Each small piece of knowledge is linked to many others, in the same subject and also across disciplines, in a network of related knowledge. Scientific expertise is organized into complex bundles of knowledge, not a simple list of isolated facts (Sawyer, 2019; diSessa, Chapter 6 in this volume).
- **Focusing on learning in addition to teaching:** Students cannot learn deeper conceptual understanding simply from teachers instructing them better. Students can only learn this by actively participating in their own learning. The new science of learning focuses on student learning processes.
- **Designing 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. LS has identified the key features of those learning environments that help students learn deeper conceptual understanding, including adults, teachers, and a variety of tools and materials. The tools may be as simple as paper and pencil or as complex as augmented-reality goggles.
- **The importance of groups and contexts:** Students often learn more effectively when they participate in collaborative activities with peers and the teacher, with the teacher guiding an improvisational knowledge-building process

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(Scardamalia & Bereiter, Chapter 19 in this volume; Tabak & Reiser, Chapter 3 in this volume).

- **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 the test, and then revert back to their misconceptions outside of the classroom (Pellegrino, Chapter 12 in this volume).
- **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 are provided with opportunities to reflectively analyze their state of knowledge (Winne & Azevedo, Chapter 5 in this volume).

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 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 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).

Learning scientists take many different disciplinary approaches and use a variety of methodologies. But regardless of the approach, LS research is rigorous and scientific. Learning scientists gather data using rigorous methodologies that have been validated by a community of scholars. They analyze and interpret data using scientific argumentation and reasoning. They interpret research findings using theoretical frameworks that enable generalizations beyond the specific research site. Of course, a single research study can examine only a small phenomenon – one student, one learning outcome, one classroom, or one community. But when the study is published, the researchers describe how the findings from this one context can be generalized beyond that context to have relevance for the larger community of learning researchers. Studies are considered to be more influential and impactful when they are generalizable to a broader scope of learners, contexts, and learning outcomes. To the extent that findings are claimed to be generalizable, those general findings are expected to be reproducible in later studies. If the findings are not reproduced, the validity of the original study must be examined more closely, or the generalizability claims must be relaxed. Findings and interpretations are subject to continued examination and elaboration.

The findings reported in these chapters have been demonstrated to apply broadly across cultures, ethnicities, classes, and nations; both inside and outside of schools; and at all ages. There is no evidence that different students will

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 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.

benefit from different pedagogy as a result of different "learning styles" (Pashler, McDaniel, Rohrer, & Bjork, 2008). The existence of "learning styles" is a popular myth in the United States (not usually encountered outside the USA); the disproven claim is that each student has a unique and preferred style of learning and that specialized instruction should be provided to each student to match their learning style. Specifically, there is no evidence that some students might learn better from instructionism. Freire (1968) argued that those working toward social justice should reject instructionism: "The revolutionary society which practices banking education is either misguided or mistrusting of men . . .. Those truly committed to liberation must reject the banking concept in its entirety" (p. 64). All students benefit from pedagogy aligned with the research findings presented in this handbook – an active, participatory, constructivist pedagogy that Freire referred to as "problem-posing" education (p. 68), a model of inquiry-based learning that has been supported by decades of LS research.

The LS research community is extremely multicultural and multinational. Across the three editions of this handbook, chapter authors come from fifteen countries and four continents. The multicultural nature of LS – with research conducted and applied across countries with dramatic cultural variations, from the USA to Finland to Singapore – demonstrates how broadly applicable these findings are across nationalities and cultures. The 2014 second edition has been translated into Chinese and Japanese, countries with cultures dramatically different from those found in the USA and in Europe. The editors of these two translations report that these findings, even from research done in Western countries, apply to their diverse cultures. Dr. Jun Oshima, translator of the Japanese second edition, reports "the findings in the learning sciences are generalizable to Japanese culture, schools, and students" (personal communication). Dr. Xu Xiao-dong, translator of the Chinese second edition, writes:

> The results of the learning science research in this handbook established by researchers in countries with different cultures from China, such as the United States and Europe, have had a profound impact on the education and teaching of Chinese primary and secondary school students in the upper grades (ages from 8 to 18) and college students. It can be said that it has universal value for practice in these areas . . . not only learners of different age levels, but also learners of different cultural levels . . .. In China, compared with the ethnic difference, regional and cultural differences are very large . . . the learning principles and methodology established by learning scientists have universal value across culture and ethnicity. (personal communication)

The ability to learn at a high level from quality, research-based pedagogy is a common, shared feature of humanity. Professor Mark McDaniel, a coauthor of *Make It Stick: The Science of Successful Learning* (Brown, Roediger, & McDaniel, 2014), reports that "the scientific principles of learning almost certainly hold universally across cultural groups" (personal communication). John Dunlosky, coeditor of *The Cambridge Handbook of Cognition and Education* (Dunlosky & Rawson, 2019), notes that "There is substantial evidence that many findings in cognitive psychology and education are culturally universal. When non-Western cultures are studied, the findings are essentially identical to the findings from Western populations" (personal communication).

No studies have found that the research-based pedagogies in this handbook result in less effective learning with one or another cultural group, ethnicity, or nationality. All students learn better with these pedagogies. In addition, multiple studies of US students in STEM classes have found that LS-based pedagogies are more effective specifically with underrepresented minorities and reduce the achievement gap with their majority-culture peers (Haak, HilleRisLambers, Pitre, & Freeman, 2011; Theobald et al., 2020). Pedagogies based on LS research improve learning outcomes for all students and contribute to equitable outcomes for all students. Readers in all of the world's countries, regardless of ethnicity or cultural background, can benefit from the research presented in this handbook.

1.1 The Goals of Education and the Nature of Knowledge

In response to climate change, how can we reduce carbon emissions while at the same time bringing millions of people out of poverty, which is likely to increase their energy use? Should we allow genetically modified organisms to be planted in third-world countries where they are likely to reduce the millions of annual deaths caused by malnourishment and starvation? How should society determine whether to approve a vaccine against a deadly virus, when a handful of recipients seem to become sick after taking it, and yet if the vaccine is not approved, thousands more will die? Today's public debate about such controversial issues shows a glaring lack of knowledge about scientific practice. As a result, too often these issues are resolved through politics and uninformed opinion rather than scientific discourse.

By the early 1900s, major industrial countries had all 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 twentieth century, philosophers came to a consensus on the nature of scientific knowledge: scientific knowledge consisted of statements about the world and logical operations that could be applied to those statements. This consensus was known as *logical empiricism* (McGuire, 1992; Suppe, 1974). Logical empiricism combined with behaviorist psychology to provide a scientific basis for the traditional instructionist approach to education: scientific knowledge consisted of facts and procedures – that is, statements about the world and logical operations that could be applied to those statements – and teaching was thought of as transmitting the facts and procedures to students.

Beginning 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 (Scardamalia & Bereiter, Chapter 19 in this volume; Songer & Kali, Chapter 24 in this volume). Learning scientists often refer to these different conceptions of knowledge as different *epistemologies*. The practice of science involves experimentation, trial and error, hypothesis testing, debate and argumentation. Science involves frequent encounters with peers in the scientific community. Scientists evaluate other scientists' claims and think about how best to support and present their claims to others. Learning scientists refer to these different ways of using knowledge, acquiring knowledge, and applying knowledge as *epistemological practices*. In Table 1.1, the two columns describe two different epistemologies, two different conceptions of knowledge and learning.

In this new view, scientific knowledge is contextualized, it emerges from historically and socially determined professional activities, and it is collaboratively generated. 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. The traditional science classroom, with its lectures and step-by-step lab exercises, leaves out these elements of science. But this kind of knowledge would be extremely useful to the general public as they read reports of an experimental drug in the daily paper, as they discuss with their doctor the potential risks of an upcoming surgery, or as they evaluate the health risks of a proposed industrial development near their neighborhood.

Increasingly, cutting-edge work in the sciences is done at the boundaries of disciplines; for this reason, students need to learn deep and connected knowledge – the underlying models, mechanisms, and practices that apply across many scientific disciplines. It is almost impossible to learn this sort of deep understanding from the disconnected and isolated short-term 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 connections among these units.

This new view of scientific knowledge has been extended beyond science to other forms of expert 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 cooking while reading a recipe, searching the Internet to learn whether you should buy a particular product, or writing an email to a colleague (Smagorinsky & Mayer, Chapter 27 in this volume). The chapters in Part V, "Learning Disciplinary Knowledge," focus on the nature of deep knowledge in each discipline and on how LS findings can help students attain those learning outcomes.

One of the most important findings of LS 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 many countries. In history, for example, reforms call for learning history by doing historical inquiry rather than memorizing dates and sequences of events: working with primary data sources and using methods of historical analysis and argumentation that are used by historians (Carretero & Perez-Manjarrez, Chapter 26 in this volume; the US National Center for History in the Schools, 1996). In science, the US Next Generation Science Standards call for students to engage in the authentic practices of scientific inquiry: constructing explanations, preparing arguments, and communicating and justifying those explanations (Songer & Kali, Chapter 24 in this volume; National Research Council, 2012).

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 LS researchers to a *situativity* view of knowledge (Engeström, Chapter 7 in 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. This view takes us far away from thinking of learning as a solitary student memorizing facts while listening to a teacher or while reading a book in a library. In a situativity perspective, learners are always participating in social practices, and learning occurs when patterns of participation in collaborative activity change over time (Rogoff, 1990). This perspective has led LS to a focus on how children learn from collaboration (as discussed in the chapters in Part IV, "Learning Together").

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 LS research is to identify exactly what practices are appropriate for students to engage in and how learning environments can be designed that are age-appropriate without losing the authenticity of professional practice.

1.2 Processes Involved in Learning

LS studies the small details of what is going on in a learning environment and exactly how they contribute to improved student performance. The learning environment includes the people in the environment (teachers, learners, parents, peers, 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 do different learning environments contribute to learning, and can we improve the design of learning environments to enhance learning? How can cultural and community knowledge be enlisted to foster learning of students from diverse backgrounds (Nasir et al., Chapter 29 in this volume)? How can we design materials and activities that keep students motivated and sustain their engagement (Renninger & Järvelä, Chapter 30 in this volume)?

Some researchers work on specific components of the learning environment – software design, the roles that teachers play, or the specific activities each student performs. Chapter 2 refers to this type of research as *elemental* because it examines the separate elements of the learning system (Nathan & Sawyer, Chapter 2 in this volume). Other researchers 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 classroom culture where learners support each other? How can we ensure that the social practices of the classroom are aligned with the community-based *repertoires of practice* (Nasir et al., Chapter 29 in this volume) that different groups of children bring to the classroom? Chapter 2 refers to this type of research as *systemic*. Learning scientists conduct research at both the elemental and the systemic level of analysis, sometimes in the same research project.

The following research topics are discussed in many of the handbook chapters, but especially in the chapters in Part I, "Foundations."

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

One of the legacies of early cognitive science research was its close studies of knowledge work. During the 1970s and 1980s, artificial intelligence (AI) researchers began to interview and observe experts with the goal of replicating that expert's knowledge in a computer program. Before it is possible to simulate expertise in a program, the researcher has to describe in elaborate detail the exact nature of the knowledge underlying that expertise. When AI researchers became interested in education, they had to consider a new twist: How do experts acquire their expertise? What are the mental stages that learners go through as they move from novice to expert? This question was the purview of cognitive development research, a group of researchers that combined developmental psychology and cognitive psychology. Cognitive development has been an important foundation for LS, including the influential theories of twentieth-century psychologists like Lev Vygotsky and Jean Piaget (Nathan & Sawyer, Chapter 2 in this volume). These researchers 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 6 in this volume).

1.2.2 How Does Learning Happen: Using Prior Knowledge

One of the most important discoveries guiding LS is that learning always takes place against a backdrop of existing knowledge. 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. But 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 (diSessa, Chapter 6 in this volume). 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 critical to reforming schooling so that it is based on LS.

1.2.3 Promoting Better Learning: Scaffolding

LS is based in a foundation of constructivism (Kafai, 2006). LS has convincingly demonstrated that when children actively participate in constructing their own knowledge, they gain deeper understanding, more generalizable knowledge, and greater motivation. LS research has resulted in specific findings about what support must be provided by the learning environment in order for learners to effectively construct their own knowledge.

To describe the supports that promote deep learning, learning scientists use the term *scaffolding* (Tabak & Reiser, Chapter 3 in this volume). Scaffolding is support given to a learner that is tailored to that learner's needs in achieving their goals of the moment. The best scaffolding provides this support in a way that helps children discover the answer on their own. Telling a child how to do something, or doing it for them, may help them get the correct answer, but it is not good scaffolding because the child does not actively participate in constructing that knowledge. 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.

1.2.4 Promoting Better Learning: Externalization and Articulation

LS has discovered that when learners externalize and articulate their developing knowledge, they learn more effectively (Collins & Kapur, Chapter 8 in this volume; Nasir et al., Chapter 29 in this volume). 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.

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 LS (see Engeström, Chapter 7 in this volume; Nathan & Sawyer, Chapter 2 in this volume). Vygotsky's explanation for the educational value of articulation is based in a theory of mental development that is both social and psychological: he argued that all knowledge begins as visible social interaction and then is gradually internalized by the learner to form new thoughts and concepts. The exact nature of this internalization process has been widely debated among learning scientists; but regardless of the specifics of one or another explanation, most learning scientists believe that collaboration and conversation contribute to learning because they allow learners to benefit from the power of articulation.

One of the most important topics of LS is how to support students in this ongoing process of articulation. Learning scientists have discovered that

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articulation is more effective if it is scaffolded – channeled so that certain kinds of knowledge are articulated in ways that are most likely to result in useful reflection (Tabak & Reiser, Chapter 3 in this volume). Students need help in articulating their developing understandings; they do not yet know how to think about thinking or how to talk about thinking. The chapters in Part IV, "Learning Together," describe several examples of learning environments that scaffold effective learning interactions.

1.2.5 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 at the same time that you are learning (Winne & Azevedo, Chapter 5 in this volume). Learning scientists have repeatedly demonstrated the importance of reflection in learning for deeper understanding. Classrooms designed on LS principles 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.

1.2.6 Promoting Better Learning: Building from Concrete to Abstract Knowledge

One of the most well-known findings of developmental psychologist Jean Piaget is that the natural progression of learning starts with more concrete information that gradually becomes more abstract. For example, Piaget's influence in schools during the 1960s and 1970s led to the widespread use of "manipulatives," blocks and colored bars to be used in math classrooms. Not every important abstract idea that we teach in schools can be represented using colored blocks, but the sophistication of computer graphics allows even abstract concepts to be represented in a visible form.

LS has taken Piaget's original insight and has developed computer software to visually represent a wide range of types of knowledge. Even very abstract disciplinary practices have been represented visually in the computer; the structure of scientific argument can be represented (Andriessen & Baker, Chapter 21 in this volume) and the step-by-step process of scientific inquiry can be represented. One of the central benefits of museum learning, for example in interactive science museums, is the presence of physical exhibits that foster inquiry and exploration (Pierroux, Knutson, & Crowley, Chapter 22 in this volume).

In the process of making the abstract concrete, well-designed software can scaffold students in the articulation of rather abstract conceptual knowledge. Their articulation can be visual or graphic rather than simply verbal. In many cases visual and spatial understandings precede verbal understandings and can be used to build verbal understanding.

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1.3 Sociocultural Studies

After the burst of activity associated with 1970s AI and cognitive psychology, by the 1980s many of these scholars had begun to realize that their goal – to understand and simulate human intelligence in the computer – was still very far off. The 1980s disillusionment with AI was so severe that it was informally known as "the AI winter." Researchers began to step back and think about why the cognitive sciences had not been more successful. The most influential answer was provided by a group of interrelated approaches including the *sociocultural*, *situative*, and *distributed cognition* approaches (Engeström, Chapter 7 in this volume; Nasir et al., Chapter 29 in this volume). Socioculturalists began with the observation that all intelligent behavior was realized in a complex environment – a human-created environment filled with tools and machines, but also a deeply social environment with collaborators and partners. Early sociocultural research unfolded in roughly four strands of scholarship, each analyzing learning outside of formal schooling. The first examined socialization – how children learn the norms and conventions of their culture, or the valued social practices of their community. A second strand of research focused on informal apprenticeship learning in non-Western societies without formal schooling (diSessa, Chapter 6 in this volume; also see Cole, 1996; Lave, 1988; Rogoff, 1990; Saxe, 1991). A third strand examined the socially distributed nature of knowledge work – including studies of navy ship navigation (Hutchins, 1995), of London Underground control rooms (Heath & Luff, 1991), of office systems (Suchman, 1987), and of air traffic control centers (Hughes, Shapiro, Sharrock, Anderson, & Gibbons, 1988). A fourth strand studied learning in museums and science centers (Pierroux et al., Chapter 22 in this volume). Learning in all four of these settings generally includes multiple individuals in complex role relationships different from the authoritarian structure of the classroom. In these environments learning is hard to understand if one thinks of it as a mental process occurring within the head of an isolated learner (Nasir et al., Chapter 29 in this volume).

These four influences led LS to expand beyond a purely cognitive focus on individual learning to also study learning in groups and contexts (Yoon & Hmelo-Silver, 2017). This is why LS research takes place at two distinct levels of analysis: the individual, or elemental, level, and the sociocultural, or systemic, level (Nathan & Sawyer, Chapter 2 in this volume). The chapters in Part IV of this handbook, "Learning Together," focus on how groups and social interaction contribute to learning, but many other chapters also include studies of groups and contexts. The inclusion of both individual and sociocultural perspectives is a hallmark of research in computer-supported collaborative learning (CSCL), a field that emerged in the 1980s and 1990s to study the new collaboration and communication tools enabled by the Internet (Stahl, Koschmann, & Suthers, Chapter 20 in this volume). As Stahl and Hesse (2006) put it in the 2006 inaugural editorial of the *International Journal of Computer*

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Supported Collaborative Learning, "We need theories of collaborative interaction that are not necessarily based on individual learning models .... We need methodologies that capture both micro-level interactions in small groups and community-level developments as mediated by social practices" (p. 4).

Efforts to study cognition and culture together resulted in innovative methodologies that allow the researcher to study *situated social practices* – visible social and interactional patterns that combine people, cultural practices, and material tools. Esmonde (2017) noted that this line of research studies how learning "is distributed across the people, artifacts, and social relations in a given context" (p. 13). The focus on situated social practice allows the researcher to consider both individual and culture at the same time without separating the two theoretically or methodologically.

Like the findings of cognitive psychology, the findings of sociocultural research also have broad applicability to learning across countries, societies, and cultures. In Chapter 29, "Learning as a Cultural Process," Nasir et al. report that LS findings contribute to our understanding of how learning interacts with culture, noting the applicability across cultural contexts of LS research on informal learning (Pierroux et al., Chapter 22 in this volume), scaffolding (Tabak & Reiser, Chapter 3 in this volume), and making knowledge visible (Collins & Kapur, Chapter 8 in this volume). And yet, although the processes of learning are universal, the content of learning varies by culture and a learner's preexisting cultural knowledge impacts their learning trajectory. A fascinating example is reported in Nasir et al. (Chapter 29 in this volume), suggesting how LS research on argumentation (Andriessen & Baker, Chapter 21 in this volume) can help to explain a culturally situated argumentation practice in Haiti known as *bay odyans* (p. 436) even though this practice is very different from a Western "scientific" style of argumentation. When this discourse practice was enlisted in a science classroom, it supported the learning of biology and physics among Haitian-American youth. As a second example, LS research showing the importance of articulation in metacognition implies that learning is more effective when the classroom scaffolding of articulation is aligned with the discourse practices that students use in their communities (Nasir et al., Chapter 29 in this volume, in Question 3, "structuring occasions for meta-level analysis," pp. 587–588). Because different cultures may have quite different discourse practices, equitable learning environments should be designed not to favor any one set of cultural practices.

People always learn in social and cultural contexts, and explanations at both the cognitive and the sociocultural levels of analysis can enhance our full understanding of learning (Nathan & Sawyer, Chapter 2 in this volume). One of the historical reasons that learning scientists began to expand their study beyond the individual level of analysis is that they study all contexts where learning occurs – not only in schools, but also with friends, families, and communities. In these learning environments, "learning should be studied as it occurs in everyday life" (Esmonde, 2017, p. 10).

1.4 Social Justice and the Learning Sciences

In most of the world's countries there are structural features of schooling that result in inequitable learning outcomes across different social groups – whether ethnic, religious, racial, or socioeconomic class. In schools that bring together students from different classes and cultural groups, many school subjects are taught in ways that result in less effective learning for students from non-dominant groups. The LS foundation in sociocultural frameworks has made it a receptive home for scholars studying how schooling reproduces social inequity and how pedagogy can be reformed to further social justice and equity. LS research can help to explain the mechanisms whereby learning environments result in inequitable learning experiences for members of different groups. The cultural knowledge associated with one's home culture is often referred to as "repertoires" or "funds" of knowledge (Nasir et al., Chapter 29 in this volume). LS studies of situated social practice have found that when a student's repertoires of knowledge are not recognized and enlisted in school practices, students of that culture will learn less effectively than students whose funds of knowledge are aligned with the culture of the school. As Vossoughi and Gutiérrez (2017) write, unequal social conditions are reproduced by "devaluing the cultural practices of historically marginalized groups, thereby predicating academic success on cultural assimilation" (p. 142).

LS has been contributing its research to further goals of social justice for many years. A first major contribution was in 2014, when the *Journal of the Learning Sciences* published a special issue titled "Social Justice Research in the Learning Sciences" (Tabak & Radinsky, 2014). Also in 2014, the International Conference of the Learning Sciences (ICLS) annual conference hosted a symposium that later resulted in the 2017 book *Power and Privilege in the Learning Sciences: Critical and Sociocultural Theories of Learning* (Esmonde & Booker, 2017b). In 2017, the annual learning sciences conference (CSCL 2017) had as its theme "Making a Difference: Prioritizing Equity and Access in CSCL." In 2020, shortly before the publication of this third edition, the International Society of the Learning Sciences created the "Equity and Justice Committee." As committee cochair Kris Gutiérrez explained, there is "a long history of learning sciences research on culture, identity, and social relations" (Gutiérrez, 2020). Of the many fields that study teaching and learning, "the learning sciences is uniquely positioned" to analyze interactions between learning and power, equity, and social justice, because of LS's long-established sociocultural foundation. The sociocultural tradition in LS "offers promise to integrate a critical understanding of power with an analysis of learning" (Esmonde & Booker, 2017a, p. 2). In 2020, just before this third edition was published, the *Handbook of the Cultural Foundations of Learning* (Nasir, Lee, Pea, & de Royston, 2020) appeared; two of the editors are among the coauthors of Chapter 29.

These important developments indicate that scholars who study inequities in educational opportunity are finding value in a deeper understanding of the science of how people learn. LS is necessary to design classrooms and schools in ways that foster inclusion and equity. As summarized at the beginning of this chapter, research shows that LS findings apply equally to all nationalities and cultural groups, and that when LS-based pedagogies are used, they reduce the achievement gap between privileged and nonprivileged students. We can no longer justify providing inferior education – instructionist, scripted, and authoritarian – to marginalized or nondominant groups on the grounds that they are not able to learn from the research-based pedagogy presented in this handbook.

1.5 Educational Technology

LS research often involves computer technology in some way. The chapters in Part III, "Grounding Technology in the Learning Sciences," each focus on technologies with great promise to enhance student learning. These chapters describe cutting-edge innovations that have been developed by learning scientists for research use and that are not yet available for widespread use in schools. These are "proof of concept" prototypes that demonstrate the potential of LS findings for the future of educational technology in schools. The interest in the potential of computer technology to benefit learning extends back to the founding of the field in the late 1980s and 1990s. In the 1991 first issue of the *Journal of the Learning Sciences* (*JLS*), the inaugural editorial anticipated articles on AI and computational models (Kolodner, 1991), and a substantial proportion of the articles that have been published in *JLS* since then involve learning environments that include computer hardware or software. In a 2014 survey of 253 LS researchers, Yoon and Hmelo-Silver (2017) asked them to list their areas of interest, and about two-thirds of them listed "learning technologies" as one of their areas – the single most-listed area of interest. In a 2018 analysis of the concepts being taught in seventy-five LS graduate programs internationally, 76 percent of the programs taught "Using technology to support learning," which was the most widely taught concept (Sommerhoff et al., 2018, pp. 333–334).

Learning scientists have found that computers only benefit learning when they take into account what we know about how children learn, and when they are designed to be closely integrated with teacher and student interactions in the classroom. Educational software has too often been based on instructionist theories, with the computer performing roles that are traditionally performed by the teacher – with the software acting as an expert authority, delivering information to the learner. Automated assessments – whether grading of multiple-choice tests, or AI text-recognition to grade brief one-sentence answers – likewise focus on the superficial learning of instructionism; it has been incredibly difficult to automate assessments of deep learning. In contrast, LS suggests that the computer should take on more of a facilitating role, helping learners have the kind of experiences that

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lead to deep learning – for example, helping them to collaborate or to externalize and reflect on their developing knowledge.

Many of the chapters in this handbook describe the next generation of educational software and technology – solidly based on the sciences of learning and designed in close collaboration with teachers and schools. Computers are only used as part of overall classroom reform and only where research shows they will have the most impact. Computer technology is central in LS because the visual and processing power of today's computers supports deep learning:

- Computers can represent abstract knowledge in concrete form.
- Computer tools can allow learners to articulate and reflect on their developing knowledge in a visual and verbal way.
- Computers can allow learners to manipulate and revise their developing knowledge in a complex process of design that supports simultaneous articulation, reflection, and learning.
- Internet-based networks of learners can share and combine their developing understandings and benefit from the power of collaborative learning.

Over half of these chapters discuss technology but none of them are about technology alone; the chapters situate technology in complex learning environment designs and LS theory. For example, the chapter on augmented reality (AR) – which is new with this third edition – begins by introducing the technical features of this exciting new technology (Schneider & Radu, Chapter 17 in this volume). But this chapter also provides examples of how AR can be integrated within complex learning environments and how AR can help us think differently about learning beyond just that one technology. The chapters situate technology within new teaching strategies, alternative ways of bringing students together in collaborating groups, and new forms of curriculum that cross traditional grades and disciplines.

In Chapter 33, the conclusion chapter, I discuss the trajectory of technological innovation over the period from the 1991 founding of the field to the publication of this third edition and what LS research suggests about the future of schooling.

1.6 Methodologies

Learning scientists ask questions like: How can we measure learning? How can we determine which learning environments work best? How can we analyze a learning environment, identify the innovations that work well, and separate out those features that need additional improvement? In other words, how can we marshal all of our scientific knowledge to design the most effective learning environments? These questions are fundamental to scientific research in education (Shavelson & Towne, 2002). The chapters in Part II, "Methodologies," each describe a scientific methodology that has been widely

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used in LS research. Several of these methodologies were developed primarily by learning scientists and are closely associated with research in LS.

In education research, one common methodology is the *experimental design*, in which students are randomly assigned to different learning environments. Many education studies are also quasi-experimental – rather than randomly assigning students to environments, the researcher identifies two existing classrooms that are similar on most variables but different on the one variable being studied. For example, two otherwise similar classrooms may use two different teaching methods, and the researcher can analyze which classroom's students learn more and better (Shavelson & Towne, 2002). Experimental and quasi-experimental designs can provide educators and policy makers with important information about the relative merits of different approaches. But they cannot tell us very much about why or how a teaching method is working – the minute-by-minute structure of the classroom activity that leads to student learning. If we could study those classroom processes, we would be in a much better position to improve teaching methods by continually revising them.

The chapters in this book use a diversity of methodologies: experimental comparisons of classrooms, experiments in cognitive psychology laboratories, studies of social interaction using the methodologies of sociology and anthropology, and a new hybrid methodology known as *design-based research* (Barab, Chapter 9 in this volume). In a 2014 survey of 253 learning scientists, only about 20 said they used exclusively quantitative methods, which include experimental designs. The rest said they used either exclusively qualitative methods or a mixture of both. The chapters in this handbook generally emphasize qualitative methodologies, but also hybrid approaches that blend quantitative and qualitative methods.

Learning scientists have discovered that deep learning is more likely to occur in complex social and technological environments. To study learning in rich social and technological environments, learning scientists have drawn on ethnography (from anthropology), ethnomethodology and conversation analysis (from sociology), and sociocultural psychology (from both anthropology and developmental psychology). Anthropological methods have been influential since the 1980s, when ethnographers began to document exactly how learning takes place within the everyday activities of a community (Hutchins, 1995; Lave, 1988; Scribner & Cole, 1973; Suchman, 1987).

Many learning scientists study the moment-to-moment processes of learning, typically by gathering large amounts of videotape data, and they use a range of methodologies to analyze these videotapes back in the laboratory – a set of methodologies known as *interaction analysis* (Enyedy & Stevens, Chapter 10 in this volume). Interaction analysis is used to identify the moment-to-moment unfolding of three things simultaneously: (1) the relations among learners, their patterns of interaction, and how they change over time; (2) the practices engaged in by the learners – individual and group procedures for solving problems, and how they change over time; and (3) individual learning.

Learning scientists usually study individual learning along with the first two kinds of change.

These qualitative methodologies are time-consuming and it is impractical to repeat such studies in multiple classrooms. But deep knowledge cannot be learned in one class session, so learning scientists use other methodologies to study longer-term learning over the entire school year and even from grade to grade (Nathan & Sawyer, Chapter 2 in this volume, pp. 43–44). During the course of a research study, learning scientists continually shift their focus closer and then farther back, studying the microgenetics of one classroom (Sherin & Chinn, Chapter 11 in this volume) and then analyzing how that class session contributes to the longer-term development of deeper conceptual understanding.

LS research is complex and difficult. A typical LS project takes a minimum of a year as researchers work closely with teachers and schools to modify the learning environment, allow time for the modification to take effect, and observe how learning emerges over time. Some projects follow learners and teachers for several years as that teacher introduces new activities and software tools to each successive class. After the years of observation are complete, the hard work continues, because the researchers have a huge amount of video data – in some cases hundreds of hours – that needs to be closely watched multiple times. A subset of the videos may be transcribed for even more detailed analyses that may include quantitative coding and statistical analysis.

1.7 The Emergence of the Field of Learning Sciences

In the 1980s, many research centers, institutes, and universities in the United States were drawing on cognitive psychology and AI to design software that could promote better learning (e.g., Bobrow & Collins, 1975; Sleeman & Brown, 1982). Roy Pea recounted the following history of LS in the United States in *Reflections on the Learning Sciences* (Pea, 2016; also see Hoadley, 2018): In 1987, John Seely Brown and James Greeno were cofounders, along with David Kearns, CEO of Xerox, Corp., of the Institute for Research on Learning (IRL) in Palo Alto, California. At about the same time, Vanderbilt University's Center for Learning and Technology (Nashville, Tennessee) was applying cognitive science to develop technology-based curriculum, and Seymour Papert's Logo group at the Massachusetts Institute of Technology (MIT: Cambridge, Massachusetts) was building constructivist learning environments on the computer. There were several other research groups, and each took a different approach: Bank Street (New York) and BBN (Boston, Massachusetts) focused a bit more on technology; IRL and Xerox PARC focused a bit more on sociocultural context; Pittsburgh's Learning Research & Development Center focused more on human development; Schank's Institute for Learning Sciences at Northwestern (Chicago, Illinois) focused on corporate training systems (Pea, 2016).

During this period, these various researchers came together to start the Artificial Intelligence in Education (AIED) conferences that are still held today. In 1987, Northwestern University (Chicago) decided to make a major commitment to this emerging field, and hired the prominent cognitive scientist Roger Schank from Yale University to lead what became known as the Institute of the Learning Sciences (ILS). In Summer 1989, Roger Schank, Allan Collins, and Andrew Ortony began to discuss the idea of founding a new journal that would focus on applying the cognitive sciences to learning. Janet Kolodner was chosen as the editor of this new journal, and the first issue of the *Journal of the Learning Sciences* was published in January 1991. In 1991, Roy Pea created the first LS doctoral program at Northwestern University, with a focus on "Cognition, Computing, and Context" (Pea, 2016, p. 53). LS doctoral programs grew in number through the 1990s (Packer & Maddox, 2016). Also in 1991, the AI and Education conference was held at Northwestern University, and Schank renamed it the International Conference of the Learning Sciences (Birnbaum, 1991). But the newly formed LS community and the AI and Education community found that they had somewhat different interests, and the AI in Education annual conference reverted to its name in 1992. The second LS conference was held in 1996, this time independently of AIED. In 2002, the ISLS was founded to bring together both LS and the field of CSCL.

After the ISLS formed in 2002, it sponsored separate conferences for each of its two research communities: the International Conference of the Learning Sciences (ICLS) conference (in even years) and the CSCL conference (in odd years). Twenty years later, in 2021, the two conferences joined to become a single unified ISLS annual conference, albeit with two distinct strands for the two fields. This inaugural joint conference was hosted in Bochum, Germany and was held virtually due to the danger posed by the highly communicable Covid-19 virus.

The ISLS sponsors two official journals, one representing each of these historical strands: the *Journal of the Learning Sciences*, founded in 1991, and the *International Journal of Computer-Supported Collaborative Learning*, founded in 2006. Although the above origin story for LS is centered in the United States, these two affiliated research areas have been increasingly international since these early years: In 1997, the CSCL conference was first held outside the USA, in Toronto, Canada, and in 2008, the ICLS conference was first held outside the USA, in Utrecht, The Netherlands. Since 2008, the annual conference has met in different countries each year, with every other year hosted in the USA. The 2006 first issue of the *International Journal of Computer-Supported Collaborative Learning* had contributions from scholars in Brazil, Canada, China, Denmark, Germany, Sweden, the United Kingdom, and the United States (Stahl & Hesse, 2006).

This is a rich history for a field that is only thirty years old. For newcomers to the field – many of the readers of this book – thirty years may seem like a long time ago. But compare this to other social science disciplines such as sociology, anthropology, and psychology, which began to form in the nineteenth century.

LS today is a fully formed academic discipline, and that is a sign of how rapidly it has grown and how productive its scholars have been in the past thirty years.

1.8 Conclusion

The schools of the future must be based in LS research. Too often have educational reforms been driven by social fads or political beliefs that are disconnected from LS. Whereas politics makes things seem simple, science reveals their true complexity. The scientific findings from LS research are rich, complex, deep, and numerous. This handbook is 746 pages and it could have been much longer – each chapter author had to work hard to identify the few core ideas and the most representative case studies from among hundreds of scientific publications on the topic.

The strength of LS is that it provides us with an understanding of the deep and complex questions at the foundation of education. Learning scientists are engaged in the hard work that has to be done before any educational reform or innovation can be successful. Whether in an expensive private school or a free public one; whether online or face-to-face; whether students communicate through the Internet or by shouting to each other in a forest school; LS provides the explanations for how learning takes place and provides recommendations for how to design those environments to result in more effective learning. Success for all students depends on the continuing advancement of the learning sciences and the dissemination and implementation of its findings. The research in this handbook can change lives.

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