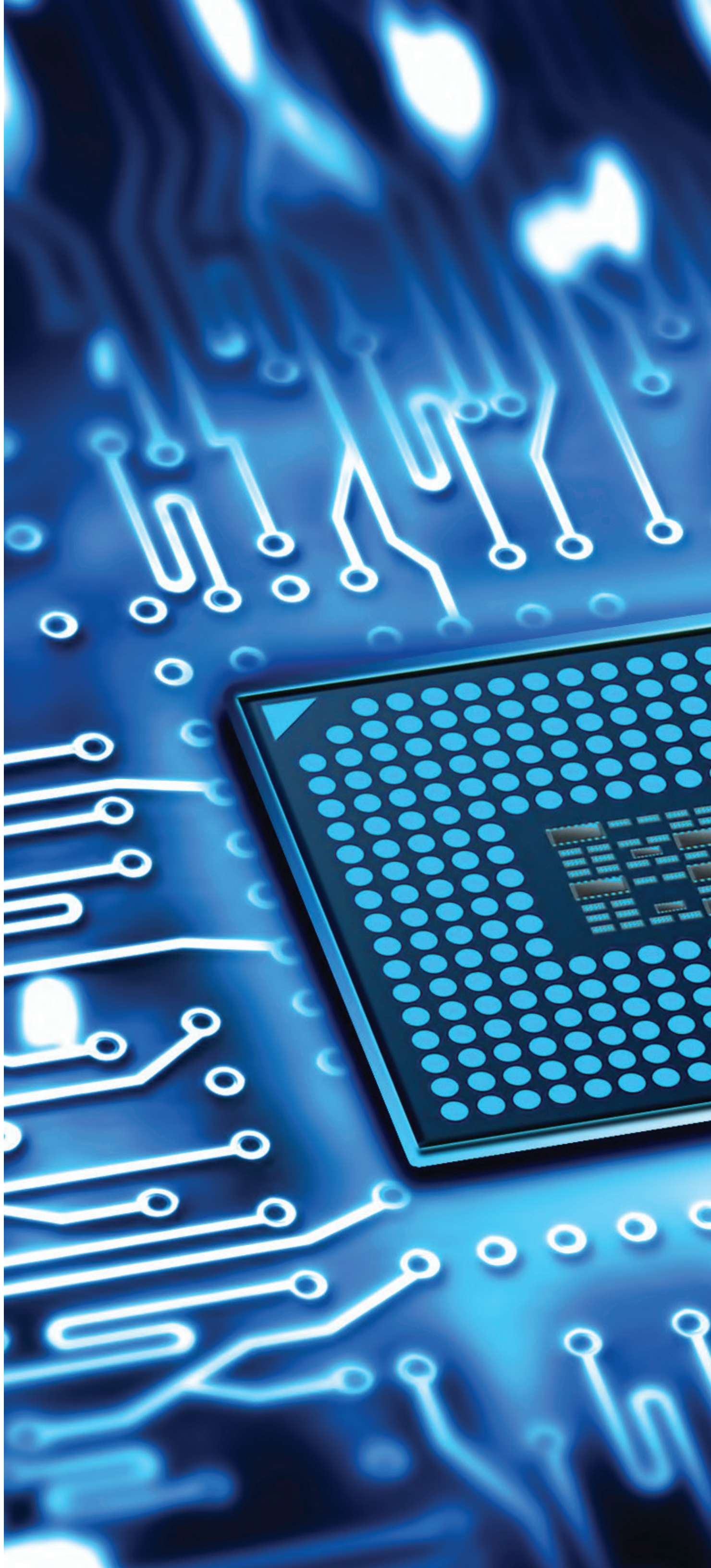
TEACHING IN THE MACHINE AGE:

How innovation can make bad teachers good and good teachers better

BY THOMAS ARNETT

DECEMBER 2016

CHRISTENSEN INSTITUTE



EXECUTIVE SUMMARY

As scientific understanding and artificial intelligence leap forward, many professions—such as law, accounting, animation, and medicine—are changing in dramatic ways. Increasingly, these advances allow non-experts and machines to perform tasks that were previously in the sole domain of experts, thus turning expert-quality work into a commodity. With new technologies displacing workers across many fields, what will be the likely impact on the teaching profession? Will machines replace teachers?

Despite the hype and fear, machines are unlikely to replace teachers anytime soon. Rather, they are poised to help overcome several structural barriers that make it difficult to ensure that an effective teacher reaches every student.

School systems face a number of challenges, including teacher shortages, a lack of clear methods for developing high-quality teachers, and teacher burnout and attrition, to name a few. And even the best teachers struggle to address the diverse learning needs of their students or find time to focus on developing students' deeper learning and noncognitive skills amidst pressures to cover core instruction.

Innovations that commoditize teacher expertise by simplifying and automating basic teaching tasks provide school leaders with new options for addressing three challenging circumstances:

- **When schools lack expert teachers.** Innovations that commoditize teacher expertise can go a long way in amplifying the effectiveness of the existing teacher workforce. Research shows that putting high-quality curriculum and online-learning resources in the hands of less-effective teachers can boost students' educational outcomes.
- **When expert teachers must tackle an array of student needs.** Even high-quality teachers struggle, at times, to address the varied learning needs of their students. A common response is for schools to train teachers how to differentiate instruction. But implementing differentiated instruction with fidelity on a day-today basis can be difficult. Fortunately, computers can provide many aspects of basic content and skills instruction, empower teachers with better assessment data, provide learning resource recommendations, and give teachers more time and energy to work one-on-one and in small groups with students.
- **When expert teachers need to teach more than academic content.** A growing body of research shows that deeper learning and noncognitive skills play a significant role, alongside content mastery, in determining students' academic and life outcomes. Innovations that commoditize teacher expertise give teachers greater capacity to focus on helping students develop these important skills.

Rather than seeing technological progress as a threat, teachers and education leaders should take advantage of the many ways technology can enhance their work. Computers, non-experts, and expert teachers each have comparative advantages that complement one another. Computers are ideal for targeting students' basic content and skill gaps and providing teachers with real-time assessment data. Non-experts, such as paraprofessionals and novice teachers, provide the human touch needed for supervising and motivating students and troubleshooting nonacademic learning difficulties. Expert teachers carry out sophisticated teaching tasks, including developing new instructional approaches, diagnosing and addressing students' nonacademic learning difficulties, providing feedback on oral and written communication, fostering an achievement-oriented classroom culture, and talking with parents about their students' individual education plans.

Great teachers are the most valuable resource in our education system. And expert teachers' work is unlikely to be reduced to standardized procedures or automated algorithms anytime soon. Yet, ensuring that every student has access to excellent teaching is not a trivial task. Fortunately, as innovations simplify and automate distinct aspects of teaching, both effective and less-effective teachers will see their capabilities enhanced by computers. This pattern provides a key insight for practitioners and policymakers who are working to guarantee that all students have access to high-quality teaching.

INTRODUCTION

During the last half-century, science fiction writers like Isaac Asimov, Arthur C. Clarke, and Gene Roddenberry imagined both the comforts and horrors of a future in which machines take on human-like faculties. Then, in the last two decades, the field of artificial intelligence leapt forward, bringing machines knocking at our doors. In 1997, IBM's Deep Blue supercomputer made headlines when it defeated the world's reigning chess champion Garry Kasparov.[1] Then, just 14 years later, a new IBM supercomputer named Watson beat champions Ken Jennings and Brad Rutter on the TV game show *Jeopardy!*. This second victory for IBM proved just how much ground machines had covered between formulating logic-based strategies and using sophisticated pattern recognition to understand human language.[2]

Winning trivial games with clearly defined rules and parameters is one thing, but today machines also contend with humans in more practical and complicated functions. Since 2011, the year Watson won *Jeopardy!*, Google has been testing its autonomous car technology on public streets. Now, nearly every major automaker produces models with self-driving functions for braking, executing lane changes, and parallel parking. Computer software can now write sports articles, financial reports, and poetry that the average person finds indistinguishable from human prose.[3] And IBM currently has its sights set on training Watson to become the world's best medical diagnostician[4] as well as an intelligent advisor to elementary school teachers.[5] These advances could offer immense benefits to humanity as they increase access to quality products and services, present new solutions to society's most pressing problems, and boost overall economic productivity. But they also have serious implications for the professions they penetrate.[6] According to a 2013 Oxford University study, about 47 percent of total U.S. employment is at risk of computer automation.[7] Professionals must ask the hard question: As machines master increasingly complex tasks, will they enhance or replace their human counterparts?

The teaching profession is not immune to the effects of scientific and technological progress. Today's students often find that it is much quicker and more convenient to throw their questions at Google than to make time for dialogue with a teacher. The resources available online include not just a list of hyperlinks to text-based websites, but also videos, interactive simulations, and games that rival teachers' abilities to make learning engaging, fun, and memorable. New learning platforms, such as Khan Academy, make it easier for students to find educational resources that match what they are trying to learn. And at the cutting edge of edtech, cognitive tutors and adaptive learning technologies can measure students' individual learning needs and then deliver targeted instruction similar to individual tutoring. Software has even started to grade students' essays with teacher-like accuracy.[8]

These advances beg the question: In the new era of edtech, will teachers be batched with assembly line workers, personal accountants, taxi drivers, sports journalists, and family-practice doctors in the latest wave of workers whose jobs fall prey to machines?

The teaching profession is not immune to the effects of scientific and technological progress.

Probably not. Despite speculative claims that technology will eliminate the need for face-to-face teachers,[9] teachers' jobs are not as threatened as some might suggest. As artificial intelligence increasingly takes on human work, the most valued and secure human jobs will be those that require complex social skills—such as teaching.[10] Good teachers do much more than just dispense information and assess students' knowledge of rote facts and skills: they coach and mentor students, identify and address social and emotional factors affecting students' learning, and provide students with expert feedback on complicated human skills such as critical thinking, creative problem solving, communication, and project management. Given the need for skillsets that only humans can perform, computers are not likely to replace teachers anytime soon.

But ensuring that every student has a good teacher is a wholly separate challenge. The U.S. education system faces a number of structural challenges that limit our ability to provide every student with high-quality teachers. First, chronic teacher shortages—especially in STEM and special education[11]—make it challenging for urban and rural schools, in particular, to recruit enough teachers. Steady declines in teacher pay, relative to other college graduates,[12] and in teacher preparation program enrollments[13]—combined with the pervasive perception that teaching is a low-status profession[14]—suggest that these shortages are not likely to go away anytime soon.

Second, schools lack reliable methods for selecting and developing high-quality prospective teachers. Researchers can pinpoint high-quality teachers *ex post facto* based on teacher observations, student survey responses, and student test scores,[15]but they are far less successful at identifying the characteristics of effective teachers[16] or illuminating a clear path for preparing and developing them.[17] Although a number of important initiatives and organizations are leading the charge to improve teacher preparation and teacher professional development,[18] these efforts are still far from having system-wide impact.

Finally, high teacher burnout and attrition rates only exacerbate the challenges of hiring and developing high-quality teachers.[19] Many of the best teachers put in time and effort well beyond the typical 40-hour workweek in an effort to make a difference in the lives of their students. This extra work, however, leaves many feeling perpetually overwhelmed and looking for an escape. The resulting teacher burnout and turnover aggravate teacher shortages, tax schools' budgets with extra recruitment and training costs, undermine the stability of school communities, and alienate good teachers from the profession.[20]

Fortunately, these are challenges that innovation can help to address. Technology is not a panacea for these systemic challenges. But while we work to improve the condition of our teaching force, innovations that commoditize professional expertise can play a pivotal role in ensuring that every student has access to high-quality teaching.

HOW DO INNOVATIONS COMMODITIZE EXPERTISE?

Many industries—from quantitatively oriented professions such as engineering and banking, to service-oriented sectors such as healthcare, to artistic fields such as photography and animation—benefit from innovations that commoditize professional expertise. These innovations simplify and automate some of the tasks of experts, making expert-quality work less scarce and more widely available.

For example, online architectural software from SmartDraw and Chief Architect allow drafters and building contractors to create plans for most common types of buildings without an architect. Online legal software from LegalZoom and Rocketlawyer help people draft contracts for services rendered or simple wills and trusts without hiring a lawyer. Credit-scoring algorithms used by Experian and Equifax automate much of the credit-worthiness research that bank loan officers once did. These industries, among others, came about in eras when only experts, steeped in intuition and experience about how to perform certain tasks, could practice a given profession. But over time, innovators have found ways to simplify and automate many aspects of professional expertise.

Innovations that simplify professional expertise

In the earliest stages of most industries, professionals draw on an assortment of observations collected over many generations to understand the problems in their field. Only skilled experts with advanced training and extensive experience can effectively tackle the problems to be solved, and their work proceeds through intuitive trial-and-error experimentation. For example, the medical condition known as scurvy was identified as far back as the days of Hippocrates, the ancient Greek father of medicine. But because the cause of this ailment was not understood, for millennia doctors treated scurvy by merely drawing on their recollection of remedies that seemed to work for other patients. Unfortunately, many of the prescribed treatments were mere folklore, which resulted in the deaths of countless ailing patients.[21]

Two forces of progress commoditize professional expertise:

- Innovations that advance the understanding of a field
- Innovations in computer science that automate the work of experts

Over time, researchers and professionals identify patterns that correlate actions with outcomes of interest. Discovering these patterns enables professionals to develop standard practices and procedures based on correlations between actions and outcomes. As standardized practices and procedures emerge, both experts and new classes of non-expert technicians and paraprofessionals can solve certain problems with a greater degree of predictable success. In the case of scurvy, doctors eventually observed that certain foods seemed to abate the symptoms. By the 1830s, the medical field had something akin to standard guidelines that prescribed fresh meat and citrus as effective treatments. With these guidelines, the crews of transoceanic ships, who were often plagued by scurvy, could diagnose and treat themselves when they came down with scurvy-like symptoms. This advancement meant that ships' crews no longer had to suffer until they reached land and could meet with a physician.

Eventually, scientific theory supplants these patterns of correlation with a solid understanding of cause and effect—such as when medical researchers identified vitamin C deficiency as the cause of scurvy or when germ theory revolutionized the medical field's understanding of a wide array of other diseases. Rigorous theory makes the results of given actions highly predictable. Accordingly, intuitive and complex work becomes routine.

With these advances in the understanding of a field, abilities that previously resided in the intuition of a select group of experts become easy for people with less experience and training to learn and repeat. When this happens, non-experts begin to carry out expert-level work with a reliable level of success by simply following rules-based practices. *Figure 1* illustrates the general pattern of how the understanding of a field evolves.

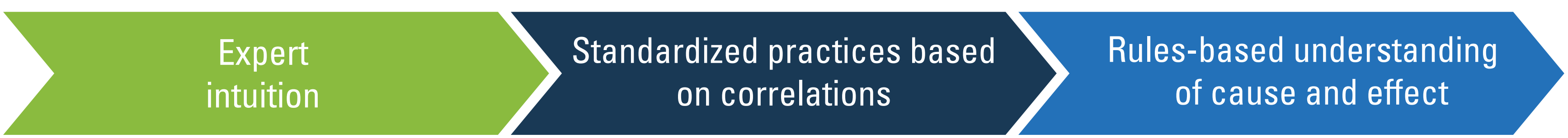
Innovations that automate professional expertise

As the understanding of a field moves from expert intuition to rules-based practices, parallel developments in the field of computer science make it possible to automate many tasks that historically required the attention of experts. Year after year, the cost of hardware and devices continues to fall, processing speeds and programming techniques leap ahead, and the field of robotics marches forward. Each of these trends pushes machines into more aspects of human work and life.

As computer science progresses, innovations in other industries that simplify expert tasks fuel the rise of computer automation. Once a task is understood well enough to be explicitly teachable to non-experts, in many cases it can also be translated into software programs that computers can execute. In this way, software has edged into tasks such as preparing tax returns, drawing up legal documents, and determining credit worthiness.

Historically, computers could only execute tasks that could be programmed as explicit instructions. But in recent years, computers have become less dependent on human programmers to learn the rules for executing tasks. With the latest developments in machine learning and artificial intelligence, computer scientists can teach computers to use advanced statistical techniques to recognize patterns in large data sets and then come up with the rules for executing complex tasks on their own. These advances rapidly accelerate the degree to which computers can imitate humans in executing complicated tasks.

Figure 1. Progress in the understanding of a field



WHAT HAPPENS TO COMMODITIZED PROFESSIONS?

Innovations that commoditize professional expertise do not necessarily eliminate the roles of professionals. Even the best artificial intelligence technologies are still a long way from being able to subsume all the tasks performed by experts. These innovations do, however, impact the work of professionals in two dramatic ways.

First, they allow **non-experts working with new technologies to substitute for experts** in completing some aspects of the experts' work. For example, using rules-based medical science and the latest diagnostic equipment, middle-skilled professionals, such as nurses, can diagnose and treat many conditions—including allergies, ear infections, ringworm, strep throat, and the flu—that previously required the attention of a licensed medical doctor.

Second, they allow **non-experts and new technologies to enhance experts' abilities** to perform higher-order tasks that cannot be deduced to rules-based instructions. For example, MetaMind, a startup developing artificial intelligence software, uses natural language processing, computer vision, and database prediction algorithms to analyze medical scans for tumors and lesions. Assisted by this technology, doctors no longer need to spend a lot of time scouring images for abnormalities. Instead, they can allocate that time to consulting with patients and developing treatments.[22]

As *Figure 2* illustrates, experts, non-experts, and new technologies each hold important comparative advantages that make them uniquely valuable to the industries they serve:

- **Computers** can execute explicit procedures and machine-learnable tasks with greater speed and precision than humans and can recognize patterns in large and complex sets of data.
- **Non-experts** are cheaper and easier to find than experts because they do not require as much specialized training; their capacity for cognitive flexibility also allows them to adapt to new circumstances and novel challenges more easily than computers.
- **Experts** possess advanced training, extensive experience, and human cognitive flexibility that allow them to perform higher-order tasks—such as identifying patterns across disparate and non-machine-readable sources of information, developing novel ideas and solutions for non-standard problems, and engaging in varied forms of complex communication with other humans—that computers and non-experts still cannot accomplish.

Innovations that commoditize expertise affect a profession in two ways:

- Non-experts and new technologies substitute for experts.
- Non-experts and new technologies enhance experts' abilities.

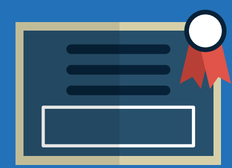
Figure 2. Comparative advantages of computers, non-experts, and experts

Computers

Execute algorithms with speed and accuracy

Analyze large data sets and recognize complex patterns

Non-experts



Complete tasks that do not have prescribed procedures

Provide labor that is more affordable and less scarce than hiring experts

Experts

Complete tasks that do not have prescribed procedures

Recognize patterns and interpret data across data sources that are not machine readable

Develop creative solutions to non-standard problems

Engage in complex interpersonal communication

In some industries, innovations that commoditize professional expertise threaten the job security of professionals. When an expert's job consists entirely of tasks that are complex yet rules-based—such as preparing common tax returns or legal documents—innovations that simplify and automate professional expertise offer low-cost alternatives to hiring expensive experts. But if an expert's job entails higher-order tasks that cannot be reduced to rules-based instructions, then innovations that simplify and automate professional expertise serve to enhance—rather than substitute for—experts' abilities.

Non-experts and new technologies can enhance experts' abilities to perform higher-order tasks in two ways. First, non-experts working with new technologies can take care of routine tasks so that experts can focus their attention, skills, and intuition on challenges that demand expertise. Second, non-experts and computers can help experts gather, process, and summarize information in ways that can lead them to new insights and enhance their ability to perform their work.

In industries, such as teaching, where professionals are under great pressure to do and accomplish more than they have in the past, assistance from non-experts and computers can be a huge boon to professionals. The animation field provides a clear and remarkable example of how innovations that simplify and automate expert tasks can enhance professionals in ways that transform an industry.

Commoditizing Disney

Skeptics often question the value that technicians and new technologies have to offer in industries where expertise is as much an art as a science. The history of the animation field demonstrates how a profession—similar to teaching in both its technical and creative elements—can be transformed by innovations that commoditize expertise.

Animated films originated in the 1910s with short, 10-minute sequences that artists typically handcrafted frame-by-frame; but the animated film industry did not assume a significant role in Hollywood until Walt Disney Studios began developing the capabilities for producing full-length feature films in 1923. Disney's genius was recognizing that although animated films depended on the artistry of expert animators, some aspects of the animation process—such as coloring drawings with a designated color palettes and drawing the pictures that get sequenced between key frames—could be simplified into rules-based tasks that could be handed off to less-skilled painters and technicians. To organize the animation studio into departments, Disney simplified and outsourced some of its expert artists' most time-consuming tasks: it hired expert animators, writers, and musical composers to bring the key storytelling elements of the films to life and then assigned departments of non-expert animators, painters, and sound technicians to follow standard processes for turning the key creative elements into a finished product. In doing so, Disney radically boosted the productivity of the animation process and, in turn, made elaborate feature-length films like *Snow White and the Seven Dwarfs* economically feasible.[23]

Decades later, computers transformed the animated film industry again as they began to automate aspects of animators' expertise. In the 1980s and early 1990s, Disney contracted with a relatively new company called Pixar to do the routine work of coloring its black and white drawings. Disney found that Pixar's proprietary Computer Animation Production System (CAPS) could produce colored images for films like *The Little Mermaid* more quickly and cheaply and with less image degradation than when workers painted the images by hand.[24] This contract work for Disney gave Pixar its early foothold in the film industry and provided the revenue it needed to stay afloat and continue developing its CAPS technology.

Before long, digital animation technology also began automating more advanced animation effects, thereby enhancing the capabilities of expert animators. With new digital animation technologies, studios could finally bring computers' calculating speed and accuracy to bear on some of the most technically challenging aspects of animation.

For example, prior to digital animation, most of the camera angle shifts in animated films involved zooming in and out or shifting up and down or side to side. Films rarely included sequences with rotating camera angles because figuring out how the elements of a drawing should shift as the camera angle turned was an extremely complex, labor-intensive, and costly process. To create a scene for the 1953 Disney film *Peter Pan*—in which the camera angle rotates around the mainmast of Captain Hook's ship as it follows Peter Pan's duel with Hook—scene planners had to calculate painstakingly the frame-by-frame shifts in the drawings using slide rules.[25] In contrast, Disney's 1991 film *Beauty and the Beast* famously showcased the power of digital animation technology in a sweeping scene in which the camera rotates around Belle and the Beast as they dance in a sprawling ballroom.[26]

Digital animation technologies do not replace the need for expert animators. Instead, they expand the frontier of expert animators' creative and artistic possibilities. With digital animation tools, animators can create films with color palettes, textures, movements, and 3D realism that were practically impossible to produce in the days of hand-drawn animated films. As animation technologies substitute for humans in performing laborious rules-based tasks, they allow expert animators and artists to focus their time and creativity on tasks that cannot be automated—such as imbuing characters with persona-forming appearances, movements, and gestures; designing settings with mesmerizing textures and lighting; and crafting story arcs and dialogue that captivate audiences. With the new capabilities afforded by technology, companies like Pixar and Disney have delighted audiences with some of the biggest box-office hits in the history of animated film such as *Toy Story*, *Finding Nemo*, and *Frozen*.[27]

As cutting-edge animation technologies expand the artistic palettes of high-end studios like Disney and Pixar, other innovations bring basic animation production to the masses. Over the last few decades, a number of software products entered the amateur animation scene that make it easy for amateurs to produce 2D animated videos from their personal computers. For example, with Adobe Character Animator software, amateur animators no longer need to create frame-by-frame drawings to produce the illusions of character speech and movement.[28] Instead, they can use the built-in camera and microphone on a personal computer to capture a voice actor's lip movements, gestures, and speech; they can then rely on the software to map those elements onto a still drawing to bring the drawing to life. Granted, these animations have nowhere near the artistic detail or 3D realism of the animated films from big studios. But the millions of subscribers to YouTube channels, such as *MinutePhysics* and *How It Should Have Ended*, demonstrate the value of empowering amateurs with technologies that simplify the animation process.

The animation field exemplifies the two effects that simplifying and automating innovations have on a profession. Computer animation technologies substitute for human labor when carrying out complex and laborious, rules-based tasks. But they do not replace experts' artistry in visual design and storytelling. Thus, the advances in the animation field both enable non-experts to do things they could not do on their own and empower experts to push the frontiers of their field. The end result is both a broader menu of entertainment options from amateurs and a more impressive lineup of visually astounding films from industry leaders.

As animation technologies substitute for humans in performing rules-based tasks, they allow expert animators and artists to focus their time and creativity on tasks that cannot be automated.

WILL INNOVATIONS REPLACE TEACHERS?

Much as innovations in animation assist both amateur and expert animators in delighting their audiences, innovations that simplify and automate aspects of teacher expertise can help teachers boost student achievement in two distinct ways. First, they empower non-experts—often paraprofessionals and novice teachers who lack expert teaching abilities—with tools that enhance their performance. Second, they enable expert teachers—teachers who have honed their teaching skills through training, practice, and experience—to identify and address students' individual learning needs more efficiently and effectively.[29] *Figure 3* illustrates the comparative advantages of expert teachers, non-experts, and computers.

Innovations that simplify teacher expertise

We typically think of textbooks as self-study tools for students, but they are also one of the oldest and most widely used examples of an innovation that simplifies teacher expertise. For expert teachers, textbooks provide content explanations, reading assignments, practice activities, and pacing guides that make unit and lesson planning more efficient; it is much easier for teachers to build on resources from a textbook than to create lesson plans and materials from scratch. For non-experts, high-quality textbooks offer a lifeline with step-by-step lesson plans and teaching tips; these resources are especially helpful for teachers who have never taught a particular concept or course before.

Research affirms the valuable role of high-quality instructional materials, such as textbooks, as low-tech innovations that simplify teacher expertise to improve the effectiveness of teachers. A 2012 Brookings Institution study found that providing teachers with high-quality instructional materials had a greater effect on student achievement than replacing an average teacher with a 75th-percentile teacher.[30] Similarly, a 2016 study showed that giving middle school math teachers access to inquiry-based lesson plans and online support significantly improved student achievement—and benefited weaker teachers the most.[31] In short, high-quality textbooks and instructional materials convert the content and pedagogical expertise of effective teachers into easy-to-follow guides that can improve teacher performance.

In a similar vein, practical books on teaching—such as Harry Wong's *The First Days of School*, Fred Jones' *Tools for Teaching*, and Doug Lemov's *Teach Like a Champion*—also serve as low-tech innovations that simplify teacher expertise by codifying techniques that teachers typically spend years honing into explicitly trainable teaching "moves" for non-experts. The process by which the authors develop their techniques follows the pattern described earlier: the understanding of a field improves from expert intuition, to correlation-based standardized practices, to a robust scientific understanding of cause and effect. In researching for *Teach Like a Champion*, Lemov spent thousands of hours observing top teachers, documenting their practices, and then articulating those practices as a set of discrete teaching techniques.[32] Currently, Lemov's techniques are examples of standardized practices based on observed correlations. But as learning science advances, education researchers will likely identify the causal mechanisms that explain Lemov's techniques and then use that understanding to develop more effective and more explicitly teachable techniques.

Innovations that automate teacher expertise

Like innovations that simplify teacher expertise, innovations that automate some aspects of teaching can also amplify the effectiveness of both non-experts and expert teachers. Many teachers already recognize that software can be a powerful instructional aid. According to the Bill & Melinda

Figure 3. Comparative advantages of computers, non-experts, and expert teachers

Computers

Streamline assessment

Track student learning progress

Provide students with immediate feedback

Adapt instruction to students' individual learning needs

Simplify instructional planning for teachers by recommending resources based on students' needs

Non-experts

Provide students with human supervision and support

Manage instruction when expert teachers are unavailable

Expert teachers

Provide students with human supervision and support

Design new instructional approaches and develop custom instructional materials

Diagnose and address cognitive, noncognitive, social, and emotional causes of students' learning difficulties

Provide expert feedback and coaching on students' critical thinking, creative problem solving, and oral and written communication

Gates Foundation's 2015 "Teachers Know Best" survey, 59 percent of teachers surveyed said that educational technologies "have the potential to deliver instruction directly to students."[33] In other words, a majority of teachers realize that these tools are capable of effectively automating some aspects of teaching.

The supply of such tools is expanding rapidly. For example, adaptive educational software from a host of companies—Curriculum Associates, MIND Research Institute, DreamBox Learning, Zearn, Redbird Advanced Learning, Achieve3000, Knewton, Khan Academy, Carnegie Learning, and others—teach students basic content knowledge and skills through videos, text, and interactive modules. The software then assesses students' current levels of understanding, provides immediate feedback, identifies misconceptions, and gives targeted instruction based on students' needs and strengths. For non-experts, these technologies provide students with instruction and additional opportunities to practice content that the teacher may not be skilled at teaching. For expert teachers, these technologies give students reinforcement and practice on content the teacher has already covered, provide additional means for adjusting instruction to students' individual needs, and gather real-time data on students' learning so that teachers can provide students with appropriate learning activities and interventions.

Some of the latest educational technologies are even starting to go beyond helping students learn basic facts and skills. For example, Pearson's WriteToLearn software uses natural language processing technology to give students personalized feedback, hints, and tips to improve their writing skills. In describing his experience using WriteToLearn, one 7th-grade English language arts teacher said, "I feel it's pretty accurate. ... Is it perfect? No. But when I reach that 67th essay, I'm not [really] accurate, either. As a team, [WriteToLearn and I] are pretty good."[34] Essay grading technology cannot substitute for a teacher's ability to provide feedback and coaching on particular words and sentences: the software merely rates students' essays in general areas—such as organization, idea development, and style—and then provides generic suggestions for improvement in these areas. But when teachers use the software as a first pass at grading and then interject their detailed feedback to address the improvement areas identified by the software, essay grading becomes a much less time-consuming and laborious process. The net result is that teachers can spend less time grading and more time teaching, while also giving students more opportunities to receive customized feedback on their writing.

Fortunately, innovations that simplify and automate teacher expertise provide teachers and school leaders with an expanded frontier of options for addressing students' needs and strengths. These innovations can help school leaders overcome major barriers to quality instruction as they wrestle with a host of challenging circumstances—namely variations in teacher quality, wide-ranging student needs, and added expectations placed on teachers.

When innovations simplify and automate distinct aspects of teaching, both effective and less-effective teachers can reach new heights.

CIRCUMSTANCE #1: WHEN SCHOOLS LACK EXPERT TEACHERS

Teachers are the most important school-related factor affecting student achievement. But a number of structural barriers—including teacher shortages, a lack of clear methods for developing high-quality teachers, and teacher burnout and attrition—make it difficult for schools to ensure that an effective teacher reaches every student.

Research shows that teacher quality varies widely—both across the teaching profession and among teachers at the same school.[35] These differences in teacher quality substantially impact students' academic and life outcomes. The Measures of Effective Teaching (MET) project found that students taught by top-quartile teachers often gain an estimated two-thirds of a school year of additional learning beyond that of students taught by bottom-quartile teachers.[36] Additionally, a 2014 American Economic Review study showed that replacing a teacher in the bottom five percent with an average teacher increases the present value of students' lifetime income by approximately $250,000 per classroom.[37] Teacher quality is also likely to impact students' civic attitudes and work mindsets.[38] In short, teacher quality affects not just students' academic achievement in a given school year, but also other hard-to-measure factors that affect the larger trajectories of their lives.

Educators, policymakers, and advocacy groups are working hard to address the causes of variations in teacher quality. Their work ranges from improving teacher preparation and professional development programs, to increasing the status and pay of teachers in order to attract and retain effective teachers, to ensuring that teacher credentialing and tenure are meaningful signals of teacher quality.[39] These are important initiatives, but dramatically improving the expertise of a large percentage of the United States' 3.1 million teaching force is still no small feat.[40]

Fortunately, innovations that commoditize teacher expertise can ensure that every student has access to quality education, even when top-tier teachers are in short supply. Efforts afoot beyond the United States, where teacher shortages are even more acute, demonstrate how education leaders can use technology and non-experts to shrink the gap in access to expert teachers. Mindspark, an educational software program that provides individualized and adaptive tutoring in math and language—available in English, Hindi, and Gujarati—illustrates how technologies that automate teacher expertise can help non-experts increase their impact on student achievement.

In 2001, three former classmates from the India Institute of Management Ahmedabad (IIM-A), and founders of a private school in Ahmedabad, India, became disheartened by the fact that instruction in most of India's primary and secondary schools focused more on rote memorization of facts than on developing students' conceptual understanding. Hoping to improve the education system in India, they founded Educational Initiatives, a private assessment company that provides standardized assessments for measuring students' depth of conceptual understanding. Schools across the country were soon using Educational Initiative's assessments to uncover student's gaps in higher-order learning. But as adoption of the assessments grew, the company soon noticed a consistent theme in the feedback it was receiving from its partner schools: "It's great to know about the shortcomings in our students' learning, but what is your proposed solution?"

In 2009, Educational Initiatives delivered its answer: an educational software program called Mindspark that could provide students with rigorous individualized, adaptive tutoring in math and English.

To develop the software, the company drew on extensive research from its assessment products to try to understand how students learn. As students took Educational Initiative's assessments, the company started to notice patterns in the incorrect answers students submitted. To uncover the causes of these incorrect answers, the company began interviewing students about the reasoning that had led them to answer incorrectly. Skill by skill and subskill by subskill, Educational Initiatives then developed a lengthy catalog of the common misunderstandings that often hindered students' learning.

Educational Initiatives then used its catalog of student misunderstandings to create software that replicated effective teaching practices. First, Mindspark programmers built diagnostic assessments that gauged students' current levels of understanding and uncovered specific misunderstandings. Then, they scoured academic research on instructional practices in order to design a host of interventions—questions, games, and interactive manipulatives—that would address these misconceptions. Finally, as Educational Initiatives rolled out the software to its first partner schools, the programmers iteratively improved the software by studying the data gathered on students' learning progress and then adapting the learning experiences to better address particular misconceptions.

Private schools across India and the Middle East with tuition rates exceeding $700 per child a year were soon using Mindspark, with roughly 80,000 students answering more than one million questions each day. But the company wanted to deploy Mindspark in more disadvantaged communities where it could have broader social impact. In 2010, driven by a quest to serve the low-income public school system in India, Educational Initiatives developed the program in the vernacular languages of Hindi and Gujarati. Then, in 2012, the company received funding from the Central Square Foundation to set up five learning centers in densely populated communities in South Delhi. At these centers, families would pay just three dollars a month for their children to receive tutoring in math and Hindi for one-and-a-half hours every day before or after school.

Initially, the company planned for batches of students in the learning centers to rotate between spending 45-minutes learning with the Mindspark software and 45-minutes working in small groups with a teacher. But as the company began searching for teachers to staff the centers, it quickly discovered that finding educated adults, especially in the low-income areas surrounding the centers, would be practically impossible. According to a 2015 Brookings Institution report, India has a shortage of roughly 689,000 primary teachers and a teacher attendance rate of just 85 percent.[41] And in the poorest neighborhoods where few adults have even a basic education, these problems are much worse.

Because of teacher shortages, Educational Initiatives shifted its plan: the centers would instead rely on the Mindspark software as the primary source of instruction. Although teachers would no longer serve as the primary delivery channels for instructional content, a cohort of less-educated adults recruited by the centers would still play a critical role in the learning model.[42] When hiring teachers to staff its centers, Educational Initiatives sought out individuals who excelled at encouraging and motivating students. As Pranav Kothari, vice president of Mindspark Centres, explained:

> Based on the size of its population, India needs seven million teachers if it is going to educate all of its students. India does not have seven million people who can teach advanced math, but it does have seven million nice people who like to work with kids. ... Children come back [to our centers] every day because they like their teacher, they feel loved, and they are recognized for their efforts. That's something only humans can do.

"Children come back every day because they like their teacher, they feel loved, and they are recognized for their efforts. That's something only humans can do."

Clearly, the Mindspark software cannot replicate many of the rich learning experiences that an effective teacher might provide. But when qualified teachers are unavailable or scarce, students who use the Mindspark software, with support from caring adults, can achieve dramatic growth. In Fall 2015, a team of researchers, led by Karthik Muralidharan of the University of California San Diego and the global co-chair of education for the Abdul Latif Jameel Poverty Action Lab (J-PAL), conducted a randomized control study to measure the learning gains of students who attended the Mindspark Centres. They found that students who attended the centers for four and a half months had learning gains that were two times higher in math and 2.5 times higher in Hindi than those of students who were randomly assigned to a control group that only received instruction through local schools.[43]

Teacher shortage and quality challenges in the United States are nowhere near as severe as they are in India. Still, the fundamental problem is the same in both countries: How do you meet students' learning needs when it is hard to ensure that an effective teacher leads every classroom? Lessons from abroad and at home suggest that U.S. school leaders would do well to consider how they might use high-quality curriculum, scripted lesson materials, and educational software to bolster the effectiveness of teachers who are still developing expertise in their profession—or in settings where effective teachers are scarce but caring adults are plentiful.[44]

CIRCUMSTANCE #2: WHEN EXPERT TEACHERS MUST TACKLE AN ARRAY OF STUDENT NEEDS

Nearly every teacher—novice or veteran alike—faces a common challenge: How can I meet the individual learning needs of *each* student in my classroom? Expert veteran teachers—through years of training, practice, and trial-and-error—often develop a range of techniques for addressing students' needs and strengths. But the inherent limitations of the traditional model of education can cause even the best teachers to struggle.

The century-old educational model common in schools across much of the world was designed to educate large populations efficiently through standardized instruction and student groupings. When young children begin school, they are grouped into age-based grades and then taught using age-appropriate, whole-class curricula. Later in the middle and high school grades, students are further grouped based on their prior achievement into advanced, regular, or remedial courses and then taught in groups using standardized curriculum and whole-class learning activities. The assumption behind this model is that students who are grouped by age and achievement levels will have the same learning needs and therefore can be instructed using the standardized curricula and common pacing guides designed for a particular grade level or course.

But reality is much messier. Students do not all enter a grade or course with the same learning needs or background knowledge; consequently, the standardized, batch-processing approach fails, by design, to help all students succeed. Indeed, students who pass the same course often have widely varying levels of mastery of the course's content. The traditional model is so long-standing and pervasive that most people take it as a given that standardized, whole-class, single-paced instruction is an inherent aspect of formal education.

One way that teachers often cope with the drawbacks of batch grouping and standardized instruction is by developing differentiated lessons that attempt to address students' individual learning needs. But true differentiation on a daily basis is a challenging practice to implement, even for the best teachers. To differentiate instruction, teachers must design multiple activities and learning resources for each lesson they teach. Much as incorporating rotating camera angles into an animated film was an impractically laborious process for Disney animators to do by hand, the extra planning and preparation required for teachers to differentiate instruction make it an unsustainable practice. According to a 2008 national teacher survey, 84 percent of teachers surveyed said that differentiated instruction is "somewhat" or "very" difficult to implement on a daily basis in their classrooms.[45]

Technology can substantially enhance teachers' abilities to differentiate instruction for their students.

Fortunately, differentiation becomes much more doable when teachers can leverage technology that automates some of the work of assessing students' needs and strengths as well as planning and delivering instruction. Below are three types of teaching tasks that technology can help to automate:

- **Assessment.** Software and devices can streamline the processes for administering and grading basic assessments, thereby allowing teachers to check students' levels of understanding more quickly and frequently. Additionally, software can aggregate and summarize assessment data in ways that help teachers quickly identify actionable insights about which students need help with particular topics or concepts.
- **Instructional planning.** Many teachers spend countless hours designing lesson plans and materials that are custom crafted to meet students' learning needs. To streamline this process, platforms ranging from Google, YouTube, and Pinterest, to Teachers Pay Teachers and Gooru, help teachers quickly scour large databases of learning resources to find ready-made lesson plans, activities, and materials aligned to students' needs and strengths. More sophisticated systems—such as the Teach to One algorithms discussed later in this paper—take this approach one step further by identifying students' learning needs using the data from computer-administered assessments and then recommending lesson resources to teachers.
- **Basic instruction.** Students can learn some aspects of basic content instruction through adaptive learning software and personalized learning playlists. Teachers can also use these technologies to align targeted instruction to students' individual levels of understanding in order to differentiate instruction more effectively and efficiently.

Much as advances in digital photography allow photographers to hassle less with lenses and aperture settings so that they can focus on composing good pictures, innovations that commoditize teacher expertise allow teachers to outsource some aspects of instruction, assessment, and planning so that they can focus on meeting students' individual learning needs. These innovations not only help teachers to better differentiate instruction, but also allow them to restructure how they use their time to help students. For example, when students spend some of their class time learning on computers, teachers are freed to spend more time working with students individually and in small groups to provide targeted instruction.[46]

One organization that is pioneering new ways to use technology to help teachers address the wide range of learning needs in their classrooms is the nonprofit New Classrooms, which evolved from School of One.[47] In the spring of 2008, Joel Rose, chief executive of human capital at the New York City Department of Education, was visiting a friend in Miami who ran employee-training centers. On the wall of one of the centers was a sign that read, "Choose Your Modality." The sign stopped Rose in his tracks. He realized that schools could work better if students could learn each concept in the way that best suited their personal needs, rather than in a one-size-fits-all classroom.

Rose secured funding and in the summer of 2009 opened the first "School of One" as a summer math program in a middle school in lower Manhattan; and with it launched a radical new approach for leveraging both teachers and technology to meet students' individual learning needs. When the students in that pilot arrived for their first day of summer school, they soon discovered that their new math program felt nothing like traditional summer school math. At the end of each day, the School of One gave each student a short online quiz to diagnose precisely what she knew. With this information in hand, overnight the School of One software pulled from a menu of over one thousand math lessons across a wide range of instructional modalities—including live lessons from teachers, advisory groups with teachers, independent learning projects, small-group collaboration, peer-to-peer learning, and virtual instruction—to match each student to a "learning playlist" for the next day. Each playlist included a customized set of teacher-led workshops, online lessons, small-group activities, or other learning resources aligned to the students' learning needs.[48] The next morning, the school projected the daily station assignment for each student onto monitors on the wall, similar to the flight monitors at an airport.

Overnight, the system also developed corresponding teaching plans for each teacher. The plans included lists of students with whom the teachers would work during each block of the day, up-to-date data on students' learning needs and preferences, a list of learning objectives the students needed to master the next day, and lesson plan recommendations aligned to learning objectives and students' learning needs. Teachers were free to adapt the lesson plans based on their professional judgment, but the lessons provided a solid roadmap to guide teachers in their work. Teachers also provided feedback to help improve the algorithm for developing student schedules and teacher plans.

The School of One's major innovation was using technology to automate teachers' expertise at analyzing student data and planning instruction. A lone teacher would be hard-pressed to keep up with administering, grading, and analyzing daily assessments; creating and coordinating unique daily learning plans for each student; and planning daily lessons targeted at students' particular learning needs. The School of One instead took advantage of computers' processing speeds and data storage capabilities to offload much of that work. By using technology to regroup students continually based on common needs, teachers can have greater impact when they deliver live instruction. And because they know that all the students with whom they are working at any moment have the prerequisite skills to be successful in the given lesson, teachers can more effectively use their flexibility and expert judgment to lead students through high-quality learning experiences.

Buoyed by its early proof of concept, at the end of that summer the School of One expanded beyond its summer pilots into mainstream schools. Then, in 2011, Rose moved on to found New Classrooms, a nonprofit with an offering called Teach to One, which is similar to the original School of One model. The *Teach to One: Math* program now serves students in 40 schools across 10 states and the District of Columbia,[49] and its measured results are noteworthy. According to a 2014 Columbia Teachers College study on Teach to One's impact in 15 different schools, at the end of the second year of program implementation, students averaged 47 percent more growth than the national average in math on the Northwest Evaluation Association's Measures of Academic Progress (MAP) assessment.[50]

Not every school needs to adopt Teach to One's computer algorithm approach to coordinate customized daily student learning playlists and teacher schedules. But most schools and teachers can greatly benefit from using software and resource platforms to automate some aspects of assessment, planning, and instruction. The more tasks teachers can outsource to technology, the more capacity they have to focus their time and attention on the individual learning needs of their students.

CIRCUMSTANCE #3: WHEN EXPERT TEACHERS NEED TO TEACH MORE THAN ACADEMICS

Formal education is often thought of as synonymous with learning academic content. But education researchers and school leaders increasingly recognize that academic achievement alone is not sufficient to prepare students for life and work in the 21st century.

Increasingly, advocates are calling for schools to place greater emphasis on fostering students' deeper learning and noncognitive skills. Recent research shows that noncognitive factors—such as goal setting, teamwork, emotional awareness, self-discipline, and grit—are strong predictors of how likely students are to persist through college and succeed in the workforce.[51] Likewise, students engaged in deeper learning develop higher-order thinking skills—such as analytical reasoning and complex problem solving—that enable them to apply knowledge to real-world circumstances and solve novel problems. Deeper learning is increasingly relevant in a world confronted with rapid changes brought on by globalization and artificial intelligence because it gives human experts a comparative advantage relative to machines.

Many schools are rising to the challenge of meeting these new learning imperatives. Unfortunately, schools that try to put added emphasis on teaching deeper learning and noncognitive skills often run up against the constraints of practical reality. As noted earlier, effective teaching is demanding work, and teachers' time is scarce. As such, schools cannot expect teachers to tackle these added responsibilities meaningfully without somehow reconfiguring teachers' existing workloads.

Fortunately, innovations that commoditize teacher expertise can play a powerful role in helping schools and teachers give more emphasis to deeper learning and noncognitive skills. Brainology, a blended-learning curriculum created by Mindset Works, a nonprofit organization founded by Stanford researcher Dr. Carol Dweck, is one example of a technology that simplifies and automates the work of helping students develop these crucial skillsets. Brainology provides interactive lessons that teach students about growth mindset. It also offers teachers tips and lesson materials that reinforce the online lessons.

Unfortunately, not many technologies like Brainology exist that can teach students deeper learning or noncognitive skills. But other technologies—such as adaptive learning software and personalized learning playlists—can free teachers from particular teaching demands to spend more time working with students individually or in small groups to develop these skills.

Summit Public Schools, a charter school management organization in the San Francisco Bay Area, provides a compelling example of how technology can enhance teachers' capacity to help students develop skills and habits beyond academic knowledge.[52] Prior to incorporating technology as a core part of its instructional model, Summit consistently earned high marks on California's Academic Performance Index (API) and garnered national acclaim, with *Newsweek* listing it as one of the top 10 most transformational high schools in America. But in 2011, Summit observed that even though nearly all of its students had gone on to college, only about 55 percent of them were on track to graduate.[53] Although this statistic put Summit's students ahead of national averages when compared to students with similar socioeconomic backgrounds, Summit was not satisfied. In response, it began thinking about new ways to design a set of experiences that would better equip its students not only with content knowledge, but also with deeper learning and noncognitive skills that would help them thrive in college and beyond.[54]

As Summit worked to reinvent its instructional model, Summit's founder and CEO, Diane Tavenner, emphasized the principle that teacher time with students is too valuable to spend lecturing about content that students can learn online. To this end, Summit's teachers spent an entire summer using their expertise in content instruction to develop online instructional resources. They wrote out the learning objectives that students would need to master each year, developed online assessment items for measuring mastery of each of those learning objectives, and created and gathered online resources—including articles, websites, videos, and web apps—to cover the learning objectives. They then curated the online content into playlists that students could work through to master each learning objective. In short, teachers used their expertise to create a comprehensive online curriculum that students could use, independent of the teacher, to learn.

With these tools in hand, Summit's teachers then redesigned their instructional model to provide four types of learning experiences that would allow them to foster students' deeper learning and noncognitive skills:

- **Project-based learning.** Students receive core content instruction for an hour every morning on Monday through Thursday and most of the day on Friday using the online playlists curated by Summit's teachers. They then spend most of the day on Monday through Thursday doing project-based learning. These projects provide teachers with more opportunities to coach students on noncognitive skills and help them foster deeper learning as students work in teams, solve real-world problems, and practice written and oral communication. Students who attend Summit from grades 6 through 12 will complete at least 200 projects by the time they graduate.
- **Competency-based learning.** Online learning enables Summit to use a competency-based learning approach that reinforces teachers' efforts to help students develop important skills and habits. With competency-based learning, students can no longer pass their courses by merely showing up and following teachers' instructions. Instead, students advance individually through online content upon demonstrating mastery of learning objectives. When students log in to Summit's Personalized Learning Platform, a personalized dashboard gives them a clear overview of whether they are on pace to complete the various projects and learning objectives for their courses. With coaching from their teachers and mentor teachers, students must then exercise skills—such as goal setting, personal management, and self-control—to decide which learning objectives they will work on that day, which learning playlist resources they will use, and how they will work toward completing projects. By wrestling with challenging learning objectives until they reach mastery, students learn that they can grow their intelligence through persistence and purposeful effort.
- **Mentorship.** Online learning also facilitates Summit's efforts to provide students with coaching and mentorship. Upon enrolling at Summit, each student is assigned a mentor teacher who provides guidance throughout the student's entire four years at the school. As other students focus on their playlists, mentors meet with each of their mentees for at least 10 minutes every Friday to discuss the student's progress toward his academic goals and coach the student on important skills and habits. Mentor teachers also act as college counselors, family liaisons, and advocates for students. Students who share a mentor meet at the end of every school day as a community group to continue to develop, practice, and model noncognitive skills. In describing the value of using online learning to create opportunities for mentorship, Diego Arambula, Summit's former chief growth and innovation officer, said:

> By relying on online learning for basic content instruction, Summit's teachers now, more than anything, are focusing on cognitive and noncognitive skills. We've done this by building 200 hours directly into the school day over the course of the school year for kids to interact individually with adults because coaching is where you can teach habits of success.

> Summit Public Schools adheres to the principle that teacher time with students is too valuable to spend lecturing about content that students can learn online.

- **Expeditions.** Summit has rearranged its academic calendar so that students can participate in four different two-week learning expeditions throughout the school year. During these expeditions, students immerse themselves in performing arts classes, internships, video production projects, web-design courses, and volunteer opportunities—all of which provide students with additional opportunities to develop noncognitive skills and foster deeper learning experiences.

Although online learning is a key enabler of Summit's instructional model, high-quality teachers remain at the heart of Summit's efforts to develop students' skills and habits. By using technology to automate some aspects of core content instruction and basic assessment, Summit has reimagined the role of teachers and, in doing so, enabled them to provide students with much richer learning experiences. Summit's pioneering approach is a model for schools that are looking for ways to better foster students' deeper learning and non-cognitive skills.[55]

CONCLUSION

When IBM's Deep Blue supercomputer beat chess champion Garry Kasparov, it seemed the world's fascination with the game might come to an end. But Deep Blue's triumph actually marked the beginning of a new era of chess competition. Following Kasparov's defeat, competitive chess players started a new form of chess, called Freestyle Chess, wherein teams composed of any number of humans and computers play against each other. The outcomes of Freestyle Chess tournaments have been startling: teams of amateur human players and less-advanced machines routinely defeat the world's most advanced chess-playing computers. It turns out that the world's best chess competitors today are not machines, but humans whose expertise in chess is augmented by machines.

The history of chess illustrates a pattern that holds true for teaching as well: as innovations that commoditize teacher expertise continue to improve, the best instructional models will not come from computers, but from non-experts and expert teachers whose capabilities are enhanced by computers.

Good teachers are the most valuable resource in our education system. But the teaching profession faces a number of challenges—inadequate preparation, low pay, poor support, limited career opportunities, and inconsistent quality—that make it difficult to ensure that there is an effective teacher in every classroom. Reforming the U.S. teaching profession so that all 3.1 million teachers are as effective as the top quartile of the current teaching force is an important but difficult order to fill. At the same time, as the world moves rapidly toward a future where nearly every aspect of work and life will be enhanced by pervasive computing, artificial intelligence is changing what students need to know and be able to do in order to find their place in the world. This shift is raising the bar on outcomes not valued by current school accountability systems, such as empathy and collaboration, creativity and design thinking, initiative and entrepreneurship. And even when top-tier teachers are present, traditional instructional approaches rarely allow them adequate time to address students' diverse needs or delve deeply into activities that foster students' deeper learning and noncognitive skills.

As we move into the future, one of the most important gifts we can give students is the confidence and ability to thrive in a novel and complex world transformed by artificial intelligence. Fortunately, innovations that commoditize some elements of teacher expertise also supply the tools to raise the effectiveness of both non-experts and expert teachers to new heights and to adapt to the new priorities of a 21st-century work force and education system.

NOTES

1 William Saletan, "Chess Bump," *Slate Magazine,* May 11, 2007, http://www.slate.com/articles/health_and_science/human_nature/2007/05/chess_bump.html (accessed September 22, 2016).

2 "The DeepQA Research Team," IBM Research, http://researcher.watson.ibm.com/researcher/view_group.php?id=2099 (accessed September 22, 2016).

3 For more, see Tim Adams, "And the Pulitzer goes to… a computer," *Guardian,* June 28, 2015, https://www.theguardian.com/technology/2015/jun/28/computer-writing-journalism-artificial-intelligence (accessed July 28, 2016); Stephen Beckett, "Robo-journalism: How a computer describes a sports match," *BBC News,* September 12, 2015, http://www.bbc.com/news/technology-34204052 (accessed July 28, 2016); and "Did a Human or a Computer Write This?," quiz, *New York Times,* March 7, 2015, http://www.nytimes.com/interactive/2015/03/08/opinion/sunday/algorithm-human-quiz.html?_r=0 (accessed July 28, 2016).

4 Lauren F. Friedman, "IBM's Watson Supercomputer May Soon Be The Best Doctor In The World," *Business Insider,* http://www.businessinsider.com/ibms-watson-may-soon-be-the-best-doctor-in-the-world-2014-4 (accessed July 28, 2016).

5 Elizabeth A. Harris, "Next Target for IBM's Watson? Third-Grade Math," *New York Times,* September 27, 2016, http://www.nytimes.com/2016/09/28/nyregion/ibm-watson-common-core.html?partner=rss&emc=rss&_r=5 (accessed October 20, 2016).

6 For detailed analysis and discussion on the likely impact of artificial intelligence on society, see "Artificial Intelligence and Life in 2030," Stanford University, September 2016, https://ai100.stanford.edu/sites/default/files/ai_100_report_0901fnlc_single.pdf. See also "Preparing for the Future of Artificial Intelligence," Executive Office of the President, National Science and Technology Council, Committee on Technology, October 2016, https://www.whitehouse.gov/sites/default/files/whitehouse_files/microsites/ostp/NSTC/preparing_for_the_future_of_ai.pdf.

7 Carl Benedikt Frey and Michael A. Osborne, "The Future of Employment: How susceptible are jobs to computerisation?," working paper, Oxford Martin School, Oxford University, September 17, 2013, http://www.oxfordmartin.ox.ac.uk/downloads/academic/The_Future_of_Employment.pdf.

8 Beth Miller, "Researcher studies teachers' use of automated essay scoring software," *Phys.org,* July 8, 2015, http://phys.org/news/2015-07-teachers-automated-essay-scoring-software.html (accessed September 22, 2016).

9 Sarah Marsh, "Could computers ever replace teachers?," *Guardian,* February 24, 2015, https://www.theguardian.com/teacher-network/2015/feb/24/computers-replace-teachers (accessed September 22, 2016).

10 David J. Deming, "The Growing Importance of Social Skills in the Labor Market," working paper, National Bureau of Economic Research, August 2015, http://www.nber.org/papers/w21473.pdf.

11 Ross Brenneman, "Is There a Teacher Shortage? That Depends How You Frame It," *Education Week Teacher,* August 6, 2015, http://blogs.edweek.org/teachers/teaching_now/2015/08/is-there-a-teacher-shortage-yes-no-maybe.html (accessed August 13, 2015).

12 Sylvia Allegretto and Lawrence Mishel, "The teacher pay gap is wider than ever," Economic Policy Institute, August 9, 2016, http://www.epi.org/files/pdf/110964.pdf.

13 Stephen Sawchuk, "Teacher-Prep Enrollment Continues to Decline," *Education Week,* March 29, 2016, http://www.edweek.org/ew/articles/2016/03/30/teacher-prep-enrollment-continues-to-decline.html (accessed August 30, 2016).

14 David F. Labaree, *The Trouble with Ed Schools* (New Haven, Conn.: Yale University Press, 2006).

15 Thomas J. Kane, Daniel F. McCaffrey, Trey Miller, and Douglas O. Staiger, "Have We Identified Effective Teachers? Validating Measures of Effective Teaching Using Random Assignment," Bill & Melinda Gates Foundation, January 2013, http://k12education.gatesfoundation.org/wp-content/uploads/2015/12/MET_Validating_Using_Random_Assignment_Research_Paper.pdf.

16 Eric A. Hanushek and Steven G. Rivkin, "The Distribution of Teacher Quality and Implications for Policy," *Annual Review of Economics,* vol. 4, September 2012, pp. 131–157.

17 Susanna Loeb, "Teacher quality: Improving teacher quality and distribution," National Academy of Education, 2008, https://cepa.stanford.edu/sites/default/files/NAE%20Teacher%20Quality.pdf.

18 Examples of initiatives and organizations working to improve teacher preparation and teacher professional development include the TeachStrong initiative, Council for the Accreditation of Educator Preparation, Deans for Impact, National Council on Teacher Quality, New Teacher Center, Learning Forward, and TNTP.

19 Timothy D. Walker, "The Disproportionate Stress Plaguing American Teachers," *Atlantic,* October 7, 2016, http://www.theatlantic.com/education/archive/2016/10/the-disproportionate-stress-plaguing-american-teachers/503219/ (accessed October 15, 2016).

20 Owen Phillips, "Revolving Door Of Teachers Costs Schools Billions Every Year," *NPR,* March 30, 2015, http://www.npr.org/sections/ed/2015/03/30/395322012/the-hidden-costs-of-teacher-turnover (accessed August 30, 2016).

21 Some of the early-prescribed treatments for scurvy included urine mouthwashes, sulfuric acid, bloodletting, and burial up to the neck in sand. See David I. Harvie, *Limeys: The Conquest of Scurvy* (Charleston, S.C.: The History Press, 2005).

22 H. James Wilson, Sharad Sachdev, and Allan Alter, "How Companies Are Using Machine Learning to Get Faster and More Efficient," *Harvard Business Review,* May 3, 2016, https://hbr.org/2016/05/how-companies-are-using-machine-learning-to-get-faster-and-more-efficient (accessed October21, 2016).

23 Jeremy G. Butler, *Television: Critical Methods and Applications* (New York: Routledge, 2012), p. 287.

24 Tom Sito, Moving Innovation: A History of Computer Animation (Cambridge, Mass.: MIT Press, 2013), pp. 231–232.

25 Tom Sito, *Drawing the Line: The Untold Story of the Animation Unions from Bosko to Bart Simpson* (Lexington, Ky.: University Press of Kentucky, 2006), p. 324.

26 *Moving Innovation,* p. 232.

27 For more on the Pixar method of computer animation, see "Pixar in a Box," Pixar Animation Studios and Khan Academy, https://www.khanacademy.org/partner-content/pixar (accessed October 20, 2016).

28 For an example of this technology in use, see "Bringing 2D characters to life with Adobe Character Animator," Adobe Creative Cloud, April 8, 2015, https://www.youtube.com/watch?v=lmPo0_WZyPU (accessed July 28, 2016).

29 Many of the points in this paper dovetail with Public Impact's Opportunity Culture work. Whereas the Opportunity Culture work emphasizes using alternative staffing arrangements and technology to extend the reach of excellent teachers, this paper focuses on using technology to enhance and amplify expert teachers. To learn more about Public Impact's Opportunity Culture work, see http://opportunityculture.org/.

30 Matthew M. Chingos and Grover J. "Russ" Whitehurst, "Choosing Blindly: Instructional Materials, Teacher Effectiveness, and the Common Core," Brookings Institution, April 10, 2012, https://www.brookings.edu/wp-content/uploads/2016/06/0410_curriculum_chingos_whitehurst.pdf.

31 C. Kirabo Jackson and Alexey Makarin, "Simplifying Teaching: A Field Experiment with Online 'Off-the-Shelf' Lessons," working paper, National Bureau of Economic Research, July 2016, http://www.nber.org/papers/w22398 (accessed August 3, 2016).

32 Doug Lemov, *Teach Like A Champion: 49 Techniques that Put Students on the Path to College* (San Francisco: Jossey-Bass, 2010), p. xi.

33 "Teachers Know Best: What Educators Want from Digital Instructional Tools 2.0," Bill & Melinda Gates Foundation, November 2015, https://s3.amazonaws.com/edtech-production/reports/Teachers-Know-Best-2.0.pdf.

34 Caralee J. Adams, "Essay-Grading Software Seen as Time-Saving Tool," *Education Week,* March 10, 2014, http://www.edweek.org/ew/articles/2014/03/13/25essay-grader.h33.html?intc=EW-TC14-TOC (accessed December 2, 2015).

35 Dan Goldhaber, "The Mystery of Good Teaching," *Education Next,* vol. 2, no. 1, Spring 2002, pp. 50–55.

36 "Learning about Teaching: Initial Findings from the Measures of Existing Teacher Project," Bill & Melinda Gates Foundation, December 2010, http://k12education.gatesfoundation.org/wp-content/uploads/2015/12/Preliminary_Finding-Policy_Brief.pdf. Furthermore, Stanford economist Eric Hanushek noted that, "having a good teacher as opposed to an average teacher for three to four years in a row would, by available estimates, close the black-white achievement gap by income." See Eric A. Hanushek, "Boosting Teacher Effectiveness," in Chester E. Finn, Jr. and Richard Sousa (ed.), *What Lies Ahead for America's Children and Their Schools* (Stanford, Calif.: Hoover Institution Press, 2014), pp. 23–35.

37 Raj Chetty, John N. Friedman, and Jonah E. Rockoff, "Measuring the Impacts of Teachers II: Teacher Value-Added and Student Outcomes in Adulthood," *American Economics Review,* vol. 104, no. 9, September 2014, pp. 2633–2679.

38 David Scott Yeager and Carol S. Dweck, "Mindsets That Promote Resilience: When Students Believe That Personal Characteristics Can Be Developed," *Educational Psychologist,* vol. 47, no. 4, 2012, pp. 302–314.

39 One notable effort is the work of the TeachStrong initiative, an advocacy effort led by the Center for American Progress and a coalition of more than 60 partner organizations to "modernize and elevate the teaching profession." The Clayton Christensen Institute is a partner in the TeachStrong coalition.

40 For a detailed discussion on the challenges of improving the quality of the existing U.S. teaching force, see Emily Ayscue Hassel and Bryan C. Hassel, "3x for All: Extending the Reach of Education's Best," Public Impact, 2009, pp. 5–6, http://opportunityculture.org/images/stories/3x_for_all-public_impact.pdf.

41 Urvashi Sahni, "Primary Education in India: Progress and Challenges," Brookings Institution, January 20, 2015, https://www.brookings.edu/opinions/primary-education-in-india-progress-and-challenges/ (accessed August 3, 2016).

42 Although the centers rely on the Mindspark software as the primary source of content instruction, the Mindspark software is also designed to help non-expert teachers develop their teaching expertise. The software provides teachers with a dashboard that shows them which of their students and making progress and which are struggling, and indicates for the teacher the specific concepts and misunderstandings with which students are struggling. The software then gives teachers two-page summaries of research papers on how to address the misconceptions with which their students are struggling.

43 Karthik Muralidharan, Abhijeet Singh, and Alejandro J. Ganimian, "Disrupting Education? Experimental Evidence on Technology-Aided Instruction in India," University of California San Diego, October 24, 2016, http://econweb.ucsd.edu/~kamurali/papers/Working%20Papers/Disrupting%20Education%20(Current%20WP).pdf.

44 This strategy is only recommended as a way to boost the performance of less-effective, non-experts. It is not an advisable strategy in classrooms led by high-performing, expert teachers. Innovations that commoditize teacher expertise can go a long way in boosting the performance of less-effective teachers, but do not match the effectiveness of expert teachers. Current resources and technologies cannot provide students with expert-quality feedback and coaching or replicate the best practices of expert teachers, such as leading an engaging Socratic discussion. Research by Eric Taylor found that although computer-aided instruction software improves the productivity of less-effective teachers, it also diminishes the productivity of the most effective teachers. See Eric S. Taylor, "New Technology and Teacher Productivity," working paper, Harvard Graduate School of Education, August 2015, https://www.cesifo-group.de/dms/ifodoc/docs/Akad_Conf/CFP_CONF/CFP_CONF_2015/ee15-Hanushek/Papers/ee15_Taylor/ee15-Taylor.pdf. Furthermore, requiring expert teachers to follow scripted curriculum or use instructional software to provide instruction, rather than leveraging their expertise, can frustrate and demotivate them. Richard Ingersoll has identified lack of freedom and autonomy as one of the primary reasons why teachers leave the profession. See Richard Ingersoll, Lisa Merrill, and Daniel Stuckey, "Seven Trends: The Transformation of the Teaching Force," Consortium for Policy Research in Education, April 2014, http://cpre.org/sites/default/files/workingpapers/1506_7trendsapril2014.pdf.

45 Tom Loveless, Steve Farkas, and Ann Duffett, "High-Achieving Students in the Era of NCLB," Thomas B. Fordham Institute, June 18, 2008, https://edex.s3-us-west-2.amazonaws.com/publication/pdfs/20080618_high_achievers_7.pdf. For more on differentiated instruction and its challenges, see Laura Pappano, "Differentiated Instruction Reexamined," *Harvard Education Letter*, vol. 27, no. 3, May/June 2011, pp. 3–5 and Chester E. Finn, Jr., "Is differentiated instruction a hollow promise?," Thomas B. Fordham Institute, May 1, 2014, https://edexcellence.net/commentary/education-gadfly-daily/flypaper/is-differentiated-instruction-a-hollow-promise (accessed August 4, 2016).

46 Some worry that online learning is a dehumanizing experience that cuts students off from social interaction. But when executed well, online learning can actually bring students and teachers closer together rather than separating them from meaningful interaction. As one teacher said, "[T]he ability to differentiate more effectively is one of the reasons I was inspired to learn more about blended learning... When I started using blended learning, it was the first time that I actually felt like I was starting to meet the needs of my students. I felt like I knew my students in a way that I hadn't before." See Thomas Arnett, "Insights from a blended-learning teacher," Clayton Christensen Institute, December 18, 2015, http://www.christenseninstitute.org/insights-from-a-blended-learning-teacher/ (accessed July 26, 2016).

47 This example of School of One is adapted from Michael B. Horn and Heather Staker, *Blended: Using Disruptive Innovation to Improve Schools* (San Francisco: Jossey-Bass, 2014), pp. 12–14.

48 For a list and descriptions of the Teach to One: Math modalities, see "The Power of Modalities," New Classrooms, http://www.newclassrooms.org/how-it-works/power-of-modalities/ (accessed November 5, 2016).

49 "'Teach to One: Math' Model Expands to 10 States," *EdSurge*, August 17, 2016, https://www.edsurge.com/news/2016-08-17-teach-to-one-math-model-expands-to-10-states (accessed October 20, 2016).

50 Douglas D. Ready, "Student Mathematics Performance in the First Two Years of Teach to One: Math," Teachers College, Columbia University, December 4, 2014, http://www.newclassrooms.org/wp-content/uploads/2016/09/Teach-to-One_Report_2013-14.pdf. A more recent study that measured the effects of *Teach to One: Math* on a smaller subset of schools found that the program had neither large positive nor large negative effects on student learning, see Jonah E. Rockoff, "Evaluation Report on the School of One i3 Expansion," Columbia Business School, September 2015, http://www.edweek.org/media/evaluation%20of%20the%20school%20of%20one%20i3%20expansion%20-%20final%20copy.pdf. Clearly, further research is needed to determine the true effectiveness of the program.

51 Camille A. Farrington, Melissa Roderick, Elaine Allensworth, Jenny Nagaoka, Tasha Seneca Keyes, David W. Johnson, and Nicole O. Beechum, "Teaching Adolescents to Become Learners: The Role of Noncognitive Factors in Shaping School Performance," literature review, University of Chicago Consortium on Chicago School Research, June 2012, http://consortium.uchicago.edu/sites/default/files/publications/Noncognitive Report.pdf.

52 This example of Summit Public Schools is adapted from Horn and Staker, pp. 171–172.

53 David Osborne, "The Schools of the Future," *U.S. News & World Report*, January 19, 2016, http://www.usnews.com/opinion/knowledge-bank/articles/2016-01-19/californias-summit-public-schools-are-the-schools-of-the-future (accessed October 20, 2016).

54 Horn and Staker, p. 147.

55 To learn more about Summit's pioneering approach, see David Osborne, "Schools of the Future: California's Summit Public Schools," Progressive Policy Institute, January 2016, http://www.progressivepolicy.org/wp-content/uploads/2016/01/2016.01-Osborne_Schools-of-the-Future_Californias-Summit-Public-Schools.pdf.

PHOTO NOTES

Page 4: A teacher mentors a student at Summit Public Schools.
Page 16: A student in India learns language and math through the Mindspark software.
Page 19: A teacher at William P. Gray Elementary School in Chicago works with a small group of students using the Teach to One model.
Page 22: A teacher leads students through project-based learning at Summit Public Schools.
Page 23: Two students works together on a project at Summit Public Schools.

Photos by Summit Public Schools, Hemang Mehta, Educational Initiatives, and Dean La Prairie.

CHRISTENSEN INSTITUTE

About the Institute

The Clayton Christensen Institute for Disruptive Innovation is a nonprofit, nonpartisan think tank dedicated to improving the world through disruptive innovation. Founded on the theories of Harvard professor Clayton M. Christensen, the Institute offers a unique framework for understanding many of society's most pressing problems. Its mission is ambitious but clear: work to shape and elevate the conversation surrounding these issues through rigorous research and public outreach. With an initial focus on education and health care, the Institute is redefining the way policymakers, community leaders, and innovators address the problems of our day by distilling and promoting the transformational power of disruptive innovation.

About the author

Thomas Arnett is a senior research fellow at the Clayton Christensen Institute, where his research focuses on the changing roles of K–12 teachers in blended-learning environments and other innovative educational models. He also examines how teacher education and professional development are shifting to support the evolving needs of teachers and school systems. He holds a BS in Economics from Brigham Young University and an MBA from the Tepper School of Business at Carnegie Mellon University, where he was a William G. McGowan Fellow.

CHRISTENSEN INSTITUTE

christenseninstitute.org