Teaching and technology: New tools for new times

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Introduction

The purpose of education in society is widely debated, but a common theme is that education must prepare students for the world they will enter after they leave school. Reasonable people may differ on the best ways to teach students, on the content of the curriculum, and on the eventual roles for which students are being prepared. One thing, however, is clear: the world and society have shifted in radical ways during the past few decades. The 21st century presents a landscape shaped by technology that places new demands on schooling, no matter what position one takes on education's ultimate purpose. This has broad implications for teachers and the work of teaching, both in terms of what it means to teach and how one teaches.

We present this chapter as an attempt to shift the discussion about technology for teaching away from questions about whether or not any particular technology is "good" for teaching and learning or "better than" some alternative approach, and instead towards a consideration of how and under what conditions technology can be productively employed by teachers to more effectively meet the challenges presented by a rapidly evolving world. We therefore focus on technology as a tool for educational transformation, and we present our discussion of technologies and teaching in terms of the adaptations, opportunities, and challenges that new technologies present to and for teaching and teachers.

Technology as a Tool for Teaching

One way to understand the perspective taken in this chapter is to contrast the views of those who perceive technology as a self-contained innovation meant to improve educational outcomes with those who see technology as a catalyst that is effective only when used to enable learning with richer content, more powerful pedagogy, more valid assessments, and links between in- and out-of-classroom learning. We view this as a dichotomy between using technology to *do conventional things better* versus using technology to *do better things* (Roschelle, Pea, Hoadley, Gordin, & Means, 2000). While there is value in *doing things better* (i.e., more efficiently and effectively), we believe that the deeper value in technology for teaching lies in rethinking the enterprise of schooling in ways that unlock powerful learning opportunities and make better use of the resources present in the 21st century world. *Doing better things* includes preparing students to be more responsive to the opportunities and challenges of a global, knowledge-based, innovation-centered civilization.

In framing this chapter, we do not examine the affordances and effects of technology in and of itself. Instead, we present evidence for the emergence of a possible next-generation educational model with new roles and responsibilities for teachers, and examine evidence of the myriad ways technology can help teachers succeed, if we think about technology in the context of an ecology of learning environments.

Definition of Technology

Defining the term “technology” presents the first challenge for this chapter. A broad definition of the term is “the application of scientific knowledge for practical purposes” (*New Oxford American Dictionary*, 2010). In common usage within education, “technology” has become equated with computers and other digital devices, even though it would be proper to think of nearly every aspect of the modern school as a form of technology. Indeed, at one time the lecture, the book, pencils and paper, and even the organization of the school day were innovations that challenged existing practices in education and offered new possibilities for the structured delivery of knowledge and information. Cuban’s (1986) historical examination of teaching and technology demonstrates how successive waves of new media in the 20th century –

film, radio, television, computers – followed similar patterns in terms of their development, advocacy, adoption or rejection or maladaptation, and eventual incorporation.

To constrain the scope of this chapter, we use the term “technology” to refer primarily to digital technologies. However, we work to avoid a techno-centric approach that views new technologies as “solutions to problems,” and instead take a socio-technical approach that views the products of technology use as emerging from interactions among social and organizational structures, people, and tools. A techno-centric perspective, for example, would ask whether the introduction of a technology such as digital whiteboards or “clicker” response systems help students learn more effectively. A socio-technical approach asks in what ways the pedagogical approach and technology infrastructure interact such that digital displays and student response systems produce educational outcomes that are different than conventional instruction, and furthermore, what pedagogical approaches best leverage the affordances of these technologies.

With a socio-technical perspective as a backdrop, we explore the implications of computing platforms and devices – as well as digital tools, media, and environments – for teachers and teaching. By computing platforms and devices, we refer to the rapid rise of 1:1 computing, such as through laptop computing initiatives, and also the ascent of mobile and personal technologies such as cellular phones and tablets. By software, we refer to broad categories of tools such as discussion and collaboration environments, intelligent tutors, instructional games and simulations, and media that support students as creators. This combination of platforms (hardware, software, and networks) for computing has been referred to as *cyberinfrastructure*, and this in turn creates a supportive infrastructure for *cyberlearning*. This term is defined by the National Science Foundation as “learning that is mediated by networked computing and communications technologies” (NSF Task Force on Cyberlearning, 2008, p. 10).

Cyberlearning builds on ideas developed in high-end computational research in science and industry, where the collaborative, integrative, and distributed nature of new technologies has revolutionized the way research is conducted, allowing for new types of organizations to emerge. In this chapter, we examine a range of software tools for teaching and learning, and consider how they afford forms of teaching and learning that go beyond what is achievable without them.

We consciously exclude some types of technologies from consideration in this chapter, for both conceptual reasons and issues of space. We do not, for example, consider the broad range of presentational tools such as PowerPoint or digital/electronic white boards. Though such technologies have become widespread in education, they are not typically used in ways that are intended to be transformational, and their adoption presents little in the way of challenges for teachers who wish to automate established ways of teaching and learning (apart from purely technical issues like technology support, which are difficult organizational issues for schools, but not of sufficient scholarly interest for consideration in a *Handbook of Research on Teaching*). We also do not address technologies that have the potential to be transformative, but which are best addressed in conjunction with considerations of subject-matter or domain-specific scholarship. An example is digital tools for written composition, which have had a marked effect on the teaching of writing (e.g., Newell et al., 2011; Owston, Murphy, & Wideman, 1992). Other examples are the use of graphing calculators to teach mathematics (e.g., Doerr & Zangor, 2000; Ruthven, 1996) or probeware for teaching science (Krajcik, Blumenfeld, Marx, & Soloway, 2000). Such technologies have been transformative in their respective disciplines, helping give learners access to more advanced ways of reasoning with data and participating in the broader practices of the discipline. But because those topics are more logically discussed in the various

Handbook chapters on teaching within a particular field of knowledge, we limit our focus in this chapter to domain-general technologies that have the potential for impact across the curriculum.

Organization of This Chapter

In the next section of this chapter, “Goals Achievable by Investing in Technology Infrastructure/Integration,” we present an argument about how the world has changed and, as a result, what new goals for education are required to prepare students for life and work in the 21st century. We consider in particular how a more extensive investment in technologies for teaching and learning could help teachers achieve those goals, including better addressing the changing nature of learners, re-conceptualizing assessments, and re-thinking learning as an activity that connects various aspects of students’ lives, rather than as fragmented experiences that isolate learning by subject area and portions of the day or year. We also consider teachers as learners in this section, and address the many ways that new developments in technology can support teachers’ own transformations of practice.

Following this, in the section titled “Evidence Supporting the Transformative Use of Various Technologies,” we introduce two key framing mechanisms for understanding technology and teaching in specific socio-technical contexts. The framing mechanisms include: 1) a way of thinking about technologies as part of environments with minimal, intermediate, and extensive levels of technology infrastructure and integration; and 2) core principles of learning and pedagogical theory for organizing learning environments as articulated by the *How People Learn* (Bransford, Brown, & Cocking, 2000) and *How Students Learn* (Donovan & Bransford, 2005) U.S. National Research Council reports. We then present an extended consideration of types of technologies that have the potential for transformative impact on teaching and learning.

These include: collaboration tools, online and hybrid instructional environments, tools that support students as programmers and creators, immersive interfaces, and games and simulations.

In the subsequent section,“The Evolving Research Agenda for Teaching with Technology,” we examine past controversies in the study of technology and learning, along with the various research approaches that have been employed to both develop and better understand technology for learning. We present an overview of several core methodologies and their potential for leading to more transformative learning environments. We also introduce key areas for further research and development towards the extensive integration of technology for transformative teaching and learning. We conclude with recommendations for a way forward in designing, implementing, and studying teaching with technology.

Goals Achievable by Investing in Technology Infrastructure/Integration

Preparing Students for Life and Work in the 21st Century

This chapter takes a strong position on the changing nature of the world and the way(s) that education must change to better address these changes. Civilization has changed in radical ways during the past few decades, and dramatic shifts are likely to continue for much of the 21st century, so the past is not a good guide to the future. The world today presents a landscape deeply shaped by technologies – transportation, communications, and computing – that place new demands on schooling to prepare today's students with knowledge and skills not necessary for prior generations. This challenge has profound implications for teachers and the work of teaching, both in terms of what it means to teach and how one teaches.

Through examining the various mechanisms by which technology can play a significant role in the work of teaching going forward, we seek to move beyond the debate about whether technology is a good investment in helping conventional instruction and traditional schooling. Instead of attempting to answer that question, we take an approach similar to the 2010 National Educational Technology Plan (NETP; U.S. Department of Education, 2010), in that we do not examine the affordances and effects of technology as an educational innovation for industrial-era schooling. Instead, we argue for the emergence of an alternative, next-generation educational model with new roles and responsibilities for teachers, and we present evidence of the myriad ways the technologies we have described could help teachers succeed in this evolving environment.

As such, this chapter takes a broad view of the context(s) for teaching, particularly in light of 21st century changes and challenges in formal education. "Next generation" models are characterized by moving beyond place-based, time-based learning; by involving many types of people as “teachers” in various life-settings of students; by focusing teaching on participatory, collaborative, guided learning; by infusing deep content rapidly updated as knowledge evolves; and by centering learning on the needs and interests of individual students rather than on a curricular framework or an instructional method (U.S. Department of Education, 2010). Why is such a next-generation model important in preparing students for a productive role in work, citizenship, and life over the next few decades?

Globalization and Financial Constraints

As Thomas Friedman persuasively argued in *The World is Flat: A Brief History of the Twenty-first Century* (Friedman, 2005), information and computing technologies, combined with increasingly fluid global transportation and communication infrastructures, have led to a leveling of the international economic playing field. In a “flat” world, it is possible for companies and other organizations to orchestrate manufacturing, support, and even complex knowledge-based work over great distances and across national boundaries.

As argued in the U.S. National Research Council (NRC) reports *Rising above the Gathering Storm* and *Rising above the Gathering Storm, Revisited: Rapidly Approaching Category 5* (National Research Council, 2007, 2010b), these changes create seismic shifts in economic opportunities both for individuals and for nations. In response, the NRC panel that authored these reports called for an aggressive program of educational improvement, particularly in the “STEM” areas (science, technology, engineering and mathematics). The NRC reports assert both that we need more qualified STEM educators and that the nature of how we prepare these educators and the materials we prepare them to use (e.g., curriculum, technologies) must change.

By considering how teacher preparation programs should respond to the demands of this situation, Darling-Hammond and Bransford's (2007) volume, *Preparing Teachers for a Changing World*, complements the NRC's *Gathering Storm* reports and Friedman's *World is Flat* descriptions of changes and challenges in the global economy. The recommendations in *Preparing Teachers for a Changing World* include a focus not only on current knowledge about how people learn and develop, but also on knowledge of the diverse contexts in which the content of education will eventually be put to use by students. Responding directly to the educational challenges raised by Friedman, Darling-Hammond, in *The Flat World and Education: How America's Commitment to Equity Will Determine Our Future* (Darling-Hammond, 2009), identified a set of skills that schools need to help students develop. These include: the ability to collaborate and communicate effectively in many forms; the ability to identify and locate information, then transform that information into new knowledge and ideas; the ability to identify problems and develop novel solution paths; and the ability to manage one's own work for continuous improvement. We return to these ideas below in a consideration of 21st century skills; we note here that many of the skills identified by Darling-Hammond intrinsically incorporate technology, as is apparent in life and work today (National Research Council, 2012). Therefore, if teachers are to be successful in supporting students' learning of these skills, technology must be both an object of education and a tool for education.

Shifts in the Division of Labor in Society and in the Classroom

At the same time that education leaders are grappling with the implications of a global shift to a knowledge-based, innovation-centered economy, financial challenges brought about by the global economic slowdown of the early 21st century are shaping national policies for education and will likely do so into the indefinite future. Western nations, including European countries and the United States, have been challenged by structural changes in their economies, brought about in part by the shift of many jobs to the developing world. These fiscal woes have contributed to diminishing national, regional, and local funding for educational systems.

In response to a continuing call for education to "do more with less," policy makers and education leaders are turning to technology. The NETP highlights multiple dimensions on which schools can employ technology to "improve learning outcomes while making more efficient use of time, money, and staff" (U.S. Department of Education, 2010, p. 63). These include both productivity gains through more efficient use of data and cost accounting practices (which we do not discuss in this chapter), and the potential reorganization of teaching and learning itself. The alternative model of education advocated in the NETP would involve shifting from the traditional, industrially derived process of dividing credit-based content delivery into standardized units of time to instead adopting a life-long and life-wide model of learning certified by competency rather than seat-time (Banks et al., 2006). The technologies we discussed earlier are central to accomplishing this shift, with accompanying opportunities and challenges for teachers learning to educate with and about new media.

The changes brought about by both globalization and pressures on education to reduce costs and improve outcomes mirror the challenges created by a widespread shift over the past century in the "division of labor" between machines and workers (Levy & Murnane, 2004). The parable of John Henry vs. the steam engine comes to mind, in which John Henry's job, which was to hammer rock so that train tracks could be laid, was challenged by an emerging technology: the steam-powered hammer. John Henry bested the steam hammer in a contest, but only to die from his exertions, a Pyrrhic victory. John Henry may have won the battle, but the steam hammer won the war, and thereafter allowed the work of railroad construction to move faster and with less human effort; a shift in the division of labor between man and machine.

Recently, in many types of work, advances in digital technologies have driven these shifts, as new types of tools have taken over the tasks people used to do. Sometimes, human roles are eliminated in this process; but more often, especially in work that involves expert decision making and complex communication, people are able to accomplish more through "distributing cognition" (Salomon, 1993) across both tools and groups of collaborators. As an illustration of recent shifts in the division of labor for a service sector professional role, Hannan and Brooks (2012) documented changes in the health professions driven by information technology. They delineate reasons why traditional clinical decision-making solely by physicians is becoming unsustainable. Technologies provide a means of enabling distributed decision making and new divisions of labor. In addition, digital technologies are one of the drivers changing the context within which work is conducted (e.g., the shift from a national industrial economy to a global, knowledge-based, innovation-centered economy). Overall, these shifts together are generating new models of how and where work is done and what roles people play.

The concept of a shift in how labor is divided is a useful lens for examining how job roles are changing in teaching. In the specific case of instruction, digital technologies can potentially alter the division of labor for teachers. For example, digitized pedagogical agents, peer mentors using social media, and informal educators remotely coordinating learning activities can accomplish some aspects of instruction, enabling teachers to extend and deepen their own activities by building on these complementary supports. In its simplest form, the division of labor at the classroom level involves teachers deciding which parts of a lesson's instruction to accomplish with technology, including when to be "in control," and when to allow systems such as *Cognitive Tutors* (Corbett, Koedinger, & Hadley, 2001) to guide student learning with little necessary intervention by the teacher. This allows teachers to direct their attention towards the students who need it the most, while enabling more proficient students to continue making progress on their own. In the context of current discussions of online learning, such as the *Khan Academy* (Thompson, 2011), people talk of “flipping the classroom,” in which students watch brief lectures in the form of digital video outside of school, so that in-classroom time can be spent in various forms of active learning rather than passive assimilation. This is a different division of labor than is usually found in today’s classroom.

As the desired learning outcomes from instruction become deeper and more sweeping (e.g., all students prepared for careers or college and for citizenship in 21st century society), teachers can go beyond simple visions of instruction to instead orchestrate digital supports that enable life-wide learning not limited to the place and time of the classroom. Thus, an ambitious version of the new division of educational labor via digital technologies creates profound shifts in what teachers do, who/what supports their instruction, what outcomes are accomplished—and how teachers themselves can unlearn their old job role and master an altered profession. This shift in the role of teachers is central to a new, next-generation model of education to replace our current model of schooling based on twentieth century, industrial era technologies, which displaced the nineteenth century, agricultural era one-room schoolhouse a century ago (Collins & Halverson, 2009).

These shifts in the division of labor also apply to the computational tools used for education. Historically, “educational technologies” have been expensive capital goods owned and managed by organizations, such as (what were once) costly mainframe and desktop computers. Increasingly, the falling cost of technologies has enabled a shift from institutional to personal technologies. This trend began with “home” computers, and has continued with “one-to-one” programs that provide a laptop or tablet computer for each student in classroom, school, or even school system. This is a radical move away from previous ways schools organized computing technology, which was typically in self-contained “computer labs.” Such arrangements of technology were useful for maintaining and securing computers in a central location, and also provided a boon for administrators who sought a showcase for progressive technology in their school buildings (Cuban, 2001).

Unfortunately, self-contained computer labs also made it less likely that the technology would become integrated into everyday teaching activities, as teachers had to physically re-locate their classes to take advantage of the new tools and were forced to compete for access to scarce resources. Advocates of one-to-one programs tout the potential for the computers to be used flexibly and universally across the curriculum, and evaluations of these programs illustrated this in practice (Lehmann & Livingston, 2011; Penuel, 2006a). Maine has a state-wide one-to-one program, as does Fairfax County, Virginia, and there are many other instances of schools giving technology directly to students so that it can be used across the curriculum. These shifts have implications not only for the provision of and management of technology, but also for teachers and students, in terms of when technology is available and how it may be integrated with teaching and learning activities. One-to-one technology opens many new opportunities for teachers to “do better things” with the support of technology, but only if they possess the knowledge and skills to do so, and only if curriculum materials, assessment frameworks, and other key components of instruction are aligned to support new practices.

21st Century Skills in the Knowledge-based, Innovation-Centered Economy

In a global, knowledge-based, innovation-centered economy, the changing context for education leads to shifts in the content of education. A report from the Computing Research Association, *New Technology-based Models of Postsecondary Learning: Conceptual Frameworks and Research Agendas*, describes the shift in types of knowledge and skills students need for the 21st century:

- *Moving from thinking about expertise as something an expert "knows" and can articulate, to a complex mix of tacit (i.e., non-conscious) and conscious competencies:* This evolution has major consequences both in how we identify critical competencies that experts exhibit, and in how we design instruction to reach those competencies. Simply asking experts to "teach" whatever comes to mind, whether in an online format available to millions or in their own classrooms, is not enough to efficiently bring many students to expert performance levels.
- *Moving from knowledge and skills localized in a student's mind to distributed understandings and performances*: Our understanding of expertise has expanded from something "stored in the head" and documented by its retrieval in sequestered testing to instead include a collection of elements accessible via technologies (such as mobile devices, search engines, and augmented reality) that enable finding necessary information rather than remembering it. Mastery involves decisions about when to make use of such resources as well as when these are not sufficient. Understanding how to apply distributed knowledge and skills in real world and novel contexts therefore requires demonstrations via sophisticated, authentic performances adapting to complex situations, rather than traditional rote recall of a small amount of what experts comprehend and do in routine situations.
- *Moving from a focus on memorizing and applying facts, simple concepts, and straightforward procedures to "higher level" conceptual and analytical capabilities deployed adaptively in diverse contexts:* By increasing the accessibility and affordability of experiences with higher level problem-solving, complex decision making, and learner-based experimentation and exploration, technology-based instruction and practice substantially increase opportunities for learners to focus their attention on the conceptual and analytical capabilities that underlie the deep understanding, retention, and transfer of learning needed to deal with life-long, real-world applications. These capabilities are key to the development of expertise and promotion of innovation that, in turn, lead to an expanding economy prepared to meet the many rapidly evolving science and technology challenges of the future.
- *Recognizing how, beyond the conceptual and procedural aspects of learner competencies that are often described as "cognitive," complementary aspects of*

> *learner competencies, so-called "non-cognitive factors," are instrumental to successful postsecondary learning, work, and citizenship.* Extensive research from social and developmental psychology has documented how learner orientations such as persistence/grit, engagement, "mindset" about intelligence (as either improvable through effort or as a non-malleable personal attribute), stereotype threat, and related constructs are consequential for learning.
> (Working Group on Postsecondary Learning, 2013, pp. 2–3)

The observations of the Computing Research Association report amplify and clarify similar observations made in the 2010 National Educational Technology Plan (U.S. Deparment of Education, 2010) in describing the demands of 21st century skills, and a statement of "key competencies" for education in a "flat world" issued by the European Union (European Parliament, n.d.). Most teachers are not prepared to develop these kinds of knowledge and skills in students. Yet the demands of a rapidly changing society call for such understandings and performances to become integrated across traditional content areas.

The 2012 National Research Council report, *Education for Life and Work*, presents a consensus view of 21st century skills (see Table 1). These skills are arrayed across cognitive, intrapersonal and interpersonal dimensions (National Research Council, 2012, pp. 12–13). Where current schooling focuses primarily on knowledge and skills in the "Cognitive Outcomes" dimension, 21st century schooling must also emphasize "Intrapersonal Outcomes" and "Interpersonal Outcomes" to best prepare students for the changing nature of work and citizenship.

Table 1: Dimensions of advanced knowledge and skills (read in columns, not across rows).

Cognitive Outcomes	***Intrapersonal Outcomes***	***Interpersonal Outcomes***
Cognitive processes and strategies	Intellectual Openness	Teamwork and Collaboration
Knowledge	Work Ethic and Conscientiousness	Leadership
Creativity	Positive Core Self-Evaluation	Communication
Critical Thinking	Metacognition	Responsibility
Information Literacy	Flexibility	Conflict Resolution
Reasoning	Initiative	
Innovation	Appreciation of Diversity	

Mastery involves both understanding how to apply advanced knowledge and skills in real world contexts—for which all three dimensions are important—and demonstrating proficiency via effective, authentic performances. What makes mastery even more complex is that much of the decision-making and task completion associated with a complex performance becomes tacit through repeated practice. Thus, what underlies proficiency is largely hidden from view, making it a complex task to describe it fully and accurately for training/learning (Working Group on Postsecondary Learning, 2013).

In part, the rising emphasis on 21st century skills is a recognition that the nature of problems in the world is changing, and that society requires problem-solvers who are prepared in new ways to attain different skills. The emphasis in school must shift from teaching what is already known ("learning about") towards teaching how to address "hard" problems, such as global climate change or the appropriate role of government in shaping individual life—topics that are currently not completely understood and that require interpretation among different points of view. This represents a fundamental and challenging shift for educators. Problem *solving*, applying standardized techniques to well understood challenges, is less and less central in modern work and citizenship. In contrast, problem *finding*, learning how to recognize when a situation presents a complex, sometimes tacit problem and knowing how to identify the resources and knowledge needed to resolve the problem, is increasingly important, but is a barely visible part of school curricula today.

Addressing "hard" problems requires an expansion in the contexts for learning. This may be a shift from self-contained classrooms, in which all required knowledge and resources can be located on a bookshelf (or even within a single textbook), towards learning environments that instead engage students with the broader world either directly or indirectly. Technology can provide resources that support such connections, whether using electronic communication tools to link learners to outside expertise, or by employing authentic simulations and virtual worlds that enable students to interact in richly complex environments (National Research Council, 2011b). Such environments are designed to engage students by helping them see the real-world utility of the knowledge and skills required to identify/resolve problems. Technology such as immersive media and simulations can facilitate transfer of learning for future application by presenting problems with greater complexity and context than is possible in traditional classroom teaching (Bransford & Schwartz, 1999).

Changes in Teacher Learning Required by Changing Contexts for Teaching

Implicit in the above discussion is that we must alter how we prepare teachers to be effective in this new environment and with new technologies. But little coordinated progress has occurred in this area. For example, in a broad review of teacher preparation to use technology, Pellegrino and colleagues lamented that:

> …There is no systematic evidence regarding the kinds of preparation that are needed, nor the best ways to provide such preparation. All that is agreed upon is that teachers' lack of knowledge of how to integrate technology for a positive impact on student learning will

> constrain the potential of electronic and multimedia technologies in K-12 education. (Pellegrino, Goldman, Bertenthal, & Lawless, 2007, p. 52)

This lack of coordination persists despite large U.S. federal investments in technology and teacher preparation, such as through the Preparing Tomorrow's Teachers to Use Technology (PT^3) program, as well as efforts from the private sector, such as the CEO Forum (CEO Forum on Education and Technology, 1999). In part, teacher preparation programs are caught between two worlds – preparing teachers for the classrooms they *will* enter as they begin their careers versus preparing teachers for the *evolving contexts* we describe above. This is indeed being between a rock and a hard place, as teacher preparation programs are already heavily taxed with a broad range of requirements for teacher certification. The changes required are philosophical, structural, and content-based (Pellegrino et al., 2007).

The entering attitudes and beliefs of pre-service teacher candidates make this challenge more difficult, as they appear to exercise a "school module" when thinking about technology. Keren-Kolb (2010) asked pre-service to list the technology they used in their everyday lives and the technology that would be in their idealized classroom environment, and found widely diverging lists. Social media, music and video sharing, and games dominated the pre-service teachers' personal technology world, while projectors and electronic whiteboards dominated their educational world. Lei (2009) found that even though "digital native" pre-service teachers had broad familiarity with technology, they had little knowledge or confidence in how to use these technologies with learners.

The situation is not better for in-service teachers with respect to how technology is conceptualized or used in practice. Though the field is coming to some consensus on the key elements of quality professional development for in-service teachers in terms of structure and content (Birman, Desimone, & Porter, 2000; Borko, Jacobs, & Koellner, 2010; Garet, Porter, Desimone, Birman, & Yoon, 2001), clarity is lacking on the role that technology should play in professional learning, including proven strategies for helping teachers become effective users of technology (Lawless & Pellegrino, 2007). As we have suggested throughout this chapter, the challenge is one that extends far beyond issues of “technology literacy” as it is typically defined (e.g., Information Technology Education Association, 2007). The challenge is to understand ways to support teachers’ learning how to integrate technology into learning environments at intermediate or extensive levels of integration, such that the technology supports them in enacting ambitious pedagogies that would not be easily achievable without the technology.

We also note that the issue at hand is not one of the technology *for* teacher professional learning, whether in-service or pre-service. In a broad review of research on online teacher professional development, Dede and colleagues observed that the researchers tended not to ask the right kinds of questions to help us understand the impact of online tools for professional development on student learning outcomes (Dede, Ketelhut, Whitehouse, & McCloskey, 2009). More recent research on online tools to support teacher learning finds, overall, no difference between online and face-to-face approaches (Fisher, Schumaker, Culbertson, & Deshler, 2010; Fishman, Konstantopoulos et al., 2013). The issue, as with much research on technology and learning, is with the questions being asked. The question should not be “Does technology help teachers learn,” but rather a design-oriented question focused on *how* technology can best be utilized to help teachers learn (Dede et al., 2009; see the section on “The Evolving Research Agenda for Teaching with Technology” for further discussion of this issue).

The 2010 NETP (U.S. Department of Education, 2010), though it does not propose a straightforward plan or path to address these shortcomings in research, offers a different vision of teaching as one of its primary themes. While teaching has long been characterized as an isolated or isolating activity, the central assertion of the NETP is that, to meet the demands of teaching in an interconnected world, isolation is no longer possible and may represent poor practice. The NETP describes the new role of teaching as “connected teaching,” and depicts teachers at the center of a network that begins in their own classroom and extends outward to include the surrounding school, community, and broader world of connected resources. Far from relying solely on their own resources behind closed classroom doors, effective teachers in a networked world manage connections between themselves and their students, from student to student, to parents, to other teachers and youth development workers inside and outside the school, and far flung data, resources, and experts.

Teachers and educational systems must also alter their practices as the nature of the students they serve changes. As global populations shift and migrate, in part to follow work opportunities, the language and cultural diversity of classrooms shifts commensurately (Darling-Hammond, 2009). This presents classroom teachers with a much more challenging environment in which to teach. Diane Ravitch (2010) argues that U.S. educational performance is actually equal to or better than it ever has been, so long as one holds “learners” constant. But the fact is that students in the U.S. school system come from a more diverse set of circumstances and socio-economic levels than at any time in the history of the nation. Further, even when teachers and schools are able to prepare students to the level of quality demanded by current high-stakes tests, such evaluation metrics are inadequate with respect to the new demands placed by the changing 21st century context for teaching and learning. Further, changes in federal and state policy related to the “mainstreaming” of students with cognitive and physical disabilities has also led to an increase in both the diversity and numbers of students in classrooms with various learning challenges

Managing changing contexts, students, and resources calls for the development of teachers' skills in the areas of communication, coordination and collaboration. Such skills have always been important in teaching, but take on increased importance and new meanings in connected teaching. Connectedness extends to teacher professional learning as well, both for pre-service and in-service teachers. Conceptions of professional learning based in collaborative and ongoing networks are powerful and consistent with general thinking about effective professional development design (e.g., Borko et al., 2010; Putnam & Borko, 2000).

Evidence Supporting the Transformative Use of Various Technologies

In this section, we examine a range of different technologies in order to uncover their affordances for supporting transformative teaching and learning. The technologies we examine are:

- Collaboration tools, including Web 2.0 technologies and tools that support knowledge building;
- Online and hybrid educational environments, which are increasingly being used to broaden access to education, but also have the potential to shift the way we conceive of teaching and learning;
- Tools that support learners as makers and creators, and which have their deep roots in helping students learn to become programmers of computers (and not just users of them);
- Immersive interfaces that create virtual worlds to situate learning or augment the real-world with an overlay of computational information; and
- Games and simulations that are designed to enhance student motivation and engagement.

Each of these technologies presents both challenges to and opportunities for teaching. We review the research on how these tools are used in education, and how they might be used for maximum effect. We discuss affordances for teacher learning by many of these technologies, and we discuss affordances for assessment as well.

For each category of technology considered, we use two key framing mechanisms or lenses: One that considers the *level of technology infrastructure/integration* available to support teaching and learning, and a second that considers how *pedagogical and learning theories are organized* to support the use of technology to achieve various goals within systems or social contexts.

Levels of Technology Infrastructure and Integration

The transformative use of technology for teaching is possible only if 1) appropriate technology infrastructure is available to support instruction, and 2) teachers are able to choose and successfully enact pedagogical strategies that integrate this infrastructure into how they foster motivation and learning. The absence of sufficient technology to empower certain types of pedagogy precludes their usage, and decisions made by teachers that fail to realize the full capacity of available technology undercut its value. Thus, judgments about transformative (or "merely" effective) teaching with technology must be based both on what infrastructure is available and on what preparation and support teachers have received not only to activate its technical features, but also to transform their instruction to make effective use of those new capabilities.

We differentiate three levels of technology infrastructure/integration that help to describe the extent to which technologies are used to transform teaching and learning environments:

- *Level One – Minimal*. The "minimal" level of technology integration is the most common entry point, where classroom technologies are used primarily to increase interest or motivation, but in whole-group or large-group presentational styles of teaching. Technology at this level may be employed for classroom management, or to engage students who would be otherwise disengaged. Technology in these classrooms is often set up as a presentation station for the teacher. Many teachers working within this level of infrastructure do not fully integrate technology's capabilities, or take advantage of the affordances of the technologies available to them.

  As an example of level one integration, consider the aforementioned case of interactive whiteboards. In the early 2000s, the United Kingdom made a significant investment in interactive whiteboard technologies for use in secondary schools. A study of the impact of these technologies on pedagogy found that a large number of teachers used the whiteboards simply as large displays for presentation programs such as PowerPoint, and relatively few teachers used the whiteboards in ways that increased interactivity meaningfully beyond what could be achieved with other displays such as projectors (Glover & Miller, 2001).

- *Level Two – Intermediate*. The "intermediate" level of technology integration finds each student with their own device, or with adequate technologies for sharing between pairs of students or among small groups. Also, the school's and district's networks are configured so that access to useful resources is not blocked (i.e., filtering is done in a thoughtful manner). At this level, teachers have access to computing devices in their own classrooms, as opposed to separate computer labs, which can be hard to schedule, leading to technology infrequently becoming part of standard instructional practice (Fishman & Pinkard, 2001). Supported by technology, instruction may be differentiated for leaners at various skill levels, and formative evaluation data may be used to personalize instruction for learners over time. At the intermediate level of technology integration, collaborative tools and technologies begin to be most effective for teaching and learning. Many of the more advanced examples of technology for teaching in this chapter fall at the intermediate level.

An example of fully integrating such an infrastructure into instruction is the use of computer-based instructional environments that use artificial intelligence algorithms to track and monitor student learning, giving teachers an overview of student progress in a “dashboard” to help them monitor and guide instructional choices (Heffernan, Heffernan, Decoteau, & Militello, 2012). Another example is the growing use of laptop, tablet or other personal computing devices to create classroom learning environments where each learner has their own computing device and can use them to pursue individualized or group project work (Penuel, 2006b).

- *Level Three – Extensive*. The “extensive” level of technology integration is associated with uses of technology that both encompass learning within school and reach beyond the classroom in “life-wide” ways as depicted in the U.S. National Educational Technology Plan (U.S. Department of Education, 2010). As this level, which is not frequently observed in current practice, teachers are adept at orchestrating learning across a range of providers within and beyond the school, and customizing instructional conditions for learners. Collaborative learning approaches are maximally effective at this level, as is engagement and transfer of skills from school to life.

  Examples of extensive technology integration are rare, but emerging more frequently as networked technologies become ubiquitous and as schools slowly adapt to the rapidly changing world. Allan Collins and Rich Halverson (2009), in their book “*Rethinking Education in the Age of Technology,”* wrote of a range of emerging settings -- from online education to interest-driven “maker spaces” and online multiplayer games – where learners gather and self-organize in complex educational endeavors. Models of schooling that embrace these new venues for learning, as described prospectively in the “Connected Learning” report (Ito et al., 2013), will fall within the extensive level of technology integration.

Note that, in this framework, the level of technology integration is determined not only by what technology is installed or available in a teachers’ classroom, but also by whether and how the available technology infrastructure is used, which can be linked to the theory or conception of learning employed by the teacher or by the designer of the curriculum materials (Becker, Wong, & Ravitz, 1999). Overall, pedagogy and context are much stronger determinants of how technology is used than the aspects or affordances of the technology by itself (Cuban, Kirkpatrick, & Peck, 2001). As we consider different levels of technology integration with respect to a variety of learning approaches, a relationship emerges between a teacher’s perspective on learning, the level of integration that is likely to be pursued, and the potential effect on teaching and/or learning that is likely to result. As we discuss specific technologies in this chapter, we refer back to these levels of technology infrastructure and integration as a lens for understanding how transformative the use of the technology is likely to be for the nature of learning and teaching.

Learning and Pedagogical Theory: *How People Learn*

Levels of technology integration and infrastructure provide an important framing mechanism for our discussions in this chapter, but an even more important lens for understanding the potential contribution of technology to teaching and learning environments is learning theory and pedagogical theory. Our consideration of these theoretical perspectives on learning is shaped by the landmark *How People Learn* (Bransford et al., 2000) and *How Students Learn* (Donovan & Bransford, 2005) reports from the National Research Council. These reports provided an overview and summation of the most durable findings from multidisciplinary research on learning, presenting a convergent view with a corresponding practical translation into guidance for research and practice.

The *How Students Learn* report articulates three core learning principles, universal in their applicability across academic subjects:

- Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information, or they may learn them for purposes of a test but revert to their preconceptions outside the classroom.
- To develop competence in an area of inquiry, students must (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application.
- A "metacognitive" approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them. (Donovan & Bransford, 2005, pp. 1-2)

Based on these, *How Students Learn* (HSL) describes four key design lenses for framing teaching and learning environments:

- The *learner-centered* lens encourages attention to preconceptions, and begins instruction with what students think and know.
- The *knowledge-centered* lens focuses on what is to be taught, why it is taught, and what mastery looks like.
- The *assessment-centered* lens emphasizes the need to provide frequent opportunities to make students' thinking and learning visible as a guide for both the teacher and the student in learning and instruction.
- The *community-centered* lens encourages a culture of questioning, respect, and risk taking. Community-centered design is depicted as an overarching lens to frame interaction within which the other three design lenses are actualized. (Donovan & Bransford, 2005, p. 13)

The chapters and case studies of HSL describe particular strategies for teaching in specific subject areas (history, math and science) that draw on these four design lenses. These are examples of pedagogical content knowledge (PCK; Shulman, 1986), or strategies for teaching that capitalize on specific features of the knowledge or skill to be learned. For example, in the chapter on guided inquiry in the high school science classroom, Minstrell and Krause (2005) describe an instructional plan with multiple phases. The first phase involves eliciting students' initial ideas and preconceptions, primarily through diagnostic questions such as, "What would happen in this situation?" (learner-centered, assessment-centered, and community-centered). The second phase is conducting experiments that resolve the question of what happens (knowledge-centered), from which the teacher elicits hypotheses from the students about what is happening (assessment-centered and community-centered). Elaboration experiments then follow to test these hypotheses (knowledge-centered), and diagnostic questions are used to test each student's understanding at the end of the unit (assessment-centered). As this description illustrates, the four lenses are not successive stages, but rather ways of conceptualizing teaching and learning that serve to guide the series of instructional activities in a classroom. Much research in science education has focused on developing and testing pedagogical strategies that emphasize paradigmatic ways of thinking and acting “as a scientist,” and such thinking is at the core of recent revisions of science standards in the United States (Achieve, Inc., 2013).

Teachers who use technology can extend the ways in which their instruction is learner-centered, knowledge-centered, assessment-centered, and community-centered. We focus our discussion of specific technologies in this chapter on tools that extend teachers’ capabilities along each dimension in ways that are not easily attained without the use of technology, and summarize the extant research on challenges and opportunities for teachers with respect to each technology. In addition, we highlight ways that technologies for teaching, viewed through these lenses, increase teachers’ capacity to meet the demands of changing 21st century contexts for teaching.

We note that, with the exception of the chapters on science, the terms *motivation* and *engagement* are not featured in HSL. Particularly in middle school and high school, issues with motivation are a major factor in learning and retention (Pintrich & Schunk, 1995;Schunk & Zimmerman, 2007). Recognizing this, the *Handbook of Research on Learning and Instruction* includes a chapter on “learning with motivation” (Anderman & Dawson, 2011) and has more embedded discussions on ways to engage students. The issue of motivation is important in considering the use of technology in instruction, because claims have long been made that digital media engage students and increase their motivation (e.g., Warschauer, 1996). Yet many research findings over the past 30 years indicate that technology is a *catalyst* for powerful ways of motivating students by increasing their interest and self-efficacy through deeper content, more active learning, timely feedback, and interconnections between school and life, as opposed to the *reason* students feel more engaged (Clark, 1983, 1994). Indeed, technology can bore and disengage students if used simply to automate teaching-by-telling and learning-by-listening.

Throughout this chapter, we discuss how, when used effectively, technology can enhance both motivation and learning.

We also note that, though we do not explicitly discuss major theories of learning such as Behaviorism, Cognitivism or Constructivism in this chapter, such theories are always present as additional lenses for considering the functioning of learning environments, including learning environments where technology is used.

Collaboration Tools: Web 2.0 and Knowledge Building Pedagogies

Collaborative learning, the practice of having students work and learn jointly or from each other, is an oft-pursued pedagogical strategy that aligns well with 21st century conceptions of learning and perceptions of important skills for 21st century knowledge work. What is usually referred to as “collaborative learning” is actually a spectrum of activities and approaches. True collaboration can be difficult to establish, and what we might wish to call “collaboration” is often actually cooperation. As Roschelle and Teasley (1995) describe the difference, “Cooperation is accomplished by the division of labour [sp.] among participants, as an activity where each person is responsible for a portion of the problem solving…”, whereas collaborative learning involves the “… mutual engagement of participants in a coordinated effort to solve the problem together” (Roschelle & Teasley, 1995, p. 70) without resorting to merely dividing a task up among learners. Supporting real collaboration presents a range of challenges for teachers, such as fostering and managing student discourse, forming and supporting groups of learners working on different problems or parts of problems at differing paces, and designing activities to foster cognitive conflict for learners (Dillenbourg, Baker, Blaye, & O’Malley, 1995; Greiffenhagen, 2012), but also a wide variety of opportunities for advancing student learning. Much collaborative learning has learners engaged in various forms of problem-based learning (e.g., Koschmann, Kelson, Feltovich, & Barrows, 1996), working on a task that is challenging, often open-ended or without a pre-defined solution, and difficult for an individual to solve on his or her own. Collaborative learning leverages socio-cognitive approaches to learning from and in communities, and usually works best if the teacher adopts the perspective that cognition is distributed across learners and tools (Pea, 1993), and is a socially constructed process (Wertsch, 1985).

Educational researchers and designers have suggested a broad variety of technological supports for collaborative learning, which we examine in this section. This includes the use of tools to structure and support collaborative learning among students, the use of tools to help make collaborative connections across time and distance, and also the use of tools to collaboratively enhance teachers' own learning and development. These tools are part of learning environments intended to foster learner-centered approaches that foster the elicitation of student perspectives and preconceptions, and move towards community-centered approaches that emphasize knowledge spread across or distributed among learners. By making thinking explicit and public, Web 2.0 technologies can also foster assessment-centered pedagogical designs. In considering the relationship between teaching and technology to support collaboration, we explore research related to pedagogical approaches, including broad conceptions of collaborative learning and the particular approach known as "knowledge building" (Scardamalia & Bereiter, 2003). We also consider a range of technological tools with affordances tuned towards collaboration and interaction, sometimes called "Web 2.0" or social media tools, which have the potential to either implicitly or explicitly leverage collaborative and knowledge building pedagogies when employed in ways that align with the goals of 21st century learning.

As is the case with each of the technologies discussed in this chapter, the extent to which the affordances of technology intended to support collaborative learning are realized hinges on how such tools are employed in the classroom, which can be linked to the theory or conception of learning employed by the teacher or by the designer of the curriculum materials. As we consider different levels of technology infrastructure/integration with respect to collaborative learning approaches, a relationship emerges between a teacher's perspective on learning, the level of integration that is likely to be pursued, and the potential effect on teaching and/or learning that is likely to result. As Laurillard (2009) put it in her review of pedagogical challenges to the use of collaborative tools, the goal is to "ensure that pedagogy exploits the technology, and not vice versa" (p. 6).

An examination of the literature on how collaboration tools are employed in K-12 teaching reveals the most transformative uses of collaboration technologies are uses that work to support or create communities of learners, communities of practice, or knowledge building pedagogies (Dillenbourg et al., 1995; Laurillard, 2009); formulations that are well-aligned with "extensive" integration of technology. The implication from the literature is that uses of collaboration tools to support "minimal" and even "intermediate" levels of technology integration are less likely to contribute to teaching or learning in meaningful ways than are extensive levels of integration, because the minimal and intermediate levels of integration do not represent a meaningful shift in the pedagogy or learning activities. It should also be noted that collaborative learning may be viewed by some as inherently less "efficient" than more didactic pedagogies; this is a by-product in general of "constructionist" as opposed to "instructionist" pedagogies (Laurillard, 2009). In general, effective teaching requires a balance between direct instruction of what is already known and allowing students to discover knowledge for themselves (Bransford et al., 2000; Schwartz & Bransford, 1998).

The term “Web 2.0” was first introduced in 1999 by user experience designer Darcy DiNucci, in a trade magazine named (in retrospect, ironically) *Print*. Looking beyond a web that was essentially read-only, DiNucci predicted that, “The Web will be understood not as screenfuls [sp.] of text and graphics but as a transport mechanism, the ether through which interactivity happens” (p. 32). The term did not catch on until several years later, as the rise of “web services” started to catch on, enabled by what one columnist (Knorr, 2003) described as the rise of the web as a platform built on universal standards that enabled two-way communication and extensibility. The comparison of an interactive and multi-directional Web 2.0 to a unidirectional Web 1.0 is analogous to discussions of a transition in the role of the teacher from “sage on the stage” to “guide at the side,” or a transition from didactic instruction and presentational materials to interactive materials that invite participation from learners. The opportunities for interaction and collaboration created by Web 2.0 technologies also form the basis of the 2010 U.S. National Educational Technology Plan’s (NETP; U.S. Department of Education, 2010) emphasis on connected learning that engages in multi-directional teaching and learning across local and networked communities. Earlier iterations of the National Educational Technology Plan recognized the existence of these tools and of the potential for what is broadly known as “e-learning,” but did not yet make the connection to their potential to support radically different modes of interaction for learning (U.S. Department of Education, 2000, 2005). The shift in perspective among educational theorists with respect to collaboration technologies is similar to that in the broader society with respect to Web 2.0 tools: the tools existed for a long time before their potential was recognized by the broader society, though many innovators were experimenting from the early days.

As is frequently the case with the development of technologies for learning, research on collaborative learning and technology long predates the popularization of Web 2.0 terminology. This research is often described under the broad heading of Computer-Supported Collaborative Learning (CSCL; Koschmann, 2003). The first academic conference focused solely on technology and collaboration was the 1995 Conference on Computer Supported Collaborative Learning, and there is much work that preceded that gathering (Kienle & Wessner, 2006). Approaches that have been described under the paradigm of CSCL include Community of Learners (A. L. Brown & Campione, 1994), Communities of Practice (Wenger, 1998), and Problem-Based Learning (Koschmann et al., 1996; Koschmann, Myers, Feltovich, & Barrows, 1993).

Dillenbourg and colleagues (Dillenbourg et al., 1995) document a shift in research on collaboration from a focus on the learning or cognition of individuals within a group, during the 1970s and 1980s, towards a focus on how the group itself functions as a unit of analysis, and how group interactions can produce knowledge and understanding. This latter perspective is highly constructivist, sociocultural, and participatory (Wertsch, 1985) in its orientation. Descriptions of cognition as distributed across people and objects, including tools and technologies (Brown et al., 1994; Pea, 1993), provides a solid underpinning for the development of pedagogy and technology to support collaborative learning.

Though there are many different theories and tools that align with principles of collaborative learning, Knowledge Building (Scardamalia & Bereiter, 2003), is one of the most frequently cited, and has a long history of interwoven pedagogical design (Scardamalia &

Bereiter, 1991; Scardamalia, 2004; Zhang, Scardamalia, Reeve, & Messina, 2009) and technological design (Scardamalia, Bereiter, McLean, Swallow, & Woodruff, 1989; Scardamalia & Bereiter, 1993). Our intent is not to cast Knowledge Building as the “best” approach to collaborative learning. Rather, we focus on Knowledge Building because it is so widely cited and because its formulation builds so intentionally on the sociocultural theories of learning that underlie extensive integrations of technology and pedagogy to support 21st century conceptions of learning. For an explicit comparison of Knowledge Building to both project-based and problem-based approaches to collaborative learning, see Bereiter and Scardamalia (2003).

Early versions of software designed to support Knowledge Building were created by scholars at the Ontario Institute for Studies in Education (OISE) and called *Computer-Supported Intentional Learning Environments* (CSILE; Scardamalia et al., 1989); later iterations developed as the Internet became more prominent are called *Knowledge Forum* (Scardamalia & Bereiter, 2003). Scardamalia and Bereiter describe knowledge-building in contrast to other forms of collaborative learning in a way that frames it squarely in 21st century terms:

> Knowledge building provides an alternative that more directly addresses the need to educate people for a world in which knowledge creation and innovation are pervasive. Knowledge building may be defined as the production and continual improvement of ideas of value to a community, through means that increase the likelihood that what the community accomplishes will be greater than the sum of individual contributions and part of broader cultural efforts. Knowledge building, thus, goes on throughout a knowledge society and is not limited to education. As applied to education, however, the approach means engaging learners in the full process of knowledge creation from an early age. [Other forms of collaborative learning] focus on kinds of learning and activities that are expected to lead eventually to knowledge building rather than engagement directly in it. (Scardamalia & Bereiter, 2003, p. 1370)

CSILE and *Knowledge Forum* play a key role in structuring knowledge building pedagogy for learners, by providing “a shared workspace for knowledge building that enables a self-organizing system of interactions among participants and their ideas and helps to eliminate the need for externally designed organizers of work" (Scardamalia & Bereiter, 2003, p. 1372). As learners create material within the shared technological space, all information becomes raw material for further advances by other learners within the classroom, which leads to a "compounding effect" whereby each individual investment in group knowledge grows far beyond the value of the initial contribution on its own. Scardamalia and Bereiter (2003) describe the relationship between the technology for knowledge building and the knowledge that is built therein:

> In knowledge building, ideas are treated as real things, as objects of inquiry and improvement in their own right. Knowledge building environments enable ideas to get out into the world and onto a path of continual improvement. This means not only preserving them but making them available to the whole community in a form that allows them to be discussed, interconnected, revised, and superseded. Threaded discourse, which is the predominant Internet technology for idea exchange, has limited value for this purpose. Typically, ideas are lodged within conversational threads, contributions are un-modifiable, and there is no way of linking ideas in different threads or assimilating them into larger wholes. By contrast, *CSILE/Knowledge Forum*, a technology designed specifically to support knowledge building, has these required provisions and scaffolding supports for idea development, graphical means for viewing and reconstructing ideas from multiple perspectives, means of joining discourses across communities, and a variety of other functions that contribute to collaborative knowledge building. (pp. 1371-1372)

Measuring the impact of *CSILE/Knowledge Forum* or knowledge building pedagogy in general requires a broadening of the perspective one takes on assessment of learning. Dillenbourg and colleagues describe a shift in the study of learning in collaboration from a Piagetian or socio-cognitive perspective, which emphasizes "individual development in the context of social interaction" (Dillenbourg et al., 1995, p. 5) to a Vygotskian or socio-cultural perspective, which emphasizes the relationship "between social interaction and individual cognitive change" (p. 5). Knowledge building goes even further, emphasizing knowledge advancement as a community achievement, and emphasizing iterative "idea improvement" and the creation of "epistemic artifacts" that externalize knowledge as the goal of the learning enterprise (Scardamalia & Bereiter, 2006). *CSILE/Knowledge Forum* provides scaffolding to enable teachers and students to engage in knowledge building discourse, which, when properly implemented, effectively promotes progressively more coherent understandings of phenomena (e.g., Woodruff & Meyer, 1997).

We step back from a focus on *CSILE/Knowledge Forum* to broaden the discussion to include the much wider range of related Web 2.0 and other social media technologies that are better known and in broader use today, and which were not created explicitly for use in education or learning, as was the case with *CSILE*. In much popular usage, Web 2.0 is understood as the "social web," connecting people to each other and leading to a proliferation of self-published content. As is often the case with new technologies, greater comfort and expertise is attributed to younger generations, in this case so-called "digital natives." And while it is certainly true that contemporary youth appropriate social media technologies rapidly, there is also evidence that their uses of these media are primarily as amplifiers of their regular behaviors (Ito, et al., 2010). There is also evidence of a gap between how teachers think about and make use of these tools and the way(s) that students perceive their potential for use in the classroom (Purcell, Heaps, Buchanan, & Friedrich, 2013; Levin & Arafeh, 2002). There is even a gap between how teachers *themselves* use social media tools in their personal lives and how they consider their usesefulness in the classroom (Keren-Kolb, 2010). Social media and Web 2.0 technologies are an example of why it is important not merely to know how to *use* a tool, but to know *how to use it for teaching* (Mishra & Koehler, 2006).

Further, the tacit epistemologies that underlie social media differ dramatically from what the "Classical" perspective—the historic views of knowledge, expertise, and learning on which formal education is based (Dede, 2008). In the Classical perspective, "knowledge" consists of accurate interrelationships among facts, based on unbiased research that produces compelling evidence about systemic causes. For example, students learn that the shift in the color of the sky at various times of day is due to differential scattering of various wavelengths of light by gas molecules in Earth's atmosphere. In the Classical view of knowledge, there is only one correct, unambiguous interpretation of factual interrelationships. In Classical education, the content and skills that experts feel every person should know are presented as factual "truth" compiled in curriculum standards and assessed with high-stakes tests.

In contrast, the tacit epistemology of social media is that "knowledge" is collective agreement about a description that may combine facts with other dimensions of human experience, such as opinions, values, and spiritual beliefs. Expertise involves understanding disputes in detail and proposing syntheses that are widely accepted by the community. Possible warrants for expertise are wide-ranging and may draw on education, experience, rhetorical fluency, reputation, or perceived spiritual authority in articulating beliefs, values, and precepts. Teachers should help students understand the difference between these epistemologies and how knowledge is constructed via these contrasting approaches.

We consider several major variations of these social media tools, but focus primarily on research related to "wikis," which are editable web pages that can be structured to support much of the same functionality as *Knowledge Forum*. We briefly touch on blogs, which may be thought of as a personal publishing or journaling platform, in which one presents information and others may comment. *Twitter*, which has been described as a "micro-blogging" platform, again encourages primarily one-way sharing of information, packaged in extremely short 140-character "tweets" that are easy to consume and re-share. Social networking sites such as

Facebook combine various tools to encourage personal network-building and the sharing of information across that network.

Wiki software for the World Wide Web was first developed by computer scientist Ward Cunningham to enable any user to create and edit a web page using nothing but the web browser itself. The wiki concept as envisioned by Cunningham encouraged the involvement of the visitor in the ongoing creation of the site, in part by greatly lowering the requirements of editing (Leuf & Cunningham, 2001). Perhaps the most famous wiki is *Wikipedia*, the crowd-sourced online encyclopedia that quickly grew to contain more entries than any traditional print-based encyclopedia, and has been deemed as the equal to traditional encyclopedias such as *Britannica* in terms of accuracy (Giles, 2005). Wikis and other social media tools have become widely used in classroom teaching, and their use has had a range of impacts on the relationship between teachers, students, and content, depending on their level of integration with classroom instruction. The impact of wikis on learning appears to be related to the organization of teaching practice (Reich, Murnane, & Willett, 2012), or as we frame it, the level of technology integration. The very term wiki, derived from the Hawaiian language, means “informal” or “quick,” which is an indication of how one might view wikis in relation to classroom teaching: ever-changing, malleable enough to fit a range of different uses (Chang, Morales-Arroyo, Than, Tun, & Wang, 2010).

In what may be the only large-scale assessment of how wikis are used in K-12 teaching, Reich, Murnane, and Willett (2012) conducted a study to investigate the extent to which wikis are used to provide opportunities for students to develop 21st century skills (intermediate or extensive integration) as opposed to being used as simply a new medium for information transmission (minimal integration). Reich and colleagues examined a representative sample of education-related wikis hosted by the service PBworks.com from 2005-2008, and found that 40% were either “trial wikis” (teachers experimenting with wikis) or teacher resource-sharing sites, 34% were sites designed by teachers for content delivery to students, 25% of wikis represented individual student assignments or portfolios, and a mere 1% were collaborative student workspaces. They also found that “wikis created in schools serving more affluent populations have more opportunities for 21st century skill development than wikis created in schools serving less affluent populations” (Reich et al., 2012, pp. 12–13). This is both a reflection of the importance of the match between pedagogy and technology, and also a reflection of one of the ways that so-called “digital divide” issues continue to manifest themselves with Web 2.0 technologies, even after basic access issues are no longer as big a problem as they were in the 1990s, a phenomenon that has been called a “second digital divide” (Attewell, 2001).

Teachers, even those who are resistant to employing technology, may not be able to avoid wikis in a culture where Wikipedia is quickly becoming the first resource students (and professionals of all stripes) turn to when searching on a topic. Concerns raised about sites like Wikipedia often focus on the authoritativeness of the content, especially in comparison to resources that have long been seen as the gold standard, such as print encyclopedias. Educators point out that the most effective way to prepare students to understand the nature of factual information presented in wikis is to have them contribute to wikis, thus developing a better understanding of what a wiki is in relation to other primary sources (Kissling, 2011). This is consistent with Bain’s (2005) approach to helping students understand what lies behind an “authoritative” text by teaching students to think like historians, rather than merely trying to memorize the facts of history or treating text as received wisdom. An appreciation for sourcing, perspective, and authorship are key elements in understanding any information resource; and this way of thinking about authority translates well to the use of Web 2.0 in instruction.

Thus far we have described the value of wikis and Web 2.0 tools in general terms with respect to collaboration and knowledge building. But there is a growing body of research linking the potential value of these tools (again, depending on how they are employed in the context of broader classroom culture and pedagogy) to more common learning goals and objectives. For instance, students appear to put more effort into their writing and are more willing to both comment on peers' writing and take peers' comments into account in revision when working with a wiki or similar tools that share the affordances of wikis such as collaborative editing and commenting. This finding echoes earlier findings of students engaging in more thoughtful editing of their work when using word processing software as opposed to hand writing (e.g., Owston et al., 1992). The value of having "real world" audiences beyond the classroom can support students' development as argumentative writers (Berland & Reiser, 2011), something that is normally challenging and can be supported with technology in a variety of ways (for a review, see Newell et al., 2011).

Social and collaborative software tools such as wikis can play an important role in formative assessment, by creating continuous opportunities for teachers to provide feedback to learners, and for learners to provide feedback to each other, casting feedback as dialogue (Hatzipanagos & Warburton, 2009). Wikis have also been used as part of teacher education programs to teach *about* assessment, giving pre-service teachers a rubric construction task using a wiki, and also providing them with a rubric to assess the quality of the wiki-based work (Lai & Ng, 2011).

Several studies report increased student engagement when using Web 2.0 tools, evidenced in some cases by spontaneous participation in course-based discussions by students not currently enrolled in the course (Grant, 2009), and in many cases by activities that are normally conducted within the 40-minute class period playing out “24/7” (Hastie, Casey, & Tarter, 2010). These changes have clear implications for the temporality of teaching, allowing teachers to interact with their students well beyond the confines of typical classroom hours. This requires increased teacher commitment, so that students believe the teacher is attending to their activities, establishing a two-way accountability. Advantages can be found at all age levels within K-12. Wikis and other Web 2.0 tools can be used with elementary-aged learners to help develop the ability to take others’ perspectives and to engage in dialogue and interaction (Pifarré & Kleine Staarman, 2011; Woo, Chu, Ho, & Li, 2011).

<u>Challenges to Teaching with Web 2.0 Tools</u>

What is required of teachers if Web 2.0 tools, such as wikis, are to be employed to support the kinds of collaborative and knowledge-building pedagogies envisioned by learning technologies theorists such as Koschmann et al. (1993) and Scardamalia and Bereiter (1991)? One challenge to using wikis to their fullest potential lies in many teachers’ reliance on a “print paradigm” in teaching, which emphasizes the preservation and transmission of knowledge, with an accompanying emphasis on authority (Ferris & Wilder, 2006). Wikis, with their emphasis on collaborative construction, appeal more to secondary orality (Ong, 1982), which has an emphasis on both community-based and aggregative knowledge (Ferris & Wilder, 2006). As discussed earlier, these tools involve a different epistemology than “classic” knowledge development and assimilation, so teachers should help students understand the distinction. Whereas primary orality is rooted in the spoken culture, secondary orality depends upon literate culture, and posits that the way we use language in writing, which is both an outgrowth of community values and has the affordance of being (relatively) easy to cite and build upon, affects the way we talk more generally.

To fully leverage Web 2.0 tools, classroom culture must support practices of collaboration and commenting on each others' work, and also re-examine school-based norms around learning as a function of the collective instead of only of the individual (Grant, 2009). Teachers must support students in learning how to participate and collaborate; teachers act as facilitators, a new role that must be learned. The requirements of school-based assessment are frequently cited as a barrier to adopting collaborative practices such as those enabled by wikis, in particular challenges with evaluating individuals' contributions within collaborative spaces (Trentin, 2008). We note that this is a limitation of the policy environment surrounding education, not a negative attribute of the technology. The built-in ability to trace individual contributions within a wiki may provide a route around this barrier, but practices for assessment in this mode are not yet common practice for teachers.

In addition, there is the potential of using wikis to assess not just individual contributions, but participation and collective cognition as well (Grant, 2009), which are key 21st century skills. There are related issues with ownership of ideas and concerns about intellectual property, and so a classroom culture of sharing must be created (Wheeler, Yeomans, & Wheeler, 2008). Using Web 2.0 tools "restrictively," or at what we would depict as a minimal level of integration, without consideration of their affordances for collaboration, inhibits their value (Hutchison & Colwell, 2012). If the socio-cultural affordances of the use context are not carefully attended to, Web 2.0 tools may have some effect, but generally much less of an effect than when issues such as the socio-cultural setting for instruction, the nature of knowledge that is the focus of learning, and the way(s) that activities are set up, including the development of shared goals, are attended to (Joubert & Wishart, 2012; Larusson & Alterman, 2009).

Another challenge is how to establish or set up wikis and Web 2.0 tools for use in classrooms. Cress and Kimmerle have conducted several studies analyzing "the potential of wikis as tools for knowledge building" (2008, p. 106). Knowledge-building in a wiki can be viewed as a process of successive internalization and externalization of knowledge across what is already represented in the wiki and what one knows as an individual and can contribute to the information represented in the wiki. Reconciling knowledge across these two states requires a process of equilibration (Piaget, 1977), which "explains how people take in new information from their environment, then how they perceive and encode this information from outside and integrate it into their own knowledge" (Cress & Kimmerle, 2008, p. 112).

An experiment by Kimmerle and colleagues (Kimmerle, Moskaliuk, & Cress, 2011) that compared several different theory-based arrangements of wikis in instruction found that wikis are more valuable when wiki-based instruction is set up to trigger perceived cognitive conflict between existing knowledge and the knowledge in the wiki. This means that educators "need to find an adequate level of incongruity" between students' prior knowledge and the desired learning outcomes (p. 146) in designing the starting content for the wiki. An empty wiki (*tabula rasa*) provides no starting point, and a wiki that is complete (or appears complete), such as one might design in a primarily knowledge-transmission mode, may discourage participation. A medium-level of incongruity has been observed to be best for knowledge building (Moskaliuk, Kimmerle, & Cress, 2009). Educators also need to carefully design their learning goals to match the affordances of wikis.

> If the aim is merely to impart facts, then wikis are not necessarily the first choice. But if the goal is to discuss and integrate different aspects of one topic, or to develop mutual

> understanding of complex issues, a wiki seems to be an appropriate tool. (Kimmerle et al., 2011, p. 146)

It is important to recognize that learning how to successfully use wikis and other Web 2.0 tools at an intermediate or extensive level of integration is a process, and one in which learning how to learn in this new environment is shared across teachers and students. Though it may be difficult to get started in the transition to knowledge-building approaches, when teachers stick with the approach over time and multiple iterations, both their own and their students' levels of agency increase as the complexity of the shared network of information increases (Laferriere, Law, & Montané, 2012). As a mechanism for getting started, some have suggested that "scripting" initial collaborative interactions may help provide models for students (and for teachers) and lead to increases in the depth of students' conceptual connections and understanding (Tissenbaum, Lui, & Slotta, 2012), and approaches that involve a gradual transfer of responsibility for collective responsibility to students are found to be effective (Zhang et al., 2009).

There are cultural challenges to using Web 2.0 tools, both within classrooms and within different global societies. For instance, in Singapore, it is unusual for students to criticize peers publicly, and there is a broader cultural practice of "saving face" in social interaction. This makes wikis, with their public and collaborative revisions, difficult to employ and thus less valuable instructionally (Netzley & Rath, 2012).

> While in the West, students may be more accustomed to vocal debates on various topics, in much of Asia there is a certain resistance or reluctance in students using social media tools in the class. The difference at times is so pronounced that instructors have been forced to choose between minimizing the importance of technology and changing the way they teach with Web 2.0 tools. (Netzley & Rath, 2012, p. 104)

In considering challenges and constraints for implementing knowledge-building pedagogies in classrooms in Hong Kong, Chan (2011) noted that a chief difficulty lies in altering the “technical core” of education practice and policy. The general isolation of teachers and the possibly related tendency away from collaborative work between and among teachers, the epistemological views of students that are not congruent with knowledge building (and which are reinforced by the larger culture of testing), and a general lack of infrastructure for supporting or scaling the complex forms of practice called for in knowledge building pedagogy are all forces that work against the use of Web 2.0 tools at intermediate or extensive levels of integration with teaching. The more teachers’ organization of instruction is geared towards collaborative learning, the more students themselves viewed the activities in the wiki as valuable learning tools (Chang et al., 2010).

Web 2.0 tools are found to be most useful when employed to facilitate learners’ construction of knowledge, and when they are used to promote more active learning, such as media creation (de Winter, Winterbottom, & Wilson, 2010). Once ideas are represented externally on a wiki (for instance), it may become easier for learners to talk to each other about them. One teacher stated that students, “could discuss what they think they understand… [and] actually when they’re discussing with each other, sometimes they realise [sp.] there are parts they don’t understand” (de Winter et al., 2010, p. 263). Wikis can facilitate a shift from teacher-centered instruction to student-centered, constructivist learning. Students who created wikis in secondary social studies classrooms, for instance, showed greater content retention in a delayed test and also demonstrated greater understanding of cause and effect relationships (Heafner & Friedman, 2008; Matthew & Felvegi, 2009). The wiki also allows for differentiation and personalization, allowing for differential amounts of structure to meet different students’ needs. For instance, templates can be employed to guide students who need a lot of structure, while the nature of the wiki allows students who want to work outside the structure to make changes as they see fit. Even when using technology in a presentational mode (minimal integration), teachers found that it was better to allow students to explore the presentation on a mobile device as compared to a whiteboard, because it allows students to progress at their own pace (de Winter et al., 2010).

Web 2.0 Tools as a Form of New Literacy Practice

Another way to conceive of Web 2.0 tools is as an instantiation of "new literacies," which are viewed as important for both teachers and students to master as a part of 21st century competencies. As discussed earlier, these include a move from consumption of media to creation of media, including remixing, and can be characterized as play, performance, appropriation, judgment, networking, and negotiation (Ito et al., 2010; Jenkins, Clinton, Purushotma, Robison, & Weigel, 2006). "Tweeting," for example, has been described as a new literacy practice connecting to 21st century learning and communication (Greenhow & Gleason, 2012; Mills & Chandra, 2011). It has also been cast as an entry-level form of writing with a public audience for early writers (Kurtz, 2009), where students collectively work to compose and edit tweets about classroom news. The constraint of 140 characters forces students to be thoughtful about what they say and how they express themselves. This positions Web 2.0 tools such as wikis, blogs, *Facebook*, and *Twitter* in a role where they could be used both to introduce core competencies that have long been valued, and also as a bridge to new forms of competencies.

Lankshear and Knobel (2006) elaborated several principles that can be used to evaluate the pedagogical integration of technologies from a new literacies and sociocultural perspective:

- *The principle of efficacious learning:* …for learning to be efficacious it is necessary that what somebody learns *now* is connected in meaningful and motivating ways to mature or insider versions of … sets of social practices composed of particular ways of using language, acting, and interacting… (Lankshear & Knobel, 2006, p. 196).
- *The principle of integrated learning:* From a sociocultural perspective, learning is integrated to the extent that... [it] occurs *inside* a practice rather than at a distance. [And]

…social practices that go together...are learned in their *relationships* to one another (Lankshear & Knobel, 2006, pp. 196–197).

- *The principle of productive appropriation and extension in learning:* [Working] to reduce or ameliorate conflict between social identities during learning… …[I]f learners already know how to perform discursive roles and tasks that can legitimately be carried over into new discursive spaces, this can be used to advantage to enable learning and proficiency in a new area (Lankshear & Knobel, 2006, p. 198).
- *The principle of critical learning:* It is necessary to create spaces for developing and negotiating differing points of view on social practices, social identities, social institutions, and the like (Lankshear & Knobel, 2006, p. 199).

Finally, Sanden and Darragh (2011) ask the following six core questions in order to examine whether the use of the technology maximally addresses students' sociocultural and pedagogical needs (they pose these questions with respect to literacy instruction, but they could be more broadly applicable). They ask if the classroom use of the technology:

- Advances students' social, emotional, and identity development by giving students agency, ownership, and/or personal voice?
- Provides opportunities for collaborating and sharing information in local and/or global settings?
- Promotes critical literacy opportunities such as evaluating content and considering different points of view?
- Allows for the processing, managing, analyzing, and synthesizing of multiple streams of information?
- Aids in developing literacy strategies for managing different types of text in a variety of contexts?
- Values and utilizes students' cultures, experiences, and funds of knowledge? (Sanden & Darragh, 2011, p. 8)

Sanden and Darragh argue that, "wikis epitomize the potential for new technologies to create an environment in which learning is a collaborative journey" (2011, p. 18). However, the implication of the frameworks they discuss is that there is a continuum of pedagogical practice for employing wikis (or any technology), and if a teacher does not move far along that continuum, the value returned by using wikis (or any technology) will be greatly diminished.

Web 2.0 Technologies and Teacher Professional Learning

Aside from their use as instructional tools within classrooms, Web 2.0 tools are also proving to be valuable for ongoing teacher professional development and for engagement in professional communities. Putnam and Borko (2000), Schlager and colleagues, (e.g., Schlager & Fusco, 2004), Renninger and Shumar (2002) and others have long stressed the importance of participation in professional community or in communities of practice (Wenger, 1998) as a key component in ongoing professional growth. Building connections to other teachers was also featured in the 2010 U.S. National Educational Technology Plan as a core part of being a "connected teacher" (U.S. Department of Education, 2010). In the 21st century, a core part of being "connected" means both real-world and virtual community, often facilitated by such Web 2.0 tools as *Facebook*, *Twitter*, blogs, and wikis.

Examples of technology-facilitated teacher professional networks can be found in all subject areas and all grade levels. And such networks have deep roots, going back to e-mail based listservs that were designed to support teacher pre-service learning (Riel, 1990), to help graduating cohorts of new teachers keep in touch with each other as they entered the profession (McMahon, 1996), and to support the growth of shared networks of interest in disciplines such as mathematics, such as with the Math Forum (Renninger & Shumar, 2004) or science education with the LabNet project (Ruopp, Gal, Drayton, & Pfister, 1993). The examples we name here are a few of many that could potentially be listed. We highlight these few in particular because of their central and foundational nature, though the tools and technologies involved almost all pre-date, and in many ways pre-figure, the Web 2.0 era.

Modern examples built using tools like wikis and *Facebook* can be found in disciplines as diverse as music (Bauer, 2010) and history (Maloy, Poirier, Smith, & Edwards, 2010), where a wiki was employed to facilitate the interpretation of new history standards among a group of pre-service history teachers. In this work, teacher learning in history was facilitated by having pre-service teachers use a wiki to organize content related to state certification exams, creating a live resource that could continue to be built and shared, also helping to create community among pre-service teachers who used the wiki (Maloy et al., 2010). Wikis and other Web 2.0 tools can also be a resource for collaborative lesson planning in general, across both pre-service and experienced teachers (He & Hartley, 2010). This moves beyond simpler online lesson plan databases, allowing for collaborative editing and evolution of lesson plans.

A common complaint about teaching as a profession is isolation, and virtual community is one way to overcome physical isolation. Many studies have explored the development of teacher collaboration and even team-teaching at a distance as a way to help teachers overcome loneliness and isolation (Maltese & Naughter, 2010) or to share materials, perspectives, and practices (Sheehy, 2008). Teachers who participate in social networks such as *Facebook* (Ranieri, Manca, & Fini, 2012) can use them both to identify distributed professional communities and to help them assimilate into networks of practice (Roach & Beck, 2012). It has also been noted that virtual community works best when it can be connected back to local community. This is consistent with findings about teacher learning from professional development in general, which emphasize the importance of congruence (Penuel, Fishman, Gallagher, Korbak, & Lopez-Prado, 2009) or coherence (Desimone, Porter, Garet, Yoon, & Birman, 2002) between the messages of the professional development and challenges or initiatives in teachers' local schools. The same applies to online teacher community, as blending online and face-to-face communities appears to increase the effectiveness of the online communities (Hutchison & Colwell, 2012; Schlager & Fusco, 2004).

Blogging, and the use of *Twitter*, have also been found to provide an important outlet for teachers and a way for teachers to discover new information. *Twitter* in particular has emerged as a useful vehicle for teachers to "follow" other teachers who may post information about resources or other materials (Gerstein, 2011). Long-form blogging has been studied as a means to support professional identity development, such as by an urban middle school science teacher (Luehmann, 2008). That teacher's blog, which required a significant investment of time by the teacher, allowed for reflection on practice, and provided a forum for working through dilemmas. A key to the success of the blog was the use of a range of blogging "features," including hyperlinks to external resources, including other blogs, the solicitation of feedback on posts, and use of multiple media. Furthermore the teacher made use of a variety of writing genres, each with a different function. For instance, "blogging dialogues" were extended considerations of material posted in others' blogs, "shout outs" praised the contributions of other bloggers, serving a nurturing role in the community, and "rants" represented passionate position statements on issues important to the teacher, such as opposition to standardized testing. Knobel and Lankshear (2009) have described the use of wikis and blogs as a means of facilitating teacher learning in the literacy community in a manner similar to how a journal club functions.

Tools for Online and Hybrid Teaching and Learning

One of the most prominent changes in the context of conventional teaching in the past decade has been the rapid rise of education conducted in whole or in part over the Internet. Of course, the idea of teaching-at-a-distance predates the Internet and covers a range of correspondence approaches, but network technologies have accelerated the expansion of teaching where teachers and students are not always co-located. This new space for teaching has taken many forms and goes by many names: e-learning, Web-based instruction, online learning, virtual schooling, and so on. Most recently, Massively Open Online Courses, or MOOCs, have dominated the conversation about online learning in higher education, though with little focus on *teaching* as opposed to issues such as access (Bogost, 2012). In many cases, the tools and techniques of online education are used to supplement traditional face-to-face instruction, in which case the combination is termed blended or hybrid instruction. Many scholars and policy makers have offered definitions for the varieties of such instruction, such as the following description from Allen and Seaman of varieties within higher education (2006, p. 4) that could also delineate the range of online courses in K-12 education:

- Online: A course where most or all of the content is delivered online. Typically have no face-to-face meetings.
- Blended/hybrid: Course that blends online and face-to-face delivery. Substantial proportion of the content is delivered online, typically employs online discussions, and typically has some face-to-face meetings.
- Web-facilitated: a course that uses web-based technology to facilitate what is essentially a face-to-face course.

Recognizing the need to develop terminology that is more flexible with respect to the continually evolving nature of online tools and contexts in education, Staker and Horn (2012) propose four different classifications for online learning approaches:

- Rotation model: a program where students within a particular course rotate among different modalities for learning, one of which is online, and where others might include lecture, small-group work, group projects, or self-directed assignments such as worksheets. This is similar to the “station” model employed in many self-contained classrooms.
- Flex model: a program where content and instruction are primarily online, and which students move through in a manner that is fluid and customized to their individual needs and schedule. However, in this model the “teacher of record” is on-site to provide face-to-face support for learners, though the level of face-to-face support may vary.
- Self-blend model: a program where students choose to take one or more courses that are entirely online to supplement their traditional face-to-face courses.
- Enriched-virtual model: a whole-school online experience where students divide their time between learning online at-a-distance and attending a traditional face-to-face school as needed, perhaps for athletic or other team experiences, or for particular coursework.

To think about these distinctions in somewhat different terms, education has primarily been a same-place, same-time enterprise. Homework has been the primary means of having students work in different place at different times. But technology opens up new opportunities for working at different times in different places (asynchronously), or at the same time in different places (synchronously) through web- or audio/video-conferencing.

A meta-analysis of student learning outcomes from online instruction, conducted by SRI International for the U.S. Department of Education, further subdivided online learning by the kind of learning experience different models provide (Means, Toyama, Murphy, Bakia, & Jones, 2009). Their analysis identified three major dimensions within the design and delivery of online instruction: expository learning, active learning, and interactive learning. Expository instruction is primarily transmission-oriented, using lectures or other materials that are delivered to learners, with the sole or primary source of knowledge coming from the instructor. Active learning designs involve a more constructivist approach, with the learners building their understanding through manipulation of digital artifacts such as drills, simulations, or games. Finally, interactive learning designs involve learners interacting with and learning from each other through collaboration, knowledge building, or other highly interactive activities mediated by technology. Note that all three of these dimensions can also vary in terms of being synchronous or asynchronous. Each dimension and type of online educational design has different implications for the work of teaching in terms of both opportunities and challenges. It is also the case that traditional face-to-face classroom learning could be characterized in terms similar to those employed by Means et al. (2009). The issue is not medium, but mode of teaching and how online tools may afford (or not) different and more engaging pedagogical approaches.

The mere act of moving to teaching online does not automatically lead to a change in pedagogy. One of the most common critiques of MOOCs is that they replicate the lecture/recitation format of large university lectures, without considering how to support learners adequately (Bogost, 2012; Working Group on Postsecondary Learning, 2013). In terms of the "levels of technology integration" we employ in this chapter to distinguish among varying depths of technology use, one might assume that the minimal level of integration is automatically achieved with online teaching, in that it would be difficult or impossible to accomplish online teaching without broad access to technology, although we return to this issue later in considering new types of "digital divides" for education. Achieving an extensive level of technology integration where learning is orchestrated across many providers and focused on collaborative and integrative learning, however, is rare even in online teaching and learning. Though there are many examples of innovation that achieve extensive integration, much online teaching and learning takes traditional lecture and recitation pedagogies and transplants them to the new medium (e.g., Chen, Wang, & Qiao, 2009; Means et al., 2009). We contend that the active or interactive dimensions of online learning designs are aligned with the extensive level of technology integration as we define it, active online designs somewhat less so, and that expository designs rarely go beyond minimal uses of technology. All four of the *How Students Learn* (Donovan & Bransford, 2005) design lenses come into play when thinking about online teaching, but a knowledge-centered lens is the most prevalent, as designers and teachers must focus on how to re-shape content for a learning context where teacher-student interactions are often impoverished, or at least different than those in traditional teaching and learning contexts. We return to these considerations below, but one group of researchers put this issue particularly well in considering the nature of distance (not just online) education:

> Distance education is in essence still education… The factors found to have an impact on the effectiveness of distance education are also factors that would affect the effectiveness of face-to-face education. Additionally, the one factor that often sets distance education apart from face-to-face education -- distance or the technology that is used to remove the effect of distance -- is quickly disappearing as [both] face-to-face [and] distance education increasingly uses technology to support teaching and learning (Zhao, Lei, Yan, Lai, & Tan, 2005, pp. 1865–1866)

Implicit in this comment is the idea that changing the context of education does not automatically change how we teach. There is also an historical caution – we have been engaging in “distance” education for a long time, though paper-based “correspondence courses,” and audio and then video-based courses meant to bring “great lectures” on a range of topics into individual homes. These are all in a way precursors to current trends in online education, and the intellectual forebears to MOOCs. Do the new affordances of the Internet and Web 2.0 tools bring new opportunities and challenges for teachers of education at a distance? In this section, we consider some of these varieties of instruction and the implications they have for how teachers teach and what we currently understand about effective practice and challenges in these various arrangements.

Online (and related) forms of teaching appear to be most employed and studied within higher education, and to a lesser (but rapidly growing) extent within secondary (high school) or middle school education. Online education at the elementary school level is rarer, though there are a few online charter schools at the elementary level with little research to date on their effectiveness. There are also many examples of online education employed in home schooling contexts, which is beyond the scope of this chapter with its focus on teaching in formal school settings. In this section, we focus primarily on online or hybrid secondary education, occasionally drawing from research on teaching online in higher education.

The Scope and History of Online Education in the United States

Online education in the U.S., where most or all of the content of a course and interactions between teacher and students takes place at a distance, has grown rapidly in the past decade (Means, Bakia, & Murphy 2014). One scholar counted 42 states that had either supplemental or full-time K-12 online programs as of 2011, with millions of students engaged in some form of online instruction (Archambault, 2011), with the remaining states making plans for online instruction. Even without clear data available, we feel confident in claiming that online options now exist in every U.S. state. Christensen, Johnson, and Horn, in their book *Disrupting Class*, predicted that by 2019 fully 50% of all high school classes would be taken online (2008). Some states are requiring an online course as part of the student experience. For example, in 2006 Michigan became the first U.S. state to require that graduating students have taken at least one online course, leading to a rapid growth from fewer than 8000 students enrolled in Michigan Virtual High School courses in 2004 to over 525,000 enrolled in 2005 (Barbour & Reeves, 2009). There are various arguments in favor of requiring online education. One argument is that online education will “expand educational access,” and increase the availability of “high quality learning opportunities” (Berge & Clark, 2005). Also, many advocates claim greater cost-effectiveness, but there have been few economic analyses conducted to date (Barbour & Reeves, 2009). The studies that do exist are inconclusive, with online education sometimes appearing less expensive per student and other times more expensive, depending on the alternatives being compared (Means, Bakia, and Murphy, 2014). Others argue (as has often been asserted for technology in education) that online education is preparation for future workplace settings where online training is often used. This is the primary argument employed by the state of Michigan in requiring at least one "online learning experience" for all graduating seniors (DiPietro, Ferdig, Black, & Preston, 2008).

There are many formal organizational arrangements for online education offered in the United States. In 2006, the National Forum on Education Statistics (2006) summarized them as follows:

- *Statewide supplemental programs* that offer courses to students who are enrolled in a traditional school program, and authorized by a state-level authority.
- *District-level supplemental programs* that offer courses to students enrolled in traditional schools within a single district, and which are not normally monitored by state agencies.
- *Single-district cyberschools* that are run as stand-alone schools within individual districts as an alternative to a face-to-face learning environment.
- *Multi-district cyberschools* that are operated or chartered within individual school districts but enroll students from several or many districts within a state.
- *Cyber charter schools* that are chartered within a single district (following state charter laws) but operate as multi-district cyberschools. These are sometimes operated by commercial (non-public) vendors. (National Forum on Educational Statistics, 2006, p.2)

Within and across these distinct forms of organization, there are different ways of structuring coursework or instruction. For instance, a *virtual school* is often organized as a complete educational program for learners, analogous to a traditional primary or secondary school. But students often have affiliations with a local school, and participate in the virtual school as a form of extension of their face-to-face education. Students engaged in online learning may opt to take individual *courses* or *classes*, or engage in a *program* where a series of courses builds upon one another to provide greater depth within a subject area (National Forum on Education Statistics, 2006). There has been a movement towards aggregation of courses and programs into larger management entities at the virtual school level. Indeed, one of the largest providers of online education in the United States is the Virtual High School (VHS), which was originally funded through a grant from the U.S. Department of Education to a single school district (The Hudson Schools in Massachusetts) working in partnership with an education technology research organization (The Concord Consortium). VHS provides educational courses and programs to students across the country; it was extensively evaluated about a decade ago and found at that time to be equally effective to traditional forms of education (Zucker & Kozma, 2003).

The variations in format for online education have implications for teachers and teaching. For example, some argue that, when courses are organized within virtual schools (such as VHS), online education may be able to deliver more consistently high-quality instruction when compared to face-to-face instruction because a team of professionals is engaged in the co-design of courses. These may include subject matter experts, instructional designers, web development specialists, and project managers, in addition to the teachers who actually lead the courses and manage student learning (Barbour & Reeves, 2009). In traditional schooling, teachers are typically responsible for the design and delivery of all aspects of the course (though curriculum frameworks and materials such as textbooks are provided by schools or districts). For that matter, in much online teaching, teachers also work individually for agencies or districts that provide online courses, but are not organized as "virtual schools." In one survey of online teachers, it was found that 42% of teachers were teaching for virtual schools that provide them with content, while the remaining teachers were responsible for creating their own online instructional materials (Archambault & Crippen, 2009). This variation creates different levels of challenges for those who teach online.

Who is Teaching Online and How?

Archambault and Crippen (2009) conducted a nationwide survey of teachers teaching online courses of various kinds, and found that these teachers were statistically similar to the overall teaching population in terms of age, gender, and racial background. However, on average online teachers had more years of experience teaching than traditional teachers, and a greater percentage of advanced degrees. Instructors in the Archambault and Crippen (2009) survey indicated a desire to teach beyond the constraints of a traditional classroom, e.g., the bell schedule or classroom management issues. They also indicated a desire to find a new or better mechanism for engaging with their students. However, online teachers described a variety of new and different challenges in the online education environment, including a lack of technical support, managing larger numbers of classes and students, and variable student motivation. We return to these challenges below.

Many teachers move back and forth between face-to-face and online teaching, what one researcher has dubbed the “trans-classroom teacher” (Lowes, 2008). The trans-classroom teacher has to make adjustments as they move between the two environments, “transferring ideas, strategies, and practices from one to the other” (Lowes, 2008), in a process that transforms both the teaching and teacher. These transitions were documented in a study of 215 teachers in the Virtual High School (VHS), whose teachers often teach both online for VHS and face-to-face in their own local schools. Major differences noted in the teachers’ practice between the two environments included ways of communicating with students they could not see, ways of knowing if they were meeting their students’ needs and ways of assessing whether and what students had learned. Interestingly, a majority of teachers reported that their experiences online caused them to make changes in their face-to-face teaching (Lowes, 2008), a finding that is reflected in other studies (e.g., Roblyer, Porter, Bielefeldt, & Donaldson, 2009). This was attributed to the need for a sharper focus on the effectiveness of each lesson taught online, which led to a more critical appraisal of similar lessons offered face-to-face.

Key Practices for Online Teaching

As argued by Zhao et al. (2005), teaching online is still *teaching*, and the overall goals for teachers are largely similar across online and face-to-face contexts. However, a shift in context also brings new affordances that teachers can leverage in organizing and delivering instruction, along with new obstacles that present challenges. The field’s models for understanding online teaching, especially K-12, are still developing as well. As two commentators put it, “At present, virtual education lacks a firm understanding of what high-performance looks like” (Dillon & Tucker, 2011, p. 52). They compare the growth of online education to the growth of charter schools in the United States: The introduction of charter schools is, superficially, an educational reform, but success depends on many design and implementation choices that vary greatly across charter schools. Dillon and Tucker wryly comment that, “without rigorous oversight, 1000 flowers blooming will also yield a lot of weeds” (p. 52), and go on to conclude that, “there is nothing magical that ensures either charter schools or virtual education will be innovative and different. Each provides the opportunity for something new and potentially powerful: charters through a new governance model, virtual learning through a new instructional model” (Dillon & Tucker, 2011, p. 57).

Much current evidence about online teaching practice comes not from research on K-12 teachers or learners, but instead from higher education or adult education, and may not apply perfectly to instruction for younger, still maturing learners (Barbour & Reeves, 2009). For instance, online learning is thought to be best suited to students who are ready to assume a high degree of autonomy. There is a higher level of attrition noted in virtual schools than in face-to-face schools, and this might be attributed to learners not ready to assume responsibility for more self-direction, even when online courses might be targeted at higher-capability learners, such as in AP courses (Zucker & Kozma, 2003). Recent research (again, conducted in higher education) suggests that online courses create another dimension of a digital divide, and that minority students, younger (less mature) students, and students with lower grade-point averages suffered academically in comparison to their peers when taking online courses (Xu & Smith Jaggars, 2013).

In this part of our discussion of research about how people teach online, we are primarily addressing models of online instruction in which teachers remain either central or prominent in the instructional process, as opposed to models where learners interact primarily with instructional materials or view recordings of teachers, but with little direct teacher-to-student interaction (we consider these models later in this section). At the same time, the models we consider here are ones that move towards an intermediate level of technology integration, implying that teachers are not merely presenting information to students via lecture (for instance), but rather are attempting to engage students in a variety of ways.

There is as yet no clear statement of “best practices” for teaching online, though there are a variety of emergent policy documents that attempt to define the dimensions of online teaching. The first standards for online teaching were published in 2006 by the Southern Regional Education Board (Smith, 2009), and later that same year the National Education Association published the *NEA Guide to Teaching Online*, later updated to the *NEA Guide for Teaching Online Courses*, a document that was developed collaboratively by the International Society for Technology in Education, the NEA, the North American Council for Online Learning, the National Commission for Teaching and America’s Future, and the Virtual High School. Ferdig et al. (Ferdig, Cavanaugh, DiPietro, Black, & Dawson, 2009) summarized across a number of such standards documents, and came up with the following list of potential roles for educators in virtual schools: Instructional designer, Course Facilitator, Local Key Contact, Administrator, Mentor, Technology Coordinator, and Guidance Counselor. The implication is that there are some roles that a teacher in a traditional face-to-face classroom might not need to play, but which they do more naturally play in an online setting. This may be because students do not know who else to ask for support, or it isn't apparent to the teachers who they might go to for help with particular issues (Ferdig et al., 2009), as opposed to in a traditional school that has on-site or in-district support staff.

Smith (2009) studied online teachers' beliefs about various standards for online teaching in general. She found that, while teachers endorse the (nascent) standards, they also found many problems with them. The components of the standards viewed as most important and relevant were identified as focused on particular teaching "dispositions," such as being flexible and self-regulated, being student-centered, and maintaining high standards. The components viewed as least important by teachers were the ones focused on community building, collaboration, and the use of adaptive technologies. This is unfortunate, given the power of those technologies when used for these ends as noted elsewhere in this section and in this chapter. Teachers also felt that the online standards did not do an adequate job of representing important aspects of online teaching, such as establishing online presence, using humor to engage students, and being flexible in the face of changing technological demands. Further, it was found that online teachers were generally unaware of the existence of these standards, a finding that is consistent with others' observations of teachers' knowledge of standards, as opposed to their focus on the constraints and guidelines provided by their local school or district (Penuel, Fishman, Gallagher, Korbak, & Lopez-Prado, 2008; Penuel et al., 2009).

In interviews with a number of online teachers, Ahn (2011) found that, with the computer as the primary communication mechanism between teacher and students, teachers' found their role shifting towards coaching, individualized assistance (as opposed to whole group instruction), and formative and ongoing assessment of student learning across a course:

> Teacher roles shift in an online environment when the computer is the primary source of instruction. The teacher does not become completely irrelevant. Rather, teachers become vital mentors, consultants, and conduits of education and information between school and family. The instructors provide highly individualized assistance to students as they progress at their own pace. The findings underscore deeper debates about the definition of teaching, teacher quality, and teacher preparation. (Ahn, 2011, p. 22)

The shift to an online environment requires that teachers have a solid understanding of pedagogical content knowledge related to their subject to understand what makes different topics easy or difficult for students to grasp, as well as technological pedagogical content knowledge (Mishra & Koehler, 2006) so that they can use technology effectively to scaffold the individual learning experiences of students (Archambault, 2011), just as this is important in technology-based face-to-face teaching. In a study of successful teachers in the Michigan Virtual School, DiPietro and colleagues (DiPietro et al., 2008) identified teachers who:

- were willing to "go the extra mile" to support student learning
- were skilled with basic uses of technology
- were interested in exploring new technologies with potential value
- were flexible with their time
- had a deep understanding of the varying learning styles of students
- worked to establish a presence in the course to motivate students
- had good organizational skills
- used course and student data to evaluate their own pedagogical strategies
- had extensive knowledge of their content area
- and understood the impact of pacing on course design and pedagogical strategies. (DiPietro et al., 2008, 16-19)

This is a daunting list, but these are generally qualities of excellent teachers in any medium, seeking to understand their students' needs and striving to continually improve both student learning and their own practice in support of that learning. In later work reflecting on the study of teachers in the Michigan Virtual School, DiPietro (2010) summarized this list in terms of 5 "beliefs" held by successful online teachers:

- *Belief 1* – The importance of connecting and establishing relationships with students. This requires effective communication and working to prevent misinterpretations introduced by electronic mediation. It is also a recognition of the increased difficulty of establishing such relationships online as compared to face-to-face.
- *Belief 2* – The need for fluid practice, recognizing that the strategies needed to teach online will be different than those developed face-to-face. Some of the practices required include learning how to guide knowledge construction, and individualizing learning for students.
- *Belief 3* – That engaging students with content is of the utmost importance in online instruction. This requires that teachers integrate technology and make content accessible, again individualizing learning where needed.
- *Belief 4* – Active management of the course is required in order to create a positive educational experience for students. This includes the maintenance of academic integrity by aligning the content with standards, posting academic honesty policies, and monitoring for cheating or other undesirable behaviors.
- *Belief 5* – The importance of supporting student success. This requires meeting student needs, structuring content to scaffold learning, and utilizing support structures including local mentors who may be available to students.

Recurring themes emerge in the literature with respect to the important skills or functions of online teachers. Establishing "presence" early in the course is viewed as critical, since otherwise it is harder for students to establish some personal connection with the teacher. Introductory or "getting to know you" activities are a common recommendation. Teachers need to be diligent monitors of student progress to make sure nobody falls between cracks. They need facility with technology, and a general enjoyment of using technology (Black, DiPietro, Ferdig, & Polling, 2009). A focused, task-oriented set of recommendations about instructional practices that facilitate student learning across different types of instructional platforms include: using multiple sources of content, always providing timely feedback, incorporating opportunities for student choice, integrating student management of learning in the structure of the course (e.g., have each student identify and monitor individual learning goals), to including rubrics for assessment, modeling typical discussion responses and final products, creating authentic learning experiences, using humor as part of student introductions, utilizing social media for networking, and ensuring that students are aware of the technology requirements of the course (Kerr, 2011). As noted earlier, these suggestions could apply in any teaching context, not just online, however, the affordances of online tools can make some tasks easier online than they would be in face-to-face teaching, and vice-versa. For instance, with the right information displays of student progress, teachers can do a more effective job of monitoring student understanding, providing feedback, and suggesting individualized instructional responses than is typically possible in face-to-face classrooms. Using humor and establishing social presence with limited social cues online may present a greater challenge than in face-to-face teaching.

Focusing in particular on the importance of teaching presence, which is likely to be difficult to establish online, a conceptual framework used to describe online teaching (in higher education), called the "Community of Inquiry" framework (Garrison & Arbaugh, 2007), highlights three interwoven forms of "presence" needed to create meaningful learning experiences in distance or online education. These are "social presence," "cognitive presence," and "teaching presence;" each applies with respect to various instructional objectives. When the objective is to support discourse, teachers must draw on a mixture of social and cognitive presence. When the goal is to establish climate, social and teaching presence are called upon. When the goal is to select or deliver content, cognitive and teaching presence are required. These ideas map well to the notion of diverse knowledge required for teaching in general (Shulman, 1987), and the ways that this knowledge must be adapted for technology-mediated teaching (Mishra & Koehler, 2006).

In the only large-scale meta-analysis of online teaching and learning to date, conducted for the U.S. Department of Education, researchers found that the sole teaching practice that was reliably linked to greater student learning online is the incorporation of mechanisms that promote student reflection on their level of understanding (Means et al., 2009). This is consistent with a finding of the *How People Learn* meta-analysis of research on learning, indicating that metacognitive awareness is a key to effective learning (Bransford et al., 2000). Findings related to other practices were mixed, and elements that are frequently incorporated in online instruction, such as video or online quizzes, did not appear to influence the amount that students learn in online classes.

Challenges to Teaching Online

Though high-quality online teaching shares many aspects of traditional instruction, there are also many divergent or even jarring differences inherent to the use of media that can create obstacles for teachers who are new and not well-prepared for online teaching. In particular, teachers who are new to online teaching, even if they are experienced teachers, report problems ranging from a lack of adequate technical support for the teaching environment, to difficulties with managing the (sometimes) larger number of students who can be enrolled in their online classes, to variable and hard-to-judge levels of student motivation (Archambault & Crippen, 2009). Research into adult learners online has painted a picture of the "successful" learner as having an independent orientation towards learning, being intrinsically motivated, and having strong time management, literacy, and technology skills (Barbour & Reeves, 2009). But those familiar with K-12 education will know that these "ideal" characteristics are much rarer among younger learners, especially among those students who may be directed to online classes for credit recovery purposes (i.e., Xu & Smith Jaggars, 2013). If we assume that successful K-12 learners are likely to share many of the characteristics of successful older online learners, the challenge for K-12 teachers is to develop practices that support their students' development toward those characteristics. Barbour and Reeves (2009) call for more direct research into online success factors for K-12 learners. Many of these factors seem related to communication, monitoring or assessing learners, and providing feedback to learners.

Because many online teachers are really “trans-classroom” teachers who move between traditional face-to-face and online teaching (Lowes, 2008), part of the challenge is unlearning practices that may have worked well face-to-face, but are not likely to be successful online. “Teachers have strong historical and personal experiences of face-to-face teaching and learning, and these are reflected in their beliefs about teaching and deeply embedded in their practices” (Gerbic, 2011, p. 222). In making the transition to online teaching, teachers need to develop an online pedagogy that integrates the strengths of online and face-to-face instruction. For instance, when a student is not actively participating in a discussion, it can be difficult for online teachers to determine what the issue is, and also difficult for those teachers to get in touch with a non-communicative student (Belair, 2011). In contrast, in a face-to-face environment, the teacher has a range of visual queues to draw from and can speak directly to the student who is not participating.

Providing assessment information to students is also challenging. Online learners may need more frequent feedback, and formative assessment plays an important role in online learning environments. A study of new online teachers in Australia reported frustration with learning how to read the signals from students online:

> [I needed to know how to determine] which student contributions actually enhanced the debates; who was original and who was responsive in discussions; how to deal with “lurkers” and non-participation, and how to educate about attributions ideas and resources. In short… I thought the collective was engaged seriously in learning but I found it hard to say the same for each individual. It was some kind of assessment meltdown. (Baskin & Anderson, 2003. p. 19)

One potential advantage for online teachers is the automatically-generated data that is available from computer-based learning environments (Dede et al., 2009; U.S. Department of Education, 2010). This data is sometimes referred to as learning analytics (U.S. Department of Education, 2012), and represents potentially powerful new information for teaching. However, learning how to interpret the information provided in log files and other reports from online tools is another area of challenge for teachers, as well as for those who develop and support online teaching tools. This problem may be partly alleviated by the development of better software tools that provide guidance either directly to students (e.g., intelligent tutoring systems; Feng, Heffernan, & Koedinger, 2009) or systems tied to large-scale real-time learning analytics (e.g., Kolowich, 2013a). This is a space that is likely to see intensive investment and research in the coming five years (Johnson et al., 2013).

Another area of concern for online teachers is isolation. Teaching is already viewed as a solitary activity for adults (e.g., Bullough, 1989), and teaching online may be even more isolating. Lack of contact with teaching peers may be less of a concern for "trans-classroom" teachers (Lowes, 2008), but issues with student contact are true for all online teachers. Teachers have reported feeling disconnected from their students, and disconnected from their traditional role as a teacher, including the many incidental conversations that occur around students outside of the formal curriculum (Hawkins, Graham, & Barbour, 2012).

Issues of culture and cultural difference are also present for online learners. Across international boundaries, instructors may discover that certain tools or approaches require a different approach. For instance, learners from cultures that prefer to avoid uncertainty are "threatened by learning situations that are unstructured and unclear… Both Chinese and Korean students, who rarely spoke in traditional classrooms, felt lost when they were expected to speak online" (Uzuner, 2009). The implication is that online instructors should make course structure transparent for learners, to reduce uncertainty. In sum, however, these differences again point to the issue of knowing one's students, and adapting instruction to suit. This is a principle of good teaching generally, not just online.

Finally, there is the issue of whether it is more or less difficult for teachers to prepare for and deliver online instruction. Can one teach more students online? Again, this depends on the model of instruction/pedagogy one employs. One longitudinal study of online teaching at the university level focused on three cases of online teaching and found that a course of 25 students required between three and seven hours of instructional and preparation time per week. Time was spent reading and responding to emails, reading, participating in, and grading online discussions, and grading assignments. This finding indicates that the time required for online instruction, when viewed on a per-student basis, is within the norms of teaching face-to-face courses (Lazarus, 2003). Other studies, however, have found that the affordances for one-to-one teacher-student interaction in online teaching can greatly increase the amount of instructional time (Cavanaugh, 2005), which is consistent with the opinion of higher education faculty, who increasingly report a belief that online teaching requires more time than face-to-face teaching, especially in the newly-emerging case of MOOCs (Kolowich, 2013b).

Learning How to Teach Online: Teacher Preparation

The Archambault (2011) national survey of online teachers examined what she described as a "major disconnect in the way that these teachers were prepared to teach, the ways in which they themselves were taught, and the current expectations for an active and engaged online classroom in elementary and secondary settings" (p. 73). At the present time, teacher education programs struggle to include technology in a meaningful way (Lei, 2009; Pellegrino et al., 2007), let alone prepare teachers for teaching online. In 2010, DiPietro pointed out that there were no set standards, qualifications, or certifications for K-12 virtual school teachers, as there were for teachers in face-to-face settings (DiPietro, 2010). Since then, several certification programs for online teaching have emerged, most notably a program at Boise State University established in 2011 that offers an online teaching endorsement for teachers who are already certified. But overall, programs like the one in Idaho are not yet a regular feature of pre-service teacher education programs.

Again, the findings of the 2011 survey suggest that, while online teachers felt adequately prepared for "traditional" components of teaching such as pedagogy and content, they feel unprepared for the additional challenges of technology (Archambault, 2011). These findings likely reflect the "trans-classroom" teacher (Lowes, 2008), and teachers are likely making an error (as discussed earlier) in thinking that the pedagogical approaches that worked for them in face-to-face instruction will translate smoothly to the online classroom.

Another challenging area for online teaching is related to certification guidelines. Currently, certification is state-based, restricting the geographic boundaries where a teacher is permitted to teach. Reciprocity agreements across state boundaries (when one state accepts a teaching endorsement granted by another state) may address some of these issues. However, given the lack of physical-space requirements represented by online teaching, place-based certification is increasingly becoming an outdated way to view readiness to teach (U.S. Department of Education, 2010). This poses challenges not just for teachers, but also for the institutions that prepare them.

Extending the Face-to-Face Classroom with Online Tools: Hybrid Instruction

Related to the move towards completely online education has been the steadily increasing use of technology by teachers to extend and enhance their face-to-face teaching. Reports such as the 2010 U.S. National Educational Technology Plan described a new role for “connected teaching” (U.S. Department of Education, 2010), and current surveys of teachers leave little doubt about the increasingly important role that online technology plays in their instruction (Purcell, Heaps, Buchanan, & Friedrich, 2013). In particular, we are focused here on the use of online teaching or computer-based instructional materials to augment face-to-face teaching. This is a type of instruction often referred to as blended or “hybrid” instruction (Allen & Seaman, 2006), where students spend part of their time interacting online and part of their time face-to-face.

A major assumption in such classrooms is that the introduction of technology-mediation will “free” the teacher to allocate time differently. For instance, one approach that is frequently referred to in this context is “flipping the classroom” (Strayer, 2007), an approach that takes instructional components typically delivered face-to-face (e.g., lectures) and instead has students watch them online. Through this, material that would typically be completed out of class (e.g., problem or homework sets) can now be done in the classroom, where the teacher is more available to help students when they get stuck. Flipping the classroom as an approach gained rapid popularity with the introduction of the online instructional environment known as *Khan Academy* (KA; Khan, 2012), which is a web resource primarily comprised of “chalk and talk” style lecture videos on a broad range of topics, delivered by Salman Khan. KA was originally intended as a self-help online resource, but support from a large charitable foundation led to the development of additional computer-based problem sets for middle-grades mathematics that are designed to allow students to make progress through mathematics learning goals supervised by teachers. Though use of KA is often referred to as "flipping the classroom," in practice there are a range of ways that the resource is employed by teachers in order to extend their classroom teaching (Murphy, Gallagher, Krumm, Mislevy, & Hafter, 2014). Many of these uses essentially capture the idea of "flipping," which is to allow students to work through problems at their own pace, seeking support from the teacher where needed. Many teachers balance the use of the KA tools with their own teaching, employing KA as a supplement, a way for students who are falling behind to catch up, or as a way to allow advanced students to work ahead (Greenberg, Medlock, & Stephens, 2011). "Flipping the classroom" with hybrid online education is another opportunity to explore the possible levels of technology integration. Creating more time to help struggling students is a minimal use of the time created by employing a hybrid approach. More extensive uses might employ the additional time in classrooms to support greater use of collaborative learning or project-based and inquiry-based learning.

These uses of technology to extend and change the way teachers teach in face-to-face instruction have deep roots; though contemporary tools deliver instructional materials via the Internet, computer-based tutors have been employed in similar ways for decades. Intelligent tutoring systems (ITS), instructional platforms which blend artificial intelligence with computer-based instructional environments, have been under development since the 1970s (Sleeman & Brown, 1982). ITS development originally employed the domain of computer programming to develop and refine cognitive models of learners acquiring skills in a well-defined domain. Early ITS work led to the development of a series of tools called "*Cognitive Tutors*," which are ITS environments that leverage cognitive models to "facilitate learning by doing, to make thinking visible, and to support complex problem analysis, solution, and communication" (Corbett et al., 2001, p. 235). Early *Cognitive Tutors* were focused on programming and geometry, and were later expanded to high school geometry and algebra. Early research findings on *Cognitive Tutors* indicated that they were about half as effective as human tutors, but two to three times as effective as conventional computer-assisted instruction (Anderson, Corbett, Koedinger, & Pelletier, 1995). More recent research indicates that the effectiveness of human tutors may have been overestimated, and that intelligent tutoring systems can be *equally* effective to human tutors (VanLehn, 2011). However, due to the nature of the cognitive models that underlie *Cognitive Tutors* and similar systems, such environments cover only a narrow portion of the curriculum and remain best suited to clearly-defined bodies of knowledge that lend themselves to learning through solving series of discrete problems of increasing difficulty, such as mathematics or engineering.

Early research on *Cognitive Tutors* and other ITS environments was conducted apart from research on teaching or classroom use; these were tools meant to help the field understand cognition and learning, and to the extent that they were tools for teaching, *Cognitive Tutors* existed apart from classroom learning. However, in the 1990s the *Cognitive Tutor* developers at Carnegie Mellon entered into a research project in partnership with public schools in Pittsburgh to develop comprehensive curriculum materials that incorporated the technology into a teacher-led mathematics curriculum. The research team attempted to work closely with partner schools to develop a technology-enabled learning environment that “served to empower rather than replace the classroom teachers” (Corbett et al., 2001, p. 251). The result was a model of instruction where students spent a portion of their classroom time working with the *Cognitive Tutors,* often in pairs, and a portion of classroom time in a more traditional teacher-led arrangements. When students were working on the computers, teachers were able to spend more time with students who needed more attention. Students were more motivated because they had more control of the pacing of instruction, and when teachers and students did interact the exchanges were generally more positive because they were often student-initiated (Schofield, 1995). In many ways, the *Cognitive Tutor* classrooms might be considered to be the first instances of a computer-supported "flipped classroom," where technology enables a shift in the focus of instruction and changes the nature of teachers' work. Where the curriculum content supports the effective use of online intelligent tutors, this can be a good way to complement the skills of an effective teacher.

A great deal of fully online teaching retains a lecture format, or lecture supplemented by online discussion, and therefore most frequently exists at the moderate level of technology integration. (We note that, depending on pedagogy, it is plausible to completely conduct instruction via technology, and yet still be classified as integrating technology at either a minimal or intermediate level.) Blended or hybrid instruction, however, offers at least the greater possibility of moving towards extensive levels of technology integration by creating greater flexibility for learners and teachers. When students are allowed to move at their own pace, as is facilitated by ITS or environments such as the *Khan Academy*, it also becomes possible for them to pursue more of their own interests in relation to classroom instruction. Learning how to orchestrate learning and teaching across multiple sources, providers, and platforms presents a tremendous challenge to teachers, but one with the potential to lead to vastly different and more productive organizations for learning. This orchestration is a view of teaching as "connected teaching," described in the 2010 National Educational Technology Plan (U.S. Department of Education, 2010). Though many proposals call for a view of teacher as an orchestrator or coordinator of student learning across multiple contexts and platforms, there is as of yet little research into how to support or prepare teachers for such practice.

Computational Thinking and Students as Makers and Creators

In this section, we turn our attention to tools and learning environments that support learning about computer programming. This topic is the closest we come to considering technology as a subject matter in and of itself, in contrast to our overall focus on technology as a tool for extending or transforming teaching and learning environments. Here, we find the diversion into technology as the subject matter for learning is warranted for at least two reasons: First, as we discuss below, proponents of learning how to program computers have long argued that the primary benefits of acquiring this skill lie not in the programming itself, but in the cognitive disciplines and ways of thinking that are imparted with benefits across a learners' lifespan. In this way learning to program is a knowledge-centered activity, focused (ideally) on mastery. Second, the past five years have seen a convergence of student-focused programming environments and the Web 2.0 tools and cultures discussed earlier, leading to a renewed interest in computer programming as a vehicle for 21st century skill development. In both cases, the historical research base and emerging new studies indicate that the teacher plays a crucial role in whether or not the promised benefits of computer programming are realized by learners.

Though we briefly touch on the tradition of "computer science" courses in K-12 education, our particular interest is in the rise of technology-enhanced learning environments that employ computational and software development tools to empower student self-directed learning and creativity. We explore environments that view the learner as a creator or maker, which have traditionally been found in informal learning contexts that are beyond the scope of this chapter, but which are increasingly moving into formal learning environments with significant opportunities and challenges for teachers and teaching. We discuss these new environments and their relationship to an emerging focus in education called "computational thinking" (Wing, 2006), which is presented as a generalized approach to learning and problem solving that is claimed to arise from the mastery of computer programming (though not solely from that activity) and has potential implications for how students approach learning and the application of knowledge across all domains. We relate the evolution of approaches to teaching programming and computational thinking to the different levels of technology infrastructure and integration that we have used throughout this chapter.

Computational Thinking and the Development of *Logo*

The use of computers and computer programming as a way to extend and enhance student thinking has a long history, going back at least to the 1970s, when learning how to program was viewed as a potentially valuable cognitive skill with benefits in other, non-programming domains. This perspective is analogous to long-held views of learning Latin as being beneficial for thinking, writing, and speaking in general: a kind of "calisthenics for the mind." In a report for the Venezuelan government, Feurzeig, Horwitz, and Nickerson (1981) described seven potentially "fundamental changes in thought" introduced by the discipline of programming (as described in Pea & Kurland, 1984, p. 143):

- Practice in being rigorous and explicit in one's thinking;
- An understanding of general concepts including procedure, variables, and functions;
- Practice with general problem-solving heuristics such as planning, decomposition, etc.
- Understanding that "debugging" errors is a "constructive and plannable (sic.) activity" useful for all kinds of problem solving;
- The general idea that smaller procedures can serve as building blocks to more complex solutions to big problems;
- Enhanced facility with the structure and language(s) of programming, leading to generally increased ability to discuss problems with others;
- Recognition that there are usually multiple solution pathways for problems with different costs and benefits, and rarely a single "best" solution.

This is a compelling list of potential benefits, stated primarily with respect to problem solving as a generalizable skill, an idea which cognitive science continues to find critical to learning

(Bransford et al., 2000). However, in practice the teaching of computer programming was most frequently realized as the teaching of facts and processes *about* computer programming, with students learning through didactic instruction based around the repetition and replication of exercises intended to drill the syntax of computer languages (Pea & Kurland, 1984). Salomon (1984), in a mostly agreeable response to Pea and Kurland, argued that the teaching of computer programming was unlikely to result in the transfer of benefits to other domains, because of the limited context in which computer programming was being taught. The limited approach, he argued, was akin to early approaches to the teaching of language or literacy, which resulted in much slower learning of language than students naturally acquire through everyday interactions (c.f. Brown, Collins, & Duguid, 1989). Pea and Kurland (1984) provided a review of much of the extant empirical research on the claims of such instruction on cognitive development and other learning outcomes, and definitively stated that there was no reliable evidence of broader effects from learning how to program. What's more, Pea and Kurland's review found little evidence that students were learning how to program in a manner that would be respected by the computer industry.

One reason the type of computer programming instruction critiqued by Pea and Kurland (1984) failed to produce its intended results, with one exception (see below), is because it was implemented in schools at a *minimal* level of technology integration. This may seem counterintuitive, since in most computer programming classes all students have computers in front of them as an infrastructure, which we earlier described as one of the determinants of at least an intermediate level of technology integration. But the pedagogical organization of such instruction – presentational, organized in labs, students completing "cookbook" exercises – is the hallmark of a minimal integration of technology. The potential for deeper use of the technology is present, enabled by the investment in infrastructure, but the pedagogical approach is the limiting factor.

The exception that we alluded to above is the work of Seymour Papert and Wally Feurzeig with the development of the child-friendly *Logo* computer language in the late 1960s and early 1970s, which was designed to allow for students to experiment with computer code represented first in physical objects (a motorized “turtle” that moved on the floor) and later in on-screen graphics that students could interact with through short computer programs of their own creation (Papert, 1980). Pea and Kurland include Papert’s work to date in their 1984 critique and review, leading to a public debate between Papert (1987), Pea (1987) and others (e.g., Walker, 1987) around what Papert labeled as “technocentric thinking” that made *Logo* the independent variable in research designs with particular learning outcomes in mind (e.g., cognitive change), rather than employing a broader “computer criticism” that considers how *Logo* is used, the long-term trajectory of the child, and other hard to define (i.e., “control”) factors. These arguments are in part fascinating for how they presage later arguments about the nature of experimental research designs in the development of educational interventions (discussed further in “The Evolving Research Agenda for Teaching with Technology” below; e.g., Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; Cook, Means, Haertel, & Michalchik, 2003). They also echo a larger theme of this chapter, which is that the introduction of technology into classrooms does not in and of itself lead to positive effects in either teaching or outcomes; what matters most is how the technology is used in relation to the teaching.

While Pea and Kurland’s (1984) assessment of the empirical evidence from Papert’s work to date may have been accurate, there was a bigger picture that their critique did not take into account. In another response to the Pea and Kurland article, Sullivan argues that:

> Papert's suggestion of the "child as programmer" represents a striking departure from present school practices where the curriculum tends to focus on programming the child… if one takes Papert's suggestion seriously about the "child as programmer", then we must be *prepared to retrain our teachers to an alternative view of the child as learner*. (Sullivan, 1984, p. 176; emphasis added)

Papert was highly critical of what he saw as predominantly passive and receptive modes of learning in school, and argued for an approach that later came to be called "constructionism" (Papert, 1991). A key aspect of Papert's vision for *Logo* was that students' projects would reflect their interests and passions, and that students would observe, admire, and mimic each others' projects and code, improving and improvising as they go. The "n" in constructionism denotes *construction* or building/creating an external and sharable artifact, as opposed to cognitive constructivism with a "v," which may refer to purely internal representations (Piaget, 1954; Papert was Piaget's student). In Papert's view, "The usual passive view of integrating computers into education supports instructionism and technocentrism" (Harel & Papert, 1990, p. 1). Papert argued that a constructivist approach on its own was still too "teacher-centric," often removing true decision-making control for the direction of activities from the learners (Papert, 1993). In short, Papert's vision of how *Logo* figured into students' learning requires a massive reconfiguration of the role of the teacher, as Sullivan (1984) pointed out. No such large-scale reconfiguration was forthcoming; and, perhaps as a result, the focus on *Logo* moved largely to informal contexts, including after-school settings like the Computer Clubhouse (Resnick, Rusk, & Cooke, 1998), and serious toys such as *Lego/Logo*. This would change, but not until several years later with the widespread growth of the Internet and social media. Papert's vision of the classroom as a learning environment embodied an extensive level of technology integration, in which students pursue topics on which they are "passionate" (Papert, 1980), with teachers helping to coordinate across students' varying interests.

Where school-based work with programming environments like *Logo* persists, they serve largely as adjuncts or extensions to existing curricula, and is used as part of an intermediate level of technology integration to change students' relationship to data and the way they think about the world. This is in service to the original goal for employing computing in the curriculum, as presented by Feurzeig and colleagues (1981, cited in Pea & Kurland, 1984). A prominent example is the work of one of Papert's students, Uri Wilensky, and the development of a *Logo* variant called *NetLogo* that is tailored to modeling complex systems and letting students explore, tweak, and reason about these systems in domains such as biology and ecology (Wilensky & Reisman, 2006). *NetLogo* is part of a tradition of computational modeling tools designed to enhance student learning in STEM disciplines, such as *StarLogo TNG* (Klopfer & Begel, 2003), and Model-It (Jackson, Stratford, Krajcik, & Soloway, 1994), and related agent-based modeling approaches where students program components of a system in order to understand and explore complex and emergent interactions among components (Sengupta, Kinnebrew, Basu, Biswas, & Clark, 2013). Such environments have been shown to play a role in helping students understand complex phenomena through the manipulation of variables and iterative running of simulations based on students' predictions and tweaking, though it is important to note that the software is designed to be embedded within larger curriculum reform efforts.

The researchers (appropriately) do not attempt to separate the effect of the software from the overall changes in the curriculum and teaching, because both operate symbiotically in the overall teaching and learning environment (Krajcik, Soloway, Blumenfeld, & Marx, 1998; Wisnudel, Stratford, Krajcik, & Soloway, 1998). Using such tools presents challenges in school settings, especially if they are integrated into everyday instruction as opposed to being isolated in computer labs where few students have access to them (Fishman & Pinkard, 2001). For students to realize the benefits of these tools, teachers need to learn to use the tools and support students' use of them. They need to become familiar with new and more challenging inquiry-oriented pedagogies (Crawford, 2000), and the supportive infrastructure for teaching needs to be aligned properly with respect to teacher professional development opportunities, policies should be aligned with respect to how teachers and students access the technologies, and the culture for using technology should be aligned with broader culture in the school (Blumenfeld, Fishman, Krajcik, Marx, & Soloway, 2000).

In present-day formulation in most schools, formal computer science courses have evolved into a component of the business curriculum, regressing to a minimal level of integration. Instead of learning how to program, students in middle and high schools are learning about computer applications such as *Microsoft Office*, database programs, authoring shells for creating websites, and, in more advanced situations, how to use computer-controlled drafting or machining technologies. Curriculum related to these topics has come to be called “technology education” (as opposed to “educational technology”), and it is approached as vocational training akin to shop class, introducing students to technology as a tool for design, engineering, and business (Information Technology Education Association, 2007).

“Traditional” computer science courses still exist as well, in which the goal is to teach students how to program a computer. These courses are often viewed as gateway courses to future study of computer science in college, and have their own literature related to teaching and what it means to teach in this discipline (e.g., Gal-Ezer & Harel, 1998). However, as noted at the outset of this section, an in-depth focus on computer science as a discipline or as vocational training is beyond the scope of this chapter. Instead, our focus is on the ways in which the act of programming computers is related to more general cognitive skills. This has come to be called "computational thinking" (Wing, 2006), and is defined as a general skill for all learners:

> Computational thinking is a fundamental skill for everyone, not just for computer scientists. To reading, writing, and arithmetic, we should add computational thinking to every child's analytical ability. Just as the printing press facilitated the spread of the three Rs, what is appropriately incestuous about this vision is that computing and computers facilitate the spread of computational thinking. (Wing, 2006, p. 33)

This restatement of what it means to think computationally captured much of the argument made by Feurzeig and colleagues (Feurzeig et al., 1981) and Papert (Papert, 1980), but parlayed those ideas into the middle of growing concern about inadequate focus on Science, Technology, Engineering, and Math (STEM) education in the United States (National Research Council, 2010a). Grover and Pea (2013) assessed the current state of educational research and thinking with respect to computational thinking, with a generally more positive outlook than Pea had in his earlier critique (Pea & Kurland, 1984). They note many issues with respect to the definition of the term, which is easily confused with *computer literacy*, *information literacy,* and *digital literacy*. They also document lack of agreement over whether computational thinking should be taught as a freestanding subject (like computer science) or integrated across the curriculum (National Research Council, 2011a), and continuing debates on what should be assessed to gauge students' level of computational thinking and how that assessment should be conducted. However, Grover and Pea note a great deal of progress in terms of learning environments and tools that support teaching more towards Papert's original pedagogical vision. This includes some of the modeling and simulation tools (discussed below in "Teaching with Computer Games and Simulations") Part of Grover and Pea's (2013) renewed interest in computer programming via computational thinking is manifestation of these ideas in a range of informal learning spaces that have been called, variously, hacker spaces, maker spaces, and so forth (Thomas & Brown, 2011). There has not been much formal research into learning in such spaces, especially with respect to teachers and teaching, so we turn our attention to one environment where researchers have been working to bridge that gap: *Scratch*, another direct descendent of Papert's original *Logo* computer language.

Scratch – Bridging Informal and Formal Learning Environments

Scratch (Resnick et al., 2009) is a visual programming environment that was originally developed for use in the after-school Computer Clubhouse setting (Resnick et al., 1998). *Scratch* was designed with three overarching goals:

- To make coding "more tinkerable," to give students the ability to mess around with programming without worrying about formalisms like syntax that make it hard to do things with traditional computer language;
- To make coding "more meaningful," so that learners (whom Resnick and colleagues refer to as "Scratchers") have the freedom to work on problems and projects they are interested in, not just what is assigned;
- And to make coding "more social," by linking Scratch projects to a community web site of Scratchers where programs can be shared, and most importantly, remixed (Resnick et al., 2009).

Remixing enables tinkering, by allowing any Scratcher to examine another's program, and then modify it or incorporate it in his or her own program. A view that learning is most effective when the learners are in control and when knowledge is represented in shareable projects and products is the forebear of several important movements in technology and learning, most notably the "maker movement" and its emphasis on students as creators, collaborators, and remixers (Jenkins et al., 2006). Through this lens, *Scratch* employs both learner- and community-centered approaches to enabling learning.

Logo has a "low floor, high ceiling" philosophy that was designed to get a beginner started no matter what they know and can do, yet provides virtually no limits for those with great expertise. To this, *Scratch* adds the concept of "wide walls" (Resnick et al., 2009), explicitly welcoming users to bring a broad variety of interests and directions to their work in *Scratch*. By leveraging a global community through Web 2.0 technologies, there are almost always like-minded Scratchers to be found on any application of *Scratch* a particular participant finds of interest. Together, these guiding principles for how *Scratch* "wants" to be used create a difficult situation for teaching in traditional K-12 environments, which is part of the reason why *Scratch* migrated to primarily to use in informal learning environments, which are more suited to learner-driven agendas. *Scratch's* "low floor" approach to introducing programming has led to its use in formal school settings where computer programming might not otherwise have been attempted, such as elementary school; and its high ceiling has led to its being used in introductory programming classes at universities including Harvard and MIT (Resnick et al., 2009). But these uses, especially the K-12 uses, have been the exception for *Scratch*, not the norm, which remains most popular in informal contexts.

The ScratchEd project (Brennan, 2012) is an explicit attempt to explore the implications of using *Scratch* in formal K-12 settings, and in so doing has captured many of the struggles that teachers face when attempting to employ technology to teach computational thinking through an extensive level of technology integration, with students participating not only in a classroom-based learning community but also in the broader global community of Scratchers. Brennan frames her exploration along two dimensions: agency and structure. She defines agency as "a learner's ability to define and pursue learning goals" and structure as "rules, roles, and resources, both explicit and assumed" (Brennan, 2012, p. 28). These dimensions capture both the "wide walls" that the *Scratch* designers value so highly in informal learning, and the rules, curriculum goals, and assessment requirements of the formal classroom within a school context. Brennan explored this interaction with 30 "*Scratch* educators" across both formal (n=15) and informal (n=15) settings.

Brennan investigated agency through conversation with students, to find out what interested them about programming in *Scratch* and participating in the community. We focus on structure here, as the dimension that is more often associated with educators. Some types of structure experienced by *Scratch* educators in the informal environment included: individuals' personal interest and current abilities; the affordances of the *Scratch* authoring environment and the community web portal; the attitudes and support of parents, siblings, and others around the Scratcher; and (peripherally), the nature of teachers' experiences with learning in schools and how this shapes their thinking about the value of computer programming (Brennan, 2012). These dimensions of structure are framed as continua. They are neither inherently positive or negative, but rather are categories along which Scratchers can encounter either support or constraint.

For *Scratch* educators working in formal K-12 classroom settings, the types of structure described were both similar to those of the informal settings, but also much more varied and fraught with potential trouble for the integration of *Scratch* in a way that values its "wide walls" roots. For instance, teachers' attitudes towards open-endedness and experience with technical, content, and pedagogical knowledge were both seen as areas of challenge. Dealing with a wide range of student abilities and potential unwillingness to experiment with new and unfamiliar modes of learning is another challenge. Issues of computer access, security, and openness were seen as challenges. A further challenge is that it might be difficult for teachers to see themselves in more collegial and mutually-supportive roles, both with other teachers and with their students. But perhaps the most difficult aspects of structure with respect to enabling or constraining agency in schools that use *Scratch* is the time-regulated nature of the school day and semester, and the challenge of balancing "simple assessment" with "meaningful assessment." When student work is allowed to follow student interests, it makes it much more challenging to establish baselines and protocols for grading, something that is not necessary in informal settings (Brennan, 2012).

The Maker Movement: Leveraging Passion-Driven Learning

The maker movement is a more recent emergence, but one with many parallels to the long-running work of Papert and *Scratch*. Though the "movement" may be recent, "makers," are a broad community with deep roots that includes scientists, engineers, crafters, musicians, and all do-it-yourselfers who enjoy understanding and creating, as opposed to merely consuming, technology (New York Hall of Science, 2010, 2013). Work in these spaces encompasses computer programming and other electronics, but also with materials such textiles as a means of broadening participation and enhancing a focus on design thinking (Peppler & Glosson, 2012). Maker culture is a manifestation of apprenticeship learning (Rogoff, 1995) and communities of practice (Wenger, 1998), where learning is driven by passion and thus learners are motivated to struggle through challenges. Recent attention to maker spaces attempts to understand why they are so powerful (Thomas & Brown, 2011), and then to build bridges between these informal learning spaces and formal education (Ito et al., 2013).

Environments and tools that support computational thinking and support learners as makers and creators offer both great opportunity for realizing the ambitious goals of extensive technology integration, but are also object lessons in how easy it is to convert an ambitious educational experience into a traditional lesson that preserves the discrete role of learner as receiver of knowledge and teacher as deliverer. Tools like *Scratch* and the bridge it provides between the informal and formal learning worlds offer some insight into a pathway to enable deep and transformative learning for students. Approaches that take transformational tools such as computational environments for simulating and tinkering with complex systems offer another pathway, but one that begins with the formal structures of schooling and teaching.

At present, maker spaces most commonly exist outside of formal education settings, such as in libraries, museums, or after-school drop-in locations. As such, maker spaces are currently removed from the domain of "formal" teaching. However, we view these (often technology-rich) environments as a prime example of a context that will grow in importance as a site for 21st century and engaged learning (e.g., Collins & Halverson, 2009; Thomas & Brown, 2011). As such, it is crucial for the field to begin to help teachers understand how to bridge between formal and informal teaching and learning spaces. This is what the 2010 National Educational Technology Plan envisioned in discussing "connected teaching" (U.S. Department of Education, 2010).

Immersive Interfaces that Situate Learning

Immersion is "being there," the subjective sense of having a comprehensive, realistic experience in a place where one is not physically located (Slater, 2009, p. 3549). For example, a well-designed movie draws viewers into the world portrayed on the screen, and they feel caught up in that virtual environment. Technologies can induce immersion via sensory stimuli, participants' abilities to influence what happens in the environment, and the use of narrative and symbolism to create credible, engaging situations (Dawley & Dede, 2013). Two types of immersive interfaces underlie a growing number of formal and informal learning experiences (Dede, 2009a):

- Multiuser virtual environment (MUVE) interfaces offer students an engaging "Alice in Wonderland" experience in which their digital avatars in a graphical, virtual context actively participate in experiences with the avatars of other participants and with computerized agents. MUVEs provide rich environments in which participants interact with digital objects and tools, such as historical photographs or virtual microscopes (Ketelhut, Nelson, Clarke, & Dede, 2010).

- Augmented reality (AR) interfaces enable students carrying mobile wireless devices through real-world contexts to interact with virtual information, visualizations, and simulations superimposed on physical landscapes. For example, via AR a tree might describe its botanical characteristics, a historic photograph might offer a contrast with the present scene, or a cloaked alien spaceship might appear, visible only through the mobile device. This type of immersion infuses digital resources throughout the real world, augmenting students' experiences and interactions (Klopfer, 2008).

The military and the entertainment industry have expended substantial resources in developing these immersive media, which have many applications in precollege and higher education, as well as for training and professional development.

Capabilities of Immersive Interfaces for Teaching and Learning

Virtual worlds began with single-user, text-based interactive environments in the 1970s, in the form of adventure games and 'multi-user domains'; through advances in technology and design, modern MUVEs are quite detailed and include sophisticated forms of interaction. In contrast, AR is a relatively new technology developing as mobile devices such as smart phones become more powerful; design strategies for rich interaction are still evolving. The sections below describe teaching strategies for the use of MUVEs, then discuss similar instructional approaches for AR.

Immersive interfaces are designed to be used in instructional contexts where each student has a device capable of interacting with the learning medium (typical of intermediate and extensive levels of technology infrastructure). If a teacher was limited to level one technology infrastructure or integration, they could in theory use an immersive interface by projecting an image of a virtual world visible to the entire class. The teacher could demonstrate aspects of a virtual world and then ask students to collectively agree on what actions a single avatar might take. However, virtual worlds are not designed for this type of whole-group interaction, and such a teaching strategy undercuts the theories of learning on which immersive interfaces are based; the same concerns apply to augmented realities. With a technology infrastructure in which teams of two to three students shared devices, a teacher could attempt to use a virtual world or augmented reality, but both theory and experience suggest substantially lower engagement and educational outcomes. For these reasons, immersive interfaces are of value primarily with intermediate and extensive levels of technology infrastructure.

Ways that Immersive Interfaces Support Knowledge-Centered Instruction

Both MUVEs and ARs enable developing knowledge-centered learning experiences in which students encounter richly detailed, simulated real-world situations with challenges that can be resolved through applying academic knowledge and skills (e.g., the biology-based protocols and practices used by a diagnostician examining a virtual patient to determine what illness is present). Sometimes these learning experiences are designed as games that foster problem solving skills related to a particular role or situation (Barab, Gresalfi, & Ingram-Goble, 2010; Shaffer, 2008); at other times, immersive media for teaching are designed not as games, but instead as simulations that draw on theory-based and empirical insights about engagement, motivation, flow, and self-efficacy (National Research Council, 2011b). The latter deliberately do not include some types of engagement common in games (e.g., extrinsic rewards, scoring systems, competition among participants) that may undercut intrinsic motivation and learning for some students, using instead the importance and relevance of the (simulated) real-world challenge as the primary motivator. Later sections of this chapter on games and simulations describe this in more detail.

How are immersive media different from similar types of knowledge-centered learning experiences a teacher might choose, such as non-immersive games and simulations? For example, one could teach some parts of physics with a simple two-dimensional game in which the player fires a cannon at a distant object, changing the angle of the cannon's barrel to determine where its shell will impact. However, an instructional designer might instead select a more complex, immersive setting if he or she wished to foster constructivist/interpretivist learning where students engage in sense-making by providing rich, loosely structured experiences and guidance (such as apprenticeships, coaching, and mentoring) that encourage meaning-making without imposing a fixed set of knowledge and skills or a narrow path to success (Dunleavy & Dede, 2013).

An instructional designer might also utilize an immersive interface because this enables the enactment of situated learning theory, in which learning is defined as embedded within and inseparable from participating in a system of activity deeply determined by a particular physical and cultural setting (Chaiklin & Lave, 1993). The unit of analysis is neither the individual nor the setting, but the relationship between the two, as indicated by the student's level of participation (Greeno, 1998). From this perspective, learning and cognition are understood both as progress along trajectories of participation in communities of practice and as the ongoing transformation of identity (Wenger, 1998).

As a pedagogical approach, immersive interfaces align well with both constructivist and situated learning theories. As a knowledge-centered instructional strategy, immersion positions the learner within a virtual or real-world physical and social context while guiding, scaffolding, and facilitating participatory and metacognitive learning processes such as authentic inquiry, active observation, peer coaching, reciprocal teaching, and legitimate peripheral participation with multiple modes of representation (Palincsar, 1998; Squire, 2010).

Another reason an instructional designer might select an immersive interface is the important educational goal of knowledge transfer. A variety of studies have documented the relative effectiveness of various educational simulations for transfer of skills into business and healthcare (Fraser et al., 2012; Mayer, Dale, Fraccastoro, & Moss, 2011; Norman, Dore, & Grierson, 2012). Research on the extent to which immersive interfaces can foster transfer of knowledge and skills into real world settings is an important frontier for the field. Much early work in this area was conducted for the military, in domains including flight simulators and language and culture simulations for soldiers serving in Afghanistan and Pakistan (Chatham, 2007). The stakes in these simulations is high (life and death), and transfer of skills from the simulation to real-world application is therefore critical.

Overall, an instructional designer might select an immersive interface to foster knowledge-centered learning and assessment of sophisticated knowledge and skills that are contextually dependent and are not based on a narrow formulaic method. Immersive interfaces provide a good vehicle for teaching advanced subject-specific skills and content in ways that the student's experience is authentic and promotes transfer. An example used in the *River City* curricular case, discussed later, is scientific inquiry. This is a well-studied cognitive and psychosocial understanding/performance based in part on subject matter knowledge appropriate for a particular context (e.g., physics in a situation involving magnetic fields, such as high voltage power lines) and in part on process skills such as using appropriate tools and techniques to gather, analyze, and interpret data; developing prescriptions, explanations, predictions, and models using evidence; thinking critically and logically to make the relationships between evidence and explanations; and recognizing and analyzing alternative explanations and predictions (National Research Council, 1996). Scientific inquiry (in its deepest sense) cannot be learned effectively through a tutoring system or some form of direct instruction; inquiry skills are best motivated and taught in a real-world apprenticeship as part of a research team, in an immersive simulation of this experience, or in guided project- or problem-based experiences in classroom settings (Kuhn, Black, Keselman, & Kaplan, 2000).

Ways that Immersive Interfaces Aid Learner-Centered and Community-Centered Instruction

Because of the richness of the representations they offer, immersive interfaces can incorporate many powerful learning mechanisms for engaging students and, over time, increasing their motivation as learners. In a MUVE, each participant uses an avatar (a digital representation of oneself) to interact with digital agents, artifacts, and contexts. Theories about motivation from social psychology describe various reasons why participants might become highly engaged in a virtual world and might be motivated to frequently seek out this experience (Dawley & Dede, 2013). Aspects of a virtual experience that promote intrinsic motivation include intrapersonal factors such as challenge, control, fantasy, and curiosity, as well as interpersonal factors such as competition, cooperation, and recognition (Bartle, 2003). The challenge dimension of engagement is heightened when a participant achieves a state of flow through facing challenges that are difficult but surmountable at his or her current level of skill (Csikszentmihalyi, 1988). Other generic, intrinsic factors that heighten motivation include the perceived humanistic value of an activity in light of personal and cultural preferences (Brophy, 1999), perceived personal competence in accomplishing the goals of an activity (Dweck, 2002; Schunk & Pajares, 2005), and perceived autonomy in making choices within an activity (Ryan & Deci, 2000).

Przybylski, Rigby, and Ryan (2010) summarized these dimensions of motivation as applied to videogames, many of which involve immersive interfaces. Lepper and Henderlong

(2000) described various ways that extrinsic incentives used to promote participating in an activity, but unrelated to the intrinsic nature of the experience, can undercut learning and intrinsic motivation, if overdone. They discussed how personal choice, the use of meaningful contexts, emphasizing learning goals, and providing appropriate levels of challenge aid with internalizing intrinsic motivation. Ryan and Deci (2000) delineated how factors such as modeling by others to whom learners feel attached, perceived competence of the learner, and personal autonomy are powerful for ensuring that educational experiences that begin with extrinsic motivators culminate in participants having strong intrinsic motivation. Habgood and Ainsworth (2011) describe design strategies for facilitating intrinsic motivation through games that integrate the learning goals into the core mechanics and the fantasy scenario of the game.

The experience of situated embodiment lies at the heart of immersive experiences in which one feels psychologically present in a context that is not where the person is physically located (Winn, 2003). In virtual worlds (VWs) and immersive simulations, situated embodiment is based on the willing suspension of disbelief (Dawley & Dede, 2013), as it is in nearly all narrative media. In contrast to passive media, however, in virtual worlds and immersive simulations the learner constructs the narrative through interaction. Situated embodiment in virtual environments and immersive simulations offers the potential for identity exploration, in which a participant plays a role different than that portrayed by that person in everyday life (Gee, 2003; Turkle, 1984, 1997). Laurel (1993) and Murray (1998) described design strategies that can enhance participants' identity exploration, such as providing options to modify the avatar's appearance, gender, or clothing; creating role-play opportunities in historical or fantasy-based settings; and experiencing learning opportunities to be someone other than themselves and reflect on the shift.

Social network knowledge construction (SNKC) is a pedagogical model for virtual world learning (Dawley, 2009). SNKC takes advantage of the various social network communication mechanisms that are available to participants in virtual worlds, leading learners through a five-stage process: identify, lurk, contribute, create, and lead. Dawley (2009) listed over 15 in-world and out-of-world communication mechanisms potentially available in virtual worlds, including private messaging, group and global chat, and social media. When leveraged effectively by teachers, these communication options can support increased engagement and motivation, group action, individual transformation, and shared meaning-making opportunities (Dawley & Dede, 2013). Community presence to induce a sense of belonging and group purpose is another affordance supported in virtual worlds through communication mechanisms such as groups, guilds, and clans (Warburton, 2009). This can provide powerful mechanisms for enhancing the community-centered dimension of instruction.

Well-designed educational MUVEs can be so motivating that students voluntarily spend substantial extra time in them outside of the classroom (National Research Council, 2011b). Virtual worlds designed for informal learning are not so engaging that they will displace entertainment games, but some sites such as *Whyville* have garnered a large set of followers who spend substantial time there (Kafai, Quintero, & Feldon, 2010). Almost all students have experienced some form of virtual world; younger children may have played in *Club Penguin* or *Webkins*, tweens in *Whyville* or *Runescape*, and adolescents in *World of Warcraft* or *America's Army*. Pupils typically bring learning strengths and preferences in entertainment virtual worlds to educational MUVEs. Teachers can leverage these out-of-classroom experiences if they are aware of them and understand the potential connections between informal experiences and the formal classroom curriculum (U.S. Department of Education, 2010).

As a complementary type of immersive interface to virtual worlds, AR utilizes mobile, context-aware technologies (e.g., smartphones, tablets with GPS location capabilities) and software that enables participants to interact with digital information interwoven within the physical environment (Dunleavy & Dede, 2013). Two forms of AR are currently available to educators: location-aware and vision-based AR. Location-aware AR presents digital media to learners as they move through a physical area with a GPS-enabled smartphone or similar mobile device. The media (i.e., text, graphics, audio, video, 3D models) augment the physical environment with narrative, navigation, and/or academic information relevant to the location. This is similar to systems used in museums to provide more information about an exhibit. In contrast, vision-based AR presents digital media to learners after they point the camera in their mobile device at an object (e.g., QR code, 2D target). This is sometimes thought of as a "heads-up" display, layering digital information on top of the real-world scene.

As an interface that fosters a blend of digital immersion and the real world, AR shares with virtual worlds many of the affordances for learning already discussed. The unique power of AR as a learning tool is its ability "to enable students to see the world around them in new ways and engage with realistic issues in a context with which the students are already connected" (Klopfer & Sheldon, 2010, p. 86). This includes the ability to present to a group of learners multiple incomplete, yet complementary perspectives on a problem situated within a physical space, enabling collaborative pedagogical techniques and design approaches, such as jigsaw and differentiated role-play, which lend themselves well to inquiry-based activities requiring argumentation (Dunleavy, Dede, & Mitchell, 2009). By embedding these multiple perspectives within the environment and contextualizing them within a problem-based narrative, AR also affords educators the ability to leverage physical space as an additional layer of content for students to observe, manipulate, and analyze (Squire et al., 2007).

Numerous studies document high engagement by students and teachers as a result of using augmented reality: adopting roles; negotiating meaning within active, inquiry-based compelling narratives; solving authentic problems; and physically exercising (Dunleavy & Dede, 2013). In a field trip situation, the ability to access resources on the Internet, coupled with readings, tools, visualizations, and simulations on the device to resolve the learning environment's challenges, are other unique affordances of AR. Due to the proliferation of mobile devices and (relative to virtual worlds) the greatly reduced technical challenge of creating these immersive learning experiences, the barriers to sustainability, distribution, and user acceptance of AR are decreasing rapidly. Many groups are now releasing apps for mobile phones that allow any user to create an AR data-layer over a physical space, making it possible for teachers to construct their own augmented learning experiences for students.

Ways That Immersive Interfaces Aid Assessment-Centered Instruction

Virtual environments—because of their situated nature and because they generate log files—make it possible to design for eliciting performances, to collect continuous data, and to interpret structures of evidence. In a virtual world, the server documents and timestamps actions by each student: movements, interactions, utterances, saved data, and so on (Dede, 2012). Augmented realities do not collect quite as rich a dataset, because students are interacting extensively in the real world in ways that the interface does not capture. Both types of immersive environments, however, collect richer data about students' behaviors and performances than do most learning technologies.

As an illustration, the virtual world in Dede's *River City* curriculum (discussed below) stores minutely detailed records of the moment-by-moment movements, actions, and utterances of each participant in the environment (Ketelhut, Dede, Clarke, Nelson, & Bowman, 2007). With the data-tracking system, information on the activities of each student as s/he explored the MUVE is collected, stored, and retrieved. These data formed the basis of a personal MUVE history of each student that followed him or her from session to session, in the form of extensive log files—a feature impossible to replicate in a classroom-based experience. The level of detail in these records was extensive: the logs indicated exactly where students went, with whom they communicated, what they said in these interactions, what virtual artifacts they activated, and how long each of these activities took. This data potentially provides very rich evidence for formative and for summative assessments of what students do and do not know (Dede, 2012).

Teaching with Virtual Worlds: Opportunities and Challenges

The following contrast between two curricula illustrates distinctions among teaching with virtual worlds designed specifically for use in classroom settings to meet curriculum standards, and virtual worlds designed for informal learning with less focus on particular curricular and assessment objectives.

River City. The NSF-funded *River City* multiuser virtual environment is centered on skills of hypothesis formation and experimental design, as well as on content related to national standards and assessments in biology and epidemiology (Dede, 2009a). Students learn to behave as scientists as they collaboratively identify problems through observation and inference, form and test hypotheses, and deduce evidence-based conclusions about underlying causes. Learners immerse themselves inside a simulated, historically accurate 19th century city. Collaborating in teams of three or four participants, they try to figure out why people are getting sick and what actions can remove sources of illness. They talk to various residents in this simulated setting, such as children and adults who have fallen ill, hospital employees, merchants, and university scientists.

Research results from *River City* showed that a broader range of students gain substantial knowledge and skills in scientific inquiry through immersive simulation than through conventional instruction or equivalent learning experiences delivered via a board game (Clarke & Dede, 2009). Findings indicated that students are deeply engaged by this curriculum and develop sophisticated problem-finding skills (in a complex setting with many phenomena, problems must be identified and formulated before they can be solved). Compared with a similar, paper-based curriculum that included laboratory experiences, students overall (regardless of factors such as gender, ethnicity, or English language proficiency) were more engaged in the immersive interface and learned as much or more (Ketelhut et al., 2010).

Many academically low-performing students did as well as their high-performing peers in *River City* (Ketelhut et al., 2007), especially on performance-based measures (such as a letter to *River City's* mayor describing an intervention to help reduce illness and providing evidence to support this claim). Digital immersion allowed these students to build confidence in their academic abilities by stepping out of their real-world identity of poor performer academically, which shifted their frame of self-reference to successful scientist in the virtual context. As discussed earlier, this suggests that immersive media may have the potential to release trapped intelligence and engagement in many learners, if we can understand how best to design instruction using this type of immersive, simulated experience.

Teachers were provided with a variety of supports to aid their usage of the *River City* curriculum. They had access to a variety of videos designed to introduce both students and teachers to the curriculum. Teachers were provided with an Implementation Guide, which detailed the types of activities students and teachers experience in the *River City* curriculum, and a Teacher Lab Book that provides day by day lesson guides, as well as appendices and a Curricular Insights document providing a detailed background on causal factors in this virtual world. As with teacher guides for more conventional curricula, these materials suggested ways to group learners and to remind students of important themes in the curriculum, as well as questions to ask students as they puzzle out what is happening over time in *River City*. Stress was placed on teachers facilitating students in conducting team inquiry, rather than providing answers.

Teachers also had access to professional development experiences to help them understand how instruction using a virtual world is different than conventional pedagogical approaches. Sometimes, when a sufficient number of teachers were available in a locality, one- or two-day workshops were delivered through face-to-face training. As an alternative, four hours of online training was delivered to some teachers via web conferencing. The project also provided professional development sessions and training materials to teachers who then served to train other teachers in using *River City*. In all these experiences, teachers learned content, instructional approaches, and the usage of various administrative tools, such as an online dashboard teachers used to assign students to teams and to track their progress through the curriculum.

Further, as an ongoing support, the *River City* research team provided teachers with daily updates showing representations of student activities (e.g., their path through the world, a summary of their accomplishments). Teachers who chose to use this information found it helped them identify struggling students, as well as misconceptions held by many students. This in turn shaped both individual interventions and group instruction. The *River City* research team refined its instructional supports and professional development over time, based on the types of challenges teachers encountered. Some teachers needed help with understanding the content in biology and epidemiology, or the process of scientific inquiry. Others struggled to shift from presenting facts and answering students' questions about content to instead guiding active learning, suggesting ways students could answer their own questions. Many teachers were startled to see typically unengaged or low performing students doing well in the *River City* curriculum and wondered why this would be the case.

Ketelhut and Schifter (2011) studied teachers' implementations of *River City* and the types of professional support that proved most helpful. They found that providing teachers with sufficient time to experience *River City* themselves and understand its pedagogical model was vital for success of a curriculum so different than what teachers were accustomed to using. Models of successful implementations were helpful for teachers, as were just-in-time supports for both technical and pedagogical challenges.

Because immersive interfaces are such a rich medium for situated learning, many different pedagogical structures and activities are incorporated into educational virtual worlds. Feedback, examples, self-explanation, peer interactions, collaborative learning, visualizations and simulations, metacognition, spatial representations and imagery, and model-based reasoning and argumentation can all be supported by a sophisticated virtual world for learning. The division of labor for these activities is complex, with in-world computer-based agents, video clips, online lab manuals and notebooks providing technology-based instruction to complement teachers' interventions.

Given this, teachers need professional development to understand how best to take advantage of these embedded affordances. For example, teachers can direct students to in-world agents who provide information and guidance – this deepens engagement, immersion, and verisimilitude compared to the teacher providing similar support. As another illustration, by having students draw on peers in their team to supply knowledge, thus coordinating complementary activities based on different experiences, leaners' skills in collaboration and metacognition are developed. These are not modes of learning available in presentation-centered (level one technology) classrooms.

Quest Atlantis. In contrast with *River City*, which was developed solely for classroom use, the *Quest Atlantis* virtual world was designed for usage both in classroom settings and as an informal learning experience. As described on its website, *Quest Atlantis* is intended to engage children ages 9–16 in a form of transformational play comprising both online and off-line learning activities, with a storyline inspiring a disposition towards social action. The core elements are 1) a 3D multi-user virtual environment, 2) learning quests and unit plans, 3) a storyline, presented through an introductory video, novel and comic book, that involves mythical characters and a set of social commitments, 4) a globally-distributed community of participants, and 5) a narrative programming toolkit for remixing user-created stories. The activities of the project take place in registered centers, typically schools, under the direction of teachers who have undergone professional development and training. Play opportunities include both curricular and optional projects that unfold both online and away from the computer, as children work alone or together to accomplish tasks within the *Quest Atlantis* community. This discussion focuses on the teacher's role in supporting academic disciplinary learning activities in *Quest Atlantis*.

As an example of such an activity, the Taiga Water Quality Unit is an interactive narrative set within an aquatic habitat (Taiga National Park) where a serious ecological problem has resulted in many fish dying. In the unit, students navigate through the virtual park and interact with other players and non-player characters who communicate their perspective on the problem. Taiga best exemplifies the potential for connecting content with context by supporting students' experience of the consequentiality of their actions. For example, after students have begun to learn about potential causes of the fish demise in Taiga Park, they are asked to make a recommendation about how to resolve the issue. In making this decision, students have to consider their conceptual tools (i.e., understanding eutrophication, erosion, and overfishing) in order to make a recommendation about what to do: stop the indigenous people from farming, or tell the loggers they can no longer cut trees in the park, or shut down the game fishing company (Barab et al., 2007). Comparison studies (Barab et al., 2009) show learning and motivation gains over traditional science curricula.

The overview letter that describes *Quest Atlantis* to potential users indicates that teachers are an integral part of the gameplay experience, taking on roles in the virtual world and complementing *Quest Atlantis* activities with associated in-class learning. The letter encourages teachers to modify and personalize the *Quest Atlantis* curriculum to their needs, including developing their own in-world learning activities. To aid in this, *Quest Atlantis* resources are available to help teachers to understand how best to support their students in this virtual world. There are suggested entry quests and videos to help teachers get started, and numerous lesson plans to follow for more guided experiences. A Teacher Toolkit is available with utilities for instructors to review work, provide feedback, track progress, and automatically maintain student data (graphs, missing work, amount completed, etc.) for easy monitoring of learning. Also, teachers can choose to evaluate their student quests themselves, or opt to assign this to student review (by others in class) or community review (by students located, potentially, anywhere in the world).

Even with these supports, using a virtual world curriculum in the classroom can be challenging (Thomas, Barab, & Tuzun, 2009). For example, maintaining appropriate chat and email content among students was a concern for teachers, particularly as the community began to have many international interactions. As with *River City*, providing technical support to keep the virtual world functioning despite issues with school infrastructures posed problems. Because the pedagogical model underlying virtual worlds is a major shift from the type of instruction many teachers typically use, providing emotional support for making this transformation was important. In an implementation of *Quest Atlantis* in Singapore, cultural issues came into play as well; students were used to learning by rote and struggled to understand how to engage with content reflectively (Lim, Nonis, & Hedberg, 2006). As a result, the teacher had to provide substantial structure for students to move through the curriculum.

Providing professional development for any multi-dimensional, rich virtual world is difficult because teachers' motivations for what they want students to get out of virtual worlds vary, ranging across emphasizing mastery of content, developing writing and critical thinking skills, or focusing on student empowerment and social commitments. As an informal learning environment, the flexibility of *Quest Atlantis* in customizing to teachers' individual goals is a strength, yet the time and effort involved in teachers personalizing the curriculum to their classrooms can be considerable.

Issues in Teaching with Virtual Worlds.

Overall, in terms of opportunities/challenges with use of virtual worlds in school contexts, classroom settings offer the opportunity to design and implement the virtual world with the teacher as a resource, as well as the intertwined constraint of teachers who do not implement the curriculum in the manner its designers intended, inadvertently undercutting student learning (Dede, 2005). Professional development is an important method of reducing issues with fidelity of implementation. For example, over the last two years of the *River City* project, 94% of participating teachers rated as useful the four-hour pre-implementation training online. In-field *River City* trainers reported fewer problems with teachers undercutting intended pedagogy in those educators who invested time in either developer-provided face-to-face or online professional development.

Also, school settings frequently have the constraint of inadequate technology infrastructures, as well as offering the intertwined benefit of student technical support. For example, in *River City* and in *Quest Atlantis* a chronic implementation problem in classroom settings was teachers' access to an adequate, reliable technology infrastructure; these teachers did not have access to a level two (intermediate) infrastructure. In schools with technology labs as their mechanism for 1-1 student-computer ratios, teachers using the *River City* curriculum sometimes complained of resentment from other teachers who were competing for access to that scarce resource. When schools instead created just-in-time classroom infrastructures using laptops on carts, precious time was lost each session in activating the network among machines and the server.

Further, for reasons of security, student safety, and privacy, districts often have idiosyncratic, flawed ways of enabling network access to outside resources, some as extreme as simply blocking everything external. In the United States, districts with an extreme interpretation of the Child Internet Protection Act (CIPA) may disable by default many of the Internet capabilities that might be built into a virtual world. For implementations of the *River City* curriculum in hundreds of schools during the 2008-09 academic year, our project team included a quarter-time technology specialist to handle, sometimes school by school, bizarre and dysfunctional network configurations. Such a situation means that teachers do not have access to a level two (intermediate) infrastructure, even though the hardware is in place.

In classroom use of a game or simulation, students often request access outside of school; this can increase immersion, enhance engagement, and more closely align instruction with students' informal learning strategies. *Quest Atlantis* utilizes this approach. However, complementing learning in the classroom with assigned or voluntary access to virtual worlds outside of school presents several challenges, unless that learning is supervised as in a club or a camp setting. Students who have ready access to the technology infrastructure needed have a differential advantage over those who do not. Further, if the virtual world is multi-user, then the possibility exists of students engaging in inappropriate behavior when unsupervised (e.g., cyberbullying, swearing). Although communities like *Quest Atlantis* rely on peer pressure to enforce positive social norms, to guarantee a safe setting the *River City* developers restricted use of their curriculum to in-school settings (class, lunch period, before or after school) in which an adult was present as monitor. They also built an automated "swear checker" that would respond to the use of bad words in student chat, reminding them to watch their language. Moreover, they provided teachers each morning with chat logs of their students from the previous day, so that they could closely monitor student activities to encourage appropriate, on-task behaviors (Clarke & Dede, 2009). Students quickly realized they were more closely monitored in the virtual world than in other types of project based learning, in which the teacher could not closely supervise every group's work simultaneously.

In summary, virtual worlds offer many advantages in teaching complex content and skills in an engaging manner that scaffolds transfer. These advantages can be realized both with in-school and out-of-school usage. However, classroom implementation involves a variety of challenges for the teacher, including overcoming technical issues, shifting to a different form of pedagogy, ensuring appropriate behavior when students interact online, and helping learners shift from rote assimilation to reflective interpretation. New models of professional development are needed to aid teachers realize the full potential of this immersive medium.

Teaching with Augmented Realities: Opportunities and Challenges

Augmented reality is a more recent medium than virtual worlds, so less is known about its strengths and limits. As discussed later, early studies have shown that augmented reality is a good mechanism for enhancing field trips, by structuring the learning experience in the field and generating collected data and artifacts that can be discussed in post-trip briefings led by the teacher (Kamarainen et al., 2013). The two examples below illustrate educational augmented realities that go beyond enhancing field trips to providing a curriculum and that have substantial research associated with their classroom use.

Environmental Detectives. The *Environmental Detectives* learning experience (http://education.mit.edu/ar/ed.html) is an early, extensive, educational augmented reality for learning that has resulted in many insights for the field (Klopfer, 2008). The goal of this experience is to develop in participants, through playing an augmented reality game, the types of authentic practices used by environmental engineers in resolving a contamination issue. Designed for participants high school age and older, the game is not tied to a classroom curriculum, but does include briefings before and after the augmented reality experience. Over a period of several hours, students assume the role of environmental engineers who are presented with the following scenario at the beginning of the simulation:

> During the construction of the underground garage of the new Stata Center at MIT, significant amounts of water are pumped up from the ground in order to lower the groundwater table so that the garage can be constructed in a dry environment. As a matter of regulation, the water is tested for the 25 most commonly found chemicals in groundwater at hazardous waste sites. As a result of the testing it is discovered that a toxin is present in the extracted water. You call the President of the University to report and he asks, "How dangerous is this toxin? Where did the contamination come from and how widespread is it? Does MIT need to take some action (and what action might this be)? What do you advise?" You promise to call him back within three hours with your advice on the problem.

Students watch a 60 second digital video-briefing from the University president in which they are enlisted to investigate the spill of the toxin, a carcinogenic degreasing agent that is commonly found in machine shops, cafeterias, and hospitals. The goal of the game is to locate the source of the spill, identify the responsible party, design a remediation plan, and brief the president of the University on any health and legal risks so that he will be prepared for a meeting with the EPA – all within two hours. At the end of the game, students make a five minute presentation to their peers outlining their theory behind the spill.

The spread of the toxin is simulated on a location-aware mobile device, which functions as a tool which students can use to investigate the toxic spill. Players can sample chemical concentrations in the groundwater, which vary depending on their location. Players are given three reusable drilling apparatuses that they can use to drill for water samples. After drilling for a sample, players must wait three minutes for the sample to return, meaning that students can only take three samples at a time, and are forced to develop sampling strategies in order to optimize the amount of ground that they can cover in limited time. Because the location-aware mobile devices are based on GPS data, which is only accurate within 10 meters, there is some built-in error to the collected readings as well.

The *Environmental Detectives* learning experience contains a multimedia database of resources that students can use to learn more about the chemical, where it is found on campus, the health risks associated with exposure to the toxin, how it flows through ground water, relevant EPA regulations, remediation strategies for cleaning up the toxin, and the political and economic consequences of EPA violations on campus. Students access these resources by obtaining interviews from virtual university faculty and staff who are spread across campus at locations roughly corresponding with actual operations. Because time is limited and there is not enough time to interview everyone or to drill more than a handful of wells, students must make choices between collecting interviews, gathering background information, and drilling wells, adjusting and reprioritizing goals as new information becomes available.

Studies showed that *Environmental Detective*s was engaging for students and built their knowledge of environmental engineering practices (Klopfer, 2008). Research indicated that key affordances of augmented reality enabling these outcomes included mobility, social interactivity, context sensitivity, connectivity, and individuality. Mobility, context sensitivity, and connectivity combine to create learning conditions similar to those in virtual worlds, where students at a location can have experiences that draw on aspects of that setting. Individuality enables students to have differing experiences, even if they visit the same locations, allowing a jigsaw pedagogy that builds collaboration in similar ways to how authentic practices are conducted by environmental scientists. Social interactivity is vital for collaboration; unlike virtual worlds, augmented realities enable face-to-face interaction with all the subtleties that conveys.

When students contrasted this augmented reality experience with a similar experience conducted in a virtual world, responses differed, based to some extent on participants' self-expressed learning preferences (e.g., kinesthetic students preferred the physical movement associated with augmented reality). Students also noted that planning the investigation was easier in the virtual world, but that the real world context of the augmented reality made that experience more compelling and authentic.

In educational augmented realities, the teacher has four roles. Before the experience, teachers must brief students with prior information and skills necessary for them to conduct authentic practice. Also, the logistics of pre-loading each mobile device and helping students activate the sequence of activities can be complex for teachers, although this is becoming simpler as devices increase in power and sophistication. During the experience, the teacher's primary responsibility is monitoring students to ensure their safety outdoors and to resolve questions or technical issues. After the activity, the teacher-led debriefing is very important in helping students understand how to relate what happened to the knowledge and skills they are developing. This cannot be completely scripted before the augmented reality experience, as a variety of unforeseeable events may occur when students are in the field. As a fourth role, in many augmented reality activities, teachers have the opportunity (if they wish) to customize the learning experience to the particular objectives and resources of their local setting. As discussed later, these roles make augmented reality more demanding on teachers than simpler types of invariant learning activities. While these types of preparation by teachers have always been part of well designed field trips, augmented reality technology provides more structure for students wandering around a site outside of the classroom setting as well as opportunities for detailed data collection, but necessitates some overhead in instructional design and in preparation for technology usage (Kamarainen et al., 2013).

Alien Contact! *Alien Contact!* is a six-day, multidisciplinary augmented reality curriculum designed to teach math and literacy skills, as well as collaboration skills, to middle and high school students (Dede, 2009a). Students are presented with the following scenario: Aliens have landed on Earth and seem to be preparing for a number of actions, including peaceful contact, invasion, plundering, or simply returning to their home planet, among other possibilities.

Similar to the other augmented realities discussed, the students work in role-based teams to twice explore the augmented reality world, interviewing virtual characters, collecting digital items, and solving mathematics and literacy puzzles to determine why the aliens have landed. Each team has four roles: Chemist, Cryptologist, Computer Hacker, and FBI Agent. In order to successfully navigate the augmented reality environment and solve various puzzles in mathematics, language arts, and scientific literacy, the students must share information and collaborate with the other members of their team. As students collect this data, they will discover different possibilities for why the aliens may have landed and must form a hypothesis based upon the data collected. At the end of the unit, the students orally present their findings as a team to the class and support their hypothesis with data collected in the field.

Research findings on the *Alien Contact!* curriculum document high levels of student engagement, as well as educational outcomes in literacy and math equivalent to students playing a similar, but less engaging board game as a control condition (Dede, 2009a). The students were highly engaged by the fictional narrative and by the roles they assumed as part of their team.

Teachers also reported that many students unengaged in class were intrigued and motivated by the augmented reality experience (Dunleavy et al., 2009).

In contrast to *Environmental Detectives*, this learning experience was designed to study “place independent” augmented reality that does not draw on location-based features (e.g., a campus, a beach). The research showed, as expected, that place-independent augmented realities are easy to use across a wide variety of settings, requiring less logistical preparation and curricular customization on the part of the teacher, but are limited to knowledge and skills that are not related to a specific location. That said, *Alien Contact!* was designed to enable easy remixing of the game template and puzzles to focus on different subject areas, knowledge, and skills.

Mitchell (2011) studied how five mathematics teachers, selected to exemplify differing characteristics (e.g., level of subject matter preparation, years of teaching experience), implemented *Alien Contact!* The study applied conceptual frameworks, based on prior research, for how teachers adapt curricula designed by others, often for the worse, to see if this occurred with *Alien Contact!* Prior studies of teachers implementing non-technology-based mathematics curricula document adaptations of task structure (e.g., converting a group activity into an individual or whole-class exercise), changing the mathematical quality of the task (e.g., failing to use alternative solution strategies or to recognize promising student productions), and altering the cognitive demands of the curriculum (Hiebert & Stigler, 2004; Hill et al., 2008; Sherin & Drake, 2004; Stein, Remillard, & Smith, 2007). Mitchell found that all five teachers implemented *Alien Contact!* with a lack of mathematical substance, showing low fidelity to the designers’ intent. Adaptations included making mathematic errors (on the part of teachers with marginal subject preparation), pedagogical simplifications to teaching-by-telling rather than facilitating students' mathematic sense-making, and reducing the cognitive demands of curricular tasks. Studies indicated these weaknesses in implementation were primarily due to the logistical complexity of managing a complex instructional experience. Teachers varied in their appraisal of the value of augmented reality, some seeing it as a powerful way of engaging students and fostering learning, others unhappy with the logistical issues and the challenge of teaching in a different manner.

Issues in Teaching with Augmented Realities

Both of these augmented reality learning experiences had substantial logistical overhead from managing the mobile devices. Some of this problem was because augmented reality is still an emerging technology, and these early implementations coupled a handheld device, such as a PocketPC, with a separate GPS device. Modern smartphones combine these two capabilities with many fewer technical and logistical challenges, and current augmented reality authoring is far easier than a few years ago (Dunleavy & Dede, 2013). That said, this type of learning experience requires level three (extensive) technology infrastructure/integration, because the learning experience takes place outside of the classroom and possibly outside of school hours.

Students also frequently experienced cognitive overload in these early augmented reality designs (Dunleavy & Dede, 2013). The complexity of the activities, the challenges of the scientific inquiry process, and the issues of making decisions as a team all contributed to this overload. More recent augmented reality designs have decreased cognitive load by: 1) creating a simplified experience structure initially and increasing complexity as the experience progresses (Perry et al., 2008); 2) scaffolding each experience explicitly (Klopfer & Squire, 2008); 3) limiting characters and items encountered by students to approximately 6 per hour (O'Shea et al., 2009); and 4) replacing text with subtitled audio (Perry et al., 2008).

Because place-based augmented realities are necessarily localized, teachers would need to create their own learning experiences in this medium, or at least adapt a generalized template (say, for water-based ecosystems) to a specific location they could use for field trips. Early studies with *EcoMOBILE* have shown that this type of template adaptation by teachers is not difficult (Kamarainen et al., 2013). This makes feasible the prospect of scaling augmented reality into widespread instructional usage.

Teaching with Computer Games and Simulations

Many of the ideas discussed in the prior section on teaching with immersive interfaces also apply to teachers using games and simulations to aid engagement and learning in and out of the classroom. This section builds on those frameworks and findings about immersive interfaces, focusing on the ways that games and simulations are different than virtual worlds and augmented realities in how teachers can effectively foster students' academic motivation and educational outcomes. Some virtual worlds (e.g., *Quest Atlantis*) and augmented realities (e.g., Environment Detectives) are immersive games, and other virtual worlds and augmented realities simulate authentic real world practices (e.g., *River City*). This section centers on instruction using simpler, non-immersive games and simulations, as well as videogames developed for entertainment purposes, but with potential value for academic learning.

The National Research Council report on *Learning science: Computer games, simulations, and education* (2011b) argued that games and simulations share important characteristics and can be defined along a continuum. Both are based on computational models that simulate phenomena: natural, engineered, or invented. Most games are built as simulations of some real world situation, or an imaginary situation that has similarities to the real world. Both simulations and games enable user interaction and some amount of user control.

However, as the NRC report described, simulations and games are distinct along several dimensions. Simulations are computational models that allow users to explore the implications of manipulating or modifying parameters in natural phenomena and in real or hypothesized situations (Clark, Nelson, Sengupta, & D'Angelo, 2009). Unlike a static visualization, such as a diagram in a textbook, simulations are dynamic and allow user interaction. As described later, some educational simulations allow users to observe and interact with representations of processes that would otherwise be imperceptible in the real world. Scientists, economists, and other professionals routinely use simulations to model and understand phenomena.

The NRC report delineated several ways in which computer games differ from simulations. Unlike simulations, which are typically used in an educational or workplace setting, games are often played in informal contexts, on a voluntary basis, without instructional guidance—although teachers sometimes bring these leisure-oriented games into classroom settings. Also, games usually have explicit goals and rules, as well as well-defined outcomes (often construed as winning or losing, although not all games are competitive). More than simulations, games provide feedback to measure players' progress towards outcomes, and players can influence progress by their actions and overall strategies of play. "Serious" games are rising in popularity, with an estimated $1.5 billion spent on education and training games worldwide in 2011 (Derryberry, 2011).

In contrast to simulations and educational games, commercial video games are a huge business that in 2011 involved $24.75 billion on video games, hardware, and accessories (Entertainment Software Association, 2012). A national survey of young Americans aged 8 to 18 found that their use of video games grew 24 percent from 2006-10, reaching a daily average of 1 hour, 13 minutes (Rideout, Foehr, & Roberts, 2010). This section describes the opportunities and challenges for teaching and learning with non-immersive educational simulations and games, as well as with commercial videogames.

Capabilities of Games and Simulations for Teaching and Learning

Two recent, substantial reviews of research on educational games (Tobias & Fletcher, 2011; Young et al., 2012) delineated findings about the capabilities of these media for teaching and learning. Tobias and Fletcher, in aggregating various studies on the effectiveness of games for education, found that capabilities acquired during gameplay can generalize to non-game environments, including education and training contexts as well as everyday life. As one illustration for transfer of generic intellectual skills, research suggests that some games can increase the speed of mental processing, sensitivity to inputs in the environment, and flexibility in allocating cognitive and perceptual resources (Anderson & Bavelier, 2011). To attain transfer from the game to curricular tasks and to tasks in the real world, substantial overlap is required between the cognitive processes engaged by the game and those required for the tasks; superficial similarities do not lead to transfer. Teachers play an important role in scaffolding this transfer, by employing pedagogies that stress the links between knowledge and skills in the game or simulation and their applications in life situations.

Overall, Tobias and Fletcher (2011) found that games providing imaginative play, rapid responses, challenges, and competition—at levels appropriate to a player's cognitive constraints (e.g., mental workload, prior knowledge)—could develop knowledge and skills related to academic topics and to life situations. They also found substantial research to support the assertion that well designed games are engaging and motivate most players to spend substantial time interacting with them.

Young and his colleagues (2012) focused on commercial video games, as opposed to serious games for learning. They concluded that studies to date did not generally support the educational value of using video games in classrooms. Their research posits that this may be due in part to how video games are often used in schools, as quick activities that may have too low a “dosage” of multiplayer interaction, continuity of learning, and extended engagement. Even under these adverse conditions, they did find some positive results of videogames for language learning and, to a lesser degree, physical education.

The outcomes from these two reviews of research on the use of games (whether explicitly educational or not) are generally consistent with the findings of the NRC report on games and simulations for teaching science (2011). The NRC found that simulations and games are worthy of future investment and investigation as a means to improve science learning. These media were seen as having the potential to advance motivation to learn science, conceptual understanding, science process skills, understanding the nature of science, scientific discourse and argumentation, and identification with science and science learning. In practice, this potential was partially realized by current simulations of scientific phenomena, which were judged by the NRC as promising in improving conceptual understanding, moderate in motivating students’ interest in science and science learning, and unproven in supporting other science learning goals. Although we believe that the early results are promising, the evidence for games in supporting science learning was judged inconclusive, largely due to a very limited base of high quality research findings. Presumably, similar conclusions could be reached for the potential of games and simulations in other curricular areas.

For all types of games and simulations, the value of the experience for learning is determined in part by reflection, which typically takes place outside of the gameplay itself. As with social media, this means that teachers must understand how the technology-based learning environment shapes students' thinking, so that instruction can complement the strengths and limits of the instructional medium.

Ways that Games and Simulations Support Knowledge-Centered Instruction

Games and simulations support developing knowledge-centered learning experiences in ways similar to MUVEs and ARs. As discussed earlier in this chapter, non-immersive games and simulations are simpler, less-constructivist media than immersive interfaces, providing more tightly structured experiences that support acquiring a fixed set of knowledge and skills by following a narrow path to success. Situated learning, a hallmark of immersive interfaces, is far less pronounced in typical games and simulations, which provide little sense of context other than the essentials of the situation that is modeled. (While video games often have detailed contexts, the emphasis is typically on fantasy environments rather than emulating authentic settings.) Knowledge transfer is less scaffolded in simple games and simulations because the real world is far more complex that the mechanisms these media depict, forcing far transfer by students rather than near transfer. That said, simple games and simulations provide a quick, relatively easy way of scaffolding the acquisition of uncomplicated knowledge and skills through active learning rather than passive assimilation. However, the teacher must aid in fostering transfer from the simulated environment to the real world.

Ways that Games and Simulations Aid Learner-Centered and Community-Centered Instruction

Games and simulations share with MUVEs and AR the ability to promote students' intrinsic motivation through intrapersonal factors such as challenge, control, fantasy, and curiosity, as well as interpersonal factors such as competition, cooperation, and recognition. As with immersive interfaces, the challenge dimension of engagement is heightened when participants can achieve flow through interacting with a well designed game or simulation. A major difference, however, is that simple games and simulations do not create the illusion of situated embodiment of one's identity into the learning experience, so the impact on self-concept may be less profound.

That said, the ways in which games and simulations provide clear goals and near-continuous feedback on progress towards those objectives is powerful for motivation and learning in ways that more open-ended, unstructured environments do not attain. For example, a personal trait that shapes student academic outcomes more strongly than gender, self-concept, and perceived utility of academic knowledge in later life is self-efficacy (Pajares & Miller, 1994). Bandura (1977) defined self-efficacy as the belief that one can successfully perform certain behaviors (e.g., succeeding on a high stakes test). Pajares (1997) argued that self-efficacy shapes a student's choices, expended effort, and emotional responses to a task. Students with higher academic self-efficacy are more likely to be engaged, see failure as an indication that more effort is needed, and be more interested in a career in the field to which an academic task relates. Perceived personal competence in accomplishing the goals of an academic activity (Dweck, 2002; Schunk & Pajares, 2005) depends in part on a student's beliefs about whether their abilities in that field are immutable (i.e., one is born either talented in mathematics or not – nothing can change that) or mutable (with practice, I can become capable in mathematics regardless of my initial abilities). Ketelhut (2007) developed and validated an instrument to assess a student's self-efficacy in scientific inquiry, showing that students with higher self-efficacy in science inquiry were more effective in learning from the *River City* virtual world. Games and simulations can provide repeated practice experiences with continuous feedback that supports building self-efficacy.

Another personal trait related to self-efficacy and identified as important in educational success is academic tenacity. The U.S. Department of Education report, *Promoting grit, tenacity, and perseverance: Critical factors for success in the 21st century* (2013), describes the interrelationships among concepts such as persistence, tenacity, grit, perseverance, and conscientiousness when applied to educational contexts. The report documents how important these traits are for success in school and life; it suggests teaching strategies for fostering these traits and for seeing one's abilities in a subject as mutable rather than fixed. These instructional strategies include (U.S. Department of Education, 2013, pp. 77–80):

- Students need to have the opportunity to take on long-term or high-order goals that, to the student, are "worthy" of pursuit.
- Students need a rigorous and supportive environment to help them accomplish these goals and develop critical psychological resources. These resources include teachers' fostering positive academic mindsets (e.g., my ability and competence grows with my effort), effortful control by students (e.g., staying focused despite distractions), and strategies and tactics (e.g., project planning skills).

Research has shown that game-like immersive interfaces can be powerful means of developing academic tenacity (Shute, 2011), and less complex games may also be effective in this. Central to achieving this outcome is the attainment of flow states through facing challenges that are difficult, but surmountable at the student's current level of skill, coupled with support that enables steady improvement in repeated attempts to accomplish a task (National Research Council, 2011b). It is important that teachers reinforce these types of mindsets for students to realize the benefits of this type of learning.

Almost all simulations and most simple educational games are designed for individual use rather than team experience, although a teacher may conduct post-play briefings in which students compare their insights and accomplishments. (In contrast, entertainment-oriented video games often involve team play.) Both educational games involving collaborative experiences and video games offer opportunities similar to MUVEs and AR for social knowledge construction.

Because simple games typically do not have built-in communication mechanisms for virtual interaction, this collective meaning making often takes place outside the game environment through face-to-face interactions in classroom settings or via virtual channels in informal contexts (National Research Council, 2011b). This means that teachers should use debriefing sessions to ensure that students realize the full learning possible from the game or simulation experience.

Ways that Games and Simulations Aid Assessment-Centered Instruction

The NRC report (2011b) contains a section on the role of simulations and games in science assessment. As discussed earlier in this chapter, immersive interfaces (as well as many simpler games and simulations) offer the capability of collecting log file data about students' behaviors and decisions; this is potentially a powerful method for formative and summative assessment. However, Quellmalz, Tims, and Schneider (2009) found that, in 79 studies of using simulations for assessment, the technological affordances of collecting behavioral data through the simulations were generally not utilized. Instead, paper and pencil tests were often applied to measure conceptual understanding from the simulations. The authors concluded that research on how to effectively assess learning through games and simulations was still in its infancy.

That said, an increasing number of high stakes summative tests are using short simulation items in which students' behaviors are analyzed as evidence of what they do and do not know (National Research Council, 2011b; Quellmalz & Pellegrino, 2009). As discussed earlier, logfiles from games and simulations can also be utilized to provide teachers with formative assessment data. As an illustration, BioLogica is a middle school simulation-oriented curriculum unit on genetics that incorporates logfile analysis into its assessment strategies (Buckley, Gobert, Horwitz, & O'Dwyer, 2010). More detailed examples of embedded assessment in games and simulations are provided in the case studies below.

The NRC report (2011b) concluded that "games and simulations hold enormous promise as a means for measuring important aspects of science learning…" (p. 103). The NRC indicated that simulations are already proving their value in both formative and summative assessment. However, the report states that games will reach their full potential in measuring students' performances only when unobtrusive, effective assessment tasks are routinely embedded into them. Further, teachers need to be prepared to utilize the diagnostic information provided by the game or simulation to differentiate their instruction to the needs of individual students.

Teaching with Games and Simulations: Opportunities and Challenges

The three examples below were selected to illustrate well studied examples of learning with a simulation, an educational game, and an entertainment videogame.

IMMEX. *Interactive Multimedia Exercises* (IMMEX) is an online set of science simulations that incorporate assessments of students' problem solving performances, progress, and retention (Stevens, Beal, & Sprang, 2009). Each simulation presents authentic real world situations that requires complex thinking and disciplinary knowledge. For example, the Hazmat unit asks students to use multiple physical and chemical tests to identify an unknown toxic spill. Thirty-nine different problem cases are randomly presented, and students' actions and strategies are tracked. Measures used for assessment include whether a student solved the problem correctly, the amount of time taken, and the strategies the student applied.

Learners who have used this system include middle and high school, college, and medical students. All types of students experienced gains in learning and engagement. Researchers found that students typically developed a consistent strategy after they encountered a particular type of simulated problem at least four times (Cooper, Sandi–Urena, & Stevens, 2008). This illustrates the importance of repeated practice and continuous feedback in learning from simulations. Students' actions were highly influenced by the problem solving strategy modeled by their teacher. Teachers had an online "digital dashboard" they used to monitor progress among their students in each class, as well as across classes. This type of formative assessment was valuable in helping teachers differentiate instruction.

Supercharged. *Supercharged* is a three-dimensional educational game designed for classroom use (Anderson & Barnett, 2011). Its purpose is to help students learn basic physics principles related to electromagnetism. Players accomplish various game tasks and overcome challenges by navigating through space via using the properties of charged particles and field lines. For example, in the most difficult challenge, players must navigate their ship through a three-dimensional electromagnetic field seeded with various static charges.

Supercharged is typical of short educational games designed to promote engaged, active learning. It develops both scientific inquiry skills and content knowledge (Jenkins, Squire, & Tan, 2003). When scaffolded by teacher-led interpretation and reflection, middle school students who played this game had higher pre/post-test gains than students who used a traditional guided inquiry curriculum (Squire, Barnett, Grant, & Higginbotham, 2004). In a later study, elementary school teachers who played *Supercharged* outperformed on pre/post-tests pre-service peers who participated in a conventional inquiry methods curriculum (Anderson & Barnett, 2011).

World of Warcraft. Steinkuehler and Duncan (2008) describe research on how the massively multiplayer online entertainment game, *World of Warcraft* (WoW), can help participants learn scientific habits of mind. WoW is the largest commercial massively multiplayer online game (MMO); in 2012, approximately ten million participants paid monthly fees to play. WoW is a very complex environment in which players can explore, slay monsters, learn trades such as blacksmithing and herbalist, acquire treasures of various types, form guilds and teams to accomplish tasks, buy and sell artifacts, customize their avatars with clothing and weaponry, and enjoy many other activities appropriate to a “swords and sorcery” fantasy experience. Participants can also vary their gameplay by selecting their race, gender, character strengths, and fundamental moral stance; for example, a female human mage belonging to the Alliance will have different experiences than a male goblin warrior belonging to the Horde.

The opportunities that all these gameplay options present are a very rich set of models that underlie WoW and determine its dynamics. Typical of other complex entertainment games, user forums are available on almost any aspect of the virtual world, and much of the discussion in those forums is about inferring the dimensions and characteristics of these underlying models, so that participants can optimize their gameplay. Steinkuehler and Duncan (2008) studied the forms of scientific argumentation, model-based reasoning, and theory-evidence coordination that arise in WoW, as an example typical of many MMOs. They found it was not unusual for players to gather collective data about a particular monster or challenge in WoW, use spreadsheets to create simple mathematical models of the data, and then argue about whose model is superior in terms of prediction and explanatory scope. This collaborative construction of knowledge through debating alternative evidence-based hypotheses parallels what takes place in various scientific communities.

Steinkuehler and Duncan (2008) analyzed a random sample of nearly 2000 discussion posts in which participants interacted about various WoW-based topics. Their findings showed that 86% of the WoW discussion posts involved social knowledge construction: the collective development of understanding, often through joint problem solving and argumentation. Of these posts, 37% built on points other participants had raised, and 28% used data or evidence of some form to warrant their claims. 58% of the posts used systems based reasoning, citing components and processes that interact in ways involving causal interactions and, sometimes, feedback loops.

While the simplistic models that underlie MMOs do not parallel the scope of complexities that underlie real world phenomena, Steinkuehler and Duncan (2008) argue that cognitive and psychosocial skills are developed in these user forums that are of value if transferred into academic settings. They conclude that teachers could build on the skills and habits many MMO players have developed in their gameplay activities outside of school and could foster transfer of these strategies to promote academic achievement. Such an instructional approach would require, however, that teachers become familiar with these types of games so that they can scaffold students' application of their social knowledge construction skills in classroom settings (Sandford, Ulicsak, Facer, & Rudd, 2007).

Beyond teachers using games and simulations, as illustrated in these case studies, some educators and researchers are promoting "gameful" instructional strategies in classrooms. This pedagogical approach sometimes involves students designing their own games, learning about the content and skills in the game through the design process. The merits and challenges of this approach were discussed earlier in the augmented reality section. An example of the extensive application of these techniques is the Quest to Learn charter school (Salen, Torres, Wolozin, Rufo-Tepper, & Shapiro, 2011). Research on the effectiveness of this approach is not yet available.

A more widely advocated "gameful" instructional strategy is "gamification:" using badges and similar rewards as extrinsic motivation for students to perform academic tasks (Edery & Mollick, 2008). While this is presented as a new educational approach, the use of behaviorist psychology to create extrinsic educational rewards has a long history in education (Parkay & Hass, 2000; Skinner, 1967). As discussed earlier, an overuse of extrinsic motivation can undercut students' development of intrinsic motivation.

Issues in Teaching with Games and Simulations

Simple educational games and simulations are less challenging to use in classroom settings than more elaborate immersive virtual worlds (Dede, 2009b). The technology infrastructure needed for implementing simple games and simulations is less complex, as even low-level devices have enough power to run these applications. While 1:1 student-computer ratios are desirable for interacting with these learning media, teachers who have only a presentation station can conduct whole-class sessions in which students collectively make choices and see the consequences of these actions. Network connections are typically not necessary, removing the issues of security, safety, and privacy associated with Internet access. Thus, teachers who have a minimal technology infrastructure can use simulations and games in whole group demonstration, those who have an intermediate infrastructure can implement individual student usage in classrooms, and those with an extensive infrastructure can involve students in using these learning experiences outside of school hours.

Further, relatively small amounts of class time are needed to use and debrief simple educational games and simulations, compared to the more elaborate immersive environments discussed earlier. The classroom use of entertainment-oriented videogames like WoW would demand much more time and technical resources, comparable to an elaborate immersive environment. However, as the case study of WoW suggests, teachers can draw on students' experiences with this type of game outside of school settings without necessarily using MMOs in the classroom during school time.

That said, the other issues discussed earlier about effective instructional strategies with immersive environments also apply to simple games and simulations. For this type of learning to be effective, teachers must shift their pedagogy from presentation to coaching, and students must change from rote assimilation to reflective interpretation (Sandford et al., 2007). To illustrate effective use of educational games, Watson, Mong, & Harris (2010) describe a high school history classroom in which a game about World War II, Making History, was implemented. The teacher was experienced in playing the game and had used it in his instruction for several years. Researchers noted that, even though the teacher was an effective lecturer adept at fostering group discussion, students were much more engaged in the active learning fostered by playing Making History. To turn that engagement into learning, the teacher implemented an instructional model in which students played the game in small groups, so that they could dialogue with each other about the rationale for various actions they took. Classroom interpretive dialogue was based around teachable moments when students found something that happened in the game surprising to them, given their current mental model of history. The teacher also kept students focused on having goals to achieve for their country, taking positions about historical events, and reflecting on the consequences of their decisions. While the game was quite successful for engagement and learning, substantially higher effort on the part of the teacher was involved than using conventional lecture/discussion pedagogy.

Overall, the primary reasons for using games in school center on engagement and the ability to model complex situations students must disentangle, building their knowledge and skills. Simulations provide opportunities for students to conduct “what if” manipulations of underlying models to understand their dynamics. The primary barriers to using simple educational simulations and games in schools are not technical, but rather the shift in pedagogy required of teachers, and the change in learning strategies of students (Sandford et al., 2007).

The Evolution of Transformative Technologies for Teaching

Combined, the characteristics of transformative technologies we have discussed in this section are consistent with a vision of teaching for personalization presented in the 2010 National Education Technology Plan (U.S. Department of Education, 2010, pp. 41–42):

> Connected teaching offers a vast array of opportunities to personalize learning. Many simulations and models for use in science, history, and other subject areas are now available online, including immersive virtual and augmented reality environments that encourage students to explore and make meaning in complex simulated situations (Dede 2009). To deeply engage their students, educators need to know about their students' goals and interests and have knowledge of learning resources and systems that can help students plan sets of learning experiences that are personally meaningful. . . . Although using technology to personalize learning is a boost to effective teaching, teaching is fundamentally a social and emotional enterprise. The most effective educators connect to young people's developing social and emotional core (Ladson-Billings, 2009; Villegas & Lucas, 2002) by offering opportunities for creativity and self-expression. Technology provides an assist here as well… Digital authoring tools for creating multimedia projects and online communities for sharing them with the world offer students outlets for social and emotional connections with educators, peers, communities, and the world at large. Educators can encourage students to do this within the context of learning activities, gaining further insights into what motivates and engages students—information they can use to encourage students to stay in school.

The NETP argues that placing the teacher at the center of the instructional process and creating tools that can make more teachers effective is critical for achieving the improvements in learning and performance crucial for 21st century education.

A Grand Challenge for research and development posed by the NETP is (2010, page 78):

> Today, we have examples of systems that can recommend learning resources a person might like, learning materials with embedded tutoring functions, software that can provide UDL [Universal Design for Learning; Rose & Meyer, 2002] supports for any technology-based learning materials, and learning management systems that move individuals through sets of learning materials and keep track of their progress and activity. What we do not have is an integrated system that can perform all these functions dynamically while optimizing engagement and learning for all learners. Such an integrated system is essential for implementing the individualized, differentiated, and

personalized learning called for in this plan. Specifically, the integrated system should be able to:

- Discover appropriate learning resources;
- Configure the resources with forms of representation and expression that are appropriate for the learner's age, language, reading ability, and prior knowledge; and
- Select appropriate paths and scaffolds for moving the learner through the learning resources with the ideal level of challenge and support.

Extending and integrating the transformative technologies for teaching we have discussed is the evolutionary path towards achieving that vision. A research synthesis that describes "digital teaching platforms" as a way to accomplish this is presented in Dede and Richards (2012).

In this section, we have described both opportunities and challenges for teachers related to transformative uses of technology. Below, we briefly summarize what we view as the new or deeper competencies required in order for technology to contribute meaningfully to instruction:

- Shifting the emphasis of instruction from what is already known ("learning about") towards teaching how to address "hard" problems that are currently not completely understood and that require interpretation among different points of view.
- Shifting practice towards "connected teaching," in which teachers are at the center of a network that begins in their own classroom and extends outward to include the surrounding school, community, and broader world of connected resources. This involves teachers in managing connections between themselves and their students, from student to student, to parents, to other teachers and youth development workers inside and outside the school, and far flung data, resources, and experts—both for students' learning and for teachers' professional development.
- Understanding what is possible within each level of technology infrastructure/integration, from minimal to extensive, and helping to lead the implementation of the level appropriate to meet the needs of their particular students.
- Understanding the ways each particular medium can enhance learner-centered, knowledge-centered, assessment-centered, and community-centered instruction.
- Understanding which parts of a lesson's instruction to accomplish with each type of technology, including when to be "in control" and when to allow the technology system to guide student learning with little intervention.
- Understanding how some types of tools, such as social media, involve different epistemologies and different relationships between students and teachers than typical in conventional instruction.

- Understanding the particular types of instructional beliefs and practices effective in online learning, such as ways of building technology-mediated relationships with students and helping them engage with content.
- Understand how to link students' informal passions to academic knowledge and skills, bridging between formal and informal teaching and learning spaces.
- Understanding how to scaffold students' motivation, learning, and metacognition through debriefings that helps them realize and transfer the insights gained from experiences in virtual worlds, augmented realities, games and simulations.
- Understanding how to differentiate and personalize students' learning experiences based on the rich diagnostic data from technology-based learning environments that can formatively shape instruction.

These are all ways of improving educational outcomes for a broader range of students than are reached by conventional, one-size-fits-all instruction. Achieving these gains requires both fluency in using transformative technologies and the capacity to effectively utilize the instructional competencies we have described.

The Evolving Research Agenda for Teaching with Technology

The various lenses through which we view technology and its role in teaching and learning have profound implications for both scholarship and practice. For example, if one believes that technology represents wholly-contained solutions to problems of teaching, then improving education involves developing the “right” technology, and getting teachers to use it the “right” way (or figuring out a way that the things they do have little or no impact on the outcomes). A research agenda accompanying such a belief would properly focus on comparing the outcomes of practice with the technology to practice without it, or perhaps comparing one technology to another.

This perspective on technology may seem extreme, but in the history of education this viewpoint has often been the guiding force, either implicitly or explicitly, and is related to a broader sense of technological utopianism. A relatively recent example of a major research study rooted in this perspective is a Congressionally-mandated experimental study in the United States that compared selected educational technology products in mathematics and reading to control or comparison classrooms that did not use the technology products. The study found no significant differences in test scores between the treatment classrooms and the control classrooms (Dynarski et al., 2007). A follow-up study asked whether teachers simply needed more time to get used to implementing the technologies, and found mixed effects. Though time using the technologies generally increased in this study, test score comparisons were again mixed. There appeared to be no differences between the first and second years of implementing a piece of software for reading performance; and, in mathematics, student performance actually decreased in the sixth grade classes using math software, though it increased for classes using algebra products. Of the 10 software products investigated in the second-year study, only one had a positive and significant overall effect on student learning, and five products actually had negative (though not significant) effects (Campuzano, Dynarski, Agodini, & Rall, 2009). A policy maker using the results of this study might reasonably conclude that an investment in technology for education is not worthwhile, or at least investing in *these* technologies is not of value. But is this the whole story?

The research question posed by the study cited above (Campuzano et al., 2009; Dynarski et al., 2007) is essentially: Is technology *x* better than *not x* when all else is considered equal? But there are other questions that can and should be asked about any given technology: What are the conditions under which a given technology contributes to learning, and might the technology be beneficial for certain types of students who do not respond well to conventional instructional techniques? Are there important educational outcomes (e.g., 21st century skills) learned through the use of a given technology that are not possible or easy to learn without the technology? Given a particular technology, what new forms or arrangements of teaching and learning are possible that may have beneficial effects, such as linking learning in and out of school? Note that we are not advocating for the abandonment of rigorous experimental studies of technological tools for learning. We are, however, arguing that studies that vary only (or primarily) the presence or absence of the technology while holding "education" constant are likely missing the point, and will not lead to substantial educational progress. What is needed are research designs that help create and improve new, technology-based models for learning and teaching, including studies that compare these different strategies against various types of students and kinds of desirable learning outcomes.

In this section, we explore major research approaches that have been employed for the study of technology and teaching, and describe a promising emerging methodological approach.

We also discuss future research directions that are aligned with the arguments presented in this chapter, drawing from recent policy documents and reports that have examined the emerging technology landscape from an educational perspective.

Historical approaches to the Study of Technology and Teaching

Research on technology and teaching has employed, at one time or another, the full range of methodological approaches and methods from the field of education. Our intent is not to comprehensively review this broad landscape, but rather to examine the lessons and limitations of particular perspectives for informing our thinking about technology, its role, and its effects on teaching and learning.

In the 1960s and 1970s, the nature of technology (largely mainframes and minicomputers, with limited networking capability) led researchers to focus on topics such as the effects of drill-and-practice software, the development and support of remote-access from universities (where the technology was housed) to schools, and how the introduction of IT might shift the curriculum (Cox, 2008). The nature of the technology meant a focus primarily on:

> …individual pupils working on his/her own through and educational program, pairs or small groups working around a computer collaborating on the problems and inputs presented to them through the software, and whole class teaching involving a teacher demonstrating an educational software program and eliciting answers to problems on the screen from the class. (Cox, 2008, p. 969)

These are all forms of instruction aligned with our description of a minimal level of integration and infrastructure.

In the 1980s and 1990s, rapid changes in the distribution and availability of technology led to an expanded research agenda. Computing costs started to come down, leading to the introduction of “personal” computers; computer networking became more broadly available; and computer programming began to appear as a course of study in schools. For the first time, the idea that teachers needed specific training in the use of technology in education became widespread. In this environment, the focus of research started to shift towards the dissemination and uptake of technology. These shifts were reflected in the National Educational Technology Plans (NETP) of the era. The 1996 plan (U.S. Department of Education, 1996) was focused almost entirely on issues of broadening access to technology in schools and on increasing the information and technology literacy of teachers and students. The end of the 1990s saw increasing access to the Internet and the introduction of web browsing software that made digital resources easily accessible to non-technical users of computers. The 2000 NETP (U.S. Department of Education, 2000) correspondingly focused on “e-learning” and the rise of online resources for learning. An explicit goal of the 2000 plan was that all teachers should learn to use technology effectively

The late 1990s and early part of the 21st century introduced yet another shift in access to information technology with the rise of personal and then mobile technologies. Laptop computers began to change the location and availability of technology in schools from centralized “labs” to classrooms and cart-based solutions that could move the computers to where students and teachers had easy access. As costs for laptops came down, some states and schools began to introduce “1:1” computing programs that provided a computer to each student (Penuel, 2006), enabling the broader use of computing as a general tool in support of learning, as opposed to uses constrained to particular educational software products (Rockman et al., 1998). These moves, leading to an intermediate level of technology infrastructure and integration, introduced new challenges for teachers in terms of both classroom management and the nature of students’ work (e.g., Windschitl & Sahl, 2002). Handheld computing devices fostered new opportunities for using technology outside of the classroom, such as for data gathering (Soloway et al., 2001) or for augmented reality (Klopfer, 2008). Growth in personally-owned devices that access the Internet, such as smart phones, introduced new challenges for schools trying to set policies for technology use (Kaiser Family Foundation, 2010), and also led to research on how teachers conceive of technology for instruction, as opposed to technology in their personal lives (Keren-Kolb, 2010; Purcell et al., 2013).

Despite the many and continuous changes in the nature of technology and how students and teachers access technology, the general approach to studying the impact of technology has remained largely the same over the years. As documented by Cuban and Kirkpatrick (1998), researchers and policy makers continually ask questions that are difficult for research to answer in part because they are about whether technology can help us achieve outcomes that are related to our values about education (e.g., “Can technology help us to produce the kinds of citizens we desire?”). Or, more frequently, studies ask comparative questions about whether the use of a particular technology is better than some other approach to teaching a topic (“Do students learn better/faster?” “Do students learn at lower cost?”). There are many reviews of research on these topics (Cuban and Kirkpatrick, 1998, provide an overview of many such reviews from the 1980s and 1990s), but the conclusions of these reviews are, at best, inconclusive. The most “accurate” answer to a question of whether a particular technology is “better” or “more effective” than some comparison condition is always “it depends.”

Instead of continuing to ask questions about the technology and practices with technology that exist right now, a more productive route is to ask what kinds of social and technological arrangements produce the kind of teaching and learning we want. It isn’t worth comparing technology *x* to *not x*, or to anything else for that matter, until you believe you have something worth testing. Design-Based Research (DBR) represents an entirely different approach, founded on the idea that creating interventions or improvements in teaching is about the design of the entire learning environment, of which technology and other material resources are but one component. We believe that DBR approaches offer the most promise for developing valuable interventions that will improve teaching and learning; as explained below, DBR and related methodologies do not rule out the possibility of experimental comparison, but they do shift the place of experimental comparison in the life cycle of research and development on technology for education.

Design-Based Research and Design-Based Implementation Research

In the early 1990s, Ann Brown wrote about the challenges presented by conducting her research on learning in the "blooming, buzzing confusion of inner-city classrooms" (Brown, 1992, p. 141). How can any phenomenon be studied "scientifically" in an environment that is constantly changing? How can problems be subdivided and addressed as components when the problems to be solved involve settings where components interact in unexpected and evolving ways? Writing in the same time period, Allan Collins argued that, in order to make progress toward educational improvement, we need to treat education as a "design science" akin to engineering, and in the process consider teachers as co-investigators, engage in iterative and flexible revision of our ideas, test the most promising ideas first (as guided by theory), compare multiple innovations against each other, and engage in a broad range of evaluative techniques to understand and verify what we observe as resulting from our designs (Collins, 1992). Brown (1992) and Collins (1992) both referred to research in this mode as "design experiments," and both stressed that the key is not just to create workable interventions, but to contribute to theory at the same time, leading to a design science for education. The objective is to create "usable knowledge" (Lagemann, 2002), and the DBR approach is often described as being in "Pasteur's

Quadrant" (Stokes, 1997), or at the intersection of basic research and engineering (as opposed to basic research, such as the work of Bohr on atomic structure, or pure invention uninformed by theory, such as the work of Edison on the light bulb).

Instead of asking if a given technology or intervention works better than some alternative, DBR instead looks at the context for teaching and learning and asks, "How could this entire system function better in support of learning?" Many of the technologies discussed in this chapter were designed using DBR principles. For instance, Computer-Supported Intentional Learning Environments (*CSILE*), which evolved into *Knowledge Forum*, is the product of many years of iterative development and refinement (Scardamalia, 2004). Computational thinking tools such as Scratch (Resnick et al., 2009) and *NetLogo* (Jacobson & Wilensky, 2006) are the products of iteration and study in a diverse range of real-world settings and contexts. It is important to stress that DBR approaches embrace a broad range of research methods, including quantitative and qualitative, from case studies to randomized efficacy trials. But methods are tied closely to different stages of design, and there is often back-and-forth between different types of methods across iterations of design and testing (Brown, 1992).

A more recent evolution in thinking about design-based research is Design-Based *Implementation* Research (DBIR). A limitation of DBR (without the "I") is that it is often focused at the level of a single classroom or group of classrooms, as opposed to at the level of schools or school systems. Under some circumstances, this focus is actually a powerful advantage for DBR, allowing researchers and teachers to work in a close partnership (Penuel, Roschelle, & Schectman, 2007) that attempts to take multiple facets of the classroom context into account. Such an approach results in interventions that are generally more ecologically valid than an innovation developed outside the classroom and introduced as a finished product. But small-scale DBR does not generally lead to a product that is designed with scalability and sustainability beyond the period of its active research and development, and there is a long history of well-validated interventions fading away as their developers turned their attention to new projects (Fishman, Marx, Blumenfeld, Krajcik, & Soloway, 2004; Fishman, Penuel, Hegedus, & Roschelle, 2011).

To address this issue, Penuel, Fishman, and colleagues (Fishman, Penuel, Allen, & Cheng, 2013; Penuel, Fishman, Cheng, & Sabelli, 2011) have begun to advocate for a form of DBR that considers scalability and sustainability as key issues from the beginning of the design process. The learning sciences centers on theories and design related to learning and teaching, and policy and implementation research focuses on theories and design related to systems and infrastructure. DBIR combines the iterative and learning-focused work of the learning sciences field with a focus on organizational change and the conditions for implementation effectiveness. We believe that DBR and DBIR together are key to developing robust technology interventions that are intended to shift the focus of teaching and learning toward intermediate or advanced levels of integration and infrastructure, to support new ways of organizing teaching and learning.

Areas for Future Research

This chapter describes a range of different technologies and emerging evidence for their role in supporting transformative teaching and learning. But what is in the future? The supportive technology infrastructure for teaching and learning will continue to grow, and the way(s) that schools are able to tap into and leverage that infrastructure will expand as well. A range of policy-informing documents have recently argued for potentially radical shifts in the way we conceive of education. These include a MacArthur-sponsored report on “connected learning” that called for elevating the myriad activities that youth pursue on their own and connecting those activities back to their formal learning experiences (Ito et al., 2013). The 2010 National Educational Technology Plan (U.S. Department of Education, 2010) described how new technology infrastructures could enable new forms of learning, new organizations of teaching, and new forms of assessment. A 2012 report from the U.S. Department of Education focuses on how the copious data generated from various online systems might inform and support transformative learning experiences (U.S. Department of Education, 2012). Another report produced at the request of the National Science Foundation (Working Group on Postsecondary Learning, 2013) focused on and opportunities and challenges posed by the evolving technology environment for postsecondary learning, but the research agenda identified in that report is relevant to teaching at all levels. We draw from each of these reports in order to present two broad areas that we believe are pressing for the next five years (and beyond) of research into technology for teaching and learning, with a range of important topics for research in each.

New Models and Contexts for Teaching and Learning

As Collins and Halverson (2009), Thomas and Brown (2011), and others have argued, there is a new "culture of learning" that is emerging with the support of ubiquitous technology. Modern media provide people of all ages with access to materials and communities of like-minded peers and experts to pursue just about any topic that interests them. The Connected Learning report (Ito et al., 2013) argued that, if formal learning (i.e., schooling) fails to understand and build bridges to these diverse interests, formal educational institutions risk losing learners altogether. Some areas for research that are highlighted in this report include:

- Developing tools to help learners map informal and interest-driven learning back to the learning outcomes of formal education.
- Developing systems to help teachers and learners coordinate learning activities across multiple sites, and over time and between contexts.
- Developing teaching and learning approaches that are self-improving, and flexible enough to change and grow with evolving technologies.

- Expanding research in online learning to support richer and deeper learning experiences (as opposed to using online tools to deliver lecture or rote teaching).

In addition to connecting formal learning to the interests of learners, we can also do much to make formal learning more interactive and engaging for learners. Research and development in this area might focus on:

- The development of immersive, authentic simulations in and across content areas that allow for deep and extended engagement through guided learning by doing.
- The development of robust platforms for interaction and collaboration, leveraging the social networking platforms learners interact with in every day life.
- The creation and maintenance of rich open-source resources to expand access to learning, including support for teachers to incorporate high-quality resources into their own teaching.
- Expanded research on game-like and game-inspired designs for learning, bringing a motivational focus explicitly to the design of formal learning environments.

<u>New Modes of Assessment and Feedback for Teachers and Learners</u>

Many of the above topics for further research on teaching and learning will be productive only if we also employ technology to enhance our ability to diagnostically assess learning. Often discussions about assessment turn to “big data,” or the large amounts of data that are generated through everyday interactions with online tools. Learning how to turn these data streams into actionable information has been core to the business models of companies such as *Google*, *Facebook*, and *Amazon*; and more challenging, sophisticated uses of data about learning can also be central to the improvement of educational practice (U.S. Department of Education, 2012). Learning analytics depends not only on access to data with relevance for learning, but also on the development of interfaces that provide relevant and actionable guidance for teachers, because more information is rarely useful without advice on what to do with the additional information. Additional work is also needed on certification systems, such as badges (Hickey, 2012) that can be used to document information on what learners know and are able to do. Some areas of needed research in this area include:

- The development of tools for making data and learning analytics relevant for teaching. This would include tools for capturing, aggregating, analyzing, reporting, and sharing data on learning. Privacy issues are also important in this domain, and research will be needed on how to balance personal data protection with teaching and learning opportunities.
- The creation and maintenance of coordinated data systems that are more responsive to students' needs. Learning needs are not purely academic, and better coordination across different sectors of students' lives might make for more effective educational programs.
- The development of more robust systems for teachers and learners to record and share information and certification about learning, such as with badging systems. Such systems have the potential to support self-directed learning activities and help link it back to formal learning, to help instructors know more about the specific skills (and weaknesses) of incoming students, and to aid students in making connections with each other and with future opportunities, such as post-secondary education providers or employers.
- The development of assessments for 21st century and other "soft" skills that are not easily measured by traditional approaches. If these skills are important (and we argue that they should be major outcomes of formal education), they must also be measurable so that teachers can help monitor student progress and support student growth towards accomplishing them.

Summary

In this section, we presented a brief overview of research and perspectives on research for technology in teaching and learning. Our goal was to illustrate how a persistent historical perspective on technology's value for learning works against progress, which we argue needs to be design-oriented and focused on continuous and iterative improvement of educational practice and performance. We presented priorities for future research directions from a range of recent policy documents, selected because of their salience to the technology infrastructures and integration framework we have used as an organizing device in this chapter. While we do not profess to be able to see the future, many of the trends represented in these research goals represent technologies and opportunities that are already present, and offer considerable potential if harnessed for educational progress.

A Way Forward

The 21st century presents a landscape shaped by technology that places new demands on schooling, no matter what position one takes on education's ultimate purpose. We believe that research, policy, and practice should focus on how and under what conditions technology can be employed productively by teachers to more effectively meet the challenges presented by this rapidly evolving world. In studying these conditions, we argue that technology is an effective catalyst only when used to enable learning with richer content, more powerful pedagogy, more valid assessments, and links between in- and out-of-classroom learning. Collectively, these capabilities could enable a new model for 21st century teaching and learning, as different from current industrial-era schools as those schools are from the one-room schoolhouses that characterized the agricultural era.

Achieving such an advance in the structure and processes of schooling requires investments both in technology infrastructure and in the human capacity of teachers, researchers, educational leaders, and stakeholders in society who could serve as resources for students' life-wide learning. In keeping with the National Research Council's seminal synthesis, *How People Learn* (Bransford et al., 2000), we see the necessary investments as encompassing learner-centered, knowledge-centered, assessment-centered, and community-centered dimensions.

Based on both theory and evidence-based practice, we posit that key technologies for teaching in which to invest include:

- Collaboration tools, including Web 2.0 technologies and tools that support knowledge building pedagogies;
- Online and hybrid educational environments, which are increasingly being used to broaden access to education, but also have the potential to shift the way we conceive of teaching and learning;
- Tools that support learners as makers and creators, and which have their deep roots in helping students learn to become programmers of computers (and not just users of them);

- Immersive interfaces that create virtual worlds to situate learning, or augment the real-world with an overlay of computational information; and
- Games and simulations that are designed to enhance student motivation and engagement.

We argue that these technologies are important because, in concert, they can help prepare students for life and work in the 21st century, mirroring in the classroom powerful methods of learning and doing that pervade the rest of society. These technologies also provide an affordable, practical division of labor to aid teachers with complex instructional tasks. In addition, these media address the learning strengths and preferences of students growing up in this digital age, including bridging formal instruction and informal learning. Further, these technologies provide powerful mechanisms for teacher learning, by which educators deepen their professional knowledge and skills in ways that mirror the types of learning environments through which they will guide their students.

Realizing the full potential of technology for teaching requires research investments based on designs that help create and improve new models for learning and teaching, including studies that examine how to modify and enhance different strategies for diversity in both learners and desired learning outcomes. We need investment in two interrelated areas for research and development: 1) the creation of more engaging learning environments for students in formal education; 2) new modes of assessment and feedback to guide learners along ambitious pathways for learning. This work, as we argued in “The Evolving Research Agenda for Teaching with Techology” section of this chapter, should include a focus both on learning environments, such as immersive simulations or games, and a focus on underlying infrastructure, such as tools for working with data and learning analytics, and the development of robust systems for teachers and learners to record and share information about learning progress. We must move beyond measuring only what is easy to measure, and develop ways to represent the myriad dimensions of learning that are required for success in an information-driven and highly interconnected society (U.S. Department of Education, 2010).

Overall, we believe that all the capabilities necessary to realize a life-wide structure and process for 21st century learning are now available, and that the transformation of teaching to leverage the affordances of modern digital technologies is a much better match for the needs of students and society than the more commonly taken path, which is to use technology to automate conventional instructional practices and organizations (Cuban, 1992).

Next Steps

To achieve this vision, we argue that two initiatives are essential: The first is developing, implementing, and studying instructional approaches that are transformative for personalized education in classrooms and life-wide learning outside of school. The second is building a robust and flexible infrastructure in classrooms and in society that allows for, and encourages, the simultaneous development of human capacity to enact transformative teaching and learning and the development of advanced technologies and infrastructures to support the pursuit difficult but important issues and problems.

Shifting from Educational Evolution to Transformation And Disruption

Any strategy for educational improvement must ask whether to adopt a change strategy that is evolutionary, revolutionary, or disruptive. Evolutionary change centers on incrementally inserting isolated innovations into our current model; an example is providing tablet computers for each student without any other simultaneous shifts. Typically, evolution is a very slow process because educational systems resist and undercut small changes in their functioning. Revolutionary change, in contrast, focuses on altering multiple parts of an educational system simultaneously to create a discontinuous transition to a new system that is different than the prior model in key respects. Implementing a DTP, for instance, based on each student having a computer is a revolutionary shift that alters some aspects of industrial-era schooling while retaining others.

As an alternative to these two types of change strategies within the current system, disruptive transformation (Christensen, Horn, Caldera, & Soares, 2011; Christensen et al., 2008), involves creating a new educational model outside of the traditional system that, over time, displaces the current model. An example would be the growing numbers of students attaining certifications based on effective participation in interest-driven and open learning experiences rather than receiving degrees based on sufficient seat-time in classroom learning (Collins & Halverson, 2009; Thomas & Brown, 2011). We believe the emergence of revolutionary 21st century models will likely involve implementing a mixture of revolutionary and disruptive changes.

Imagine an alternate universe in which the first *Handbook of Research on Teaching* was published about a century ago, in 1914. The chapters would likely have centered on studies related to the challenges of teaching in the one-room schoolhouse: How can a single teacher handle all subjects? Given the age span of children for whom teachers are responsible, what instructional strategies are effective across the range of human development? What are the most important things for teachers to model in preparing students for life on the farm? Of course, such a volume would rapidly have become irrelevant given the shift to the industrial-era school, whose structures, processes, and goals have posed a different set of challenges for teachers and priorities for research. If one extends this thought experiment to current research and policy on technology for education, it becomes clear that it would be a mistake to make investments that try to get better at teaching and learning in ways that may soon become irrelevant. One cannot prepare children for a global, knowledge-based, innovation-centered civilization by making slow, small improvements in an industrial model of schooling. We urge that design, practice, research, policy, and leadership focus on transformation and disruption, not evolution. This chapter sketches a potential path.

Investing in a Robust, Flexible Infrastructure of People and Tools

Learning technologies are not like fire, where one has only to stand close to the flame to get its primary benefits. Digital technologies are not in and of themselves the innovation we need in teaching and learning. Technologies are catalysts that, when applied well, can empower factors we know are powerful for learning: student engagement, deep content, guided learning by doing, valid assessments, and links between classrooms and life. But this can succeed only if people use powerful infrastructures of tools to enhance learning in sophisticated ways. That is why teacher learning is also a critical element of any reform agenda. If almost every recommendation in this chapter is achieved, but professional development of educators and investment in moderate to extensive infrastructure in classrooms are not, then the next generation model of education we espouse will not be attained.

This type of professional development is very challenging because participants must not only learn new skills, but also "unlearn" almost unconscious beliefs, assumptions, and values about the nature of teaching, learning, and schooling. Professional development that requires unlearning necessitates high levels of emotional/social support in addition to mastering the intellectual/technical dimensions involved. The ideal form for this type of professional development is distributed learning communities, so that the learning process is consistent with the knowledge and culture to be acquired. In other words, teachers must experience technology-based learning as the medium of their professional development as well as its message. This will require shifts in the current organization of both pre-service (Pellegrino et al., 2007) and in-service (Lawless & Pellegrino, 2007) teacher learning. Such shifts must emphasize teachers at the center of a connected learning system where they are responsible not just for the delivery of particular content, but also for helping students organize knowledge in order to produce new insights, as opposed to reproducing facts. Views of teacher learning as a professional continuum (Feiman-Nemser, 2001; Mundry, Spector, Stiles, & Loucks-Horsley, 1999) are an important start. Technology can help to provide support across that continuum.

Conclusion

At this point in history, the primary barriers in transforming to a 21st century educational system are not conceptual, technical or economic, but instead psychological, political, and cultural. Some people oppose any form of educational change that is not fully understood, arguing that traditional schooling was effective for them and that innovators should not "experiment on children." But the most dangerous experiment we can perform is to keep our current systems of schooling in place, hoping that various small changes and the introduction of new technologies will make up for their shortcomings. Over time, the disconnect between what society needs and what industrial-age educational models can provide is widening, and cohort after cohort of students has needlessly high rates of failure, creating terrible consequences for those learners and our nation. With the right investment, we can have the means necessary to implement technology-enhanced models of education that prepare all students for a future very different from the immediate past. Whether we have the stakeholder commitment and societal will to actualize such a vision remains to be seen.

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