RESEARCH BRIEF

Applying New Education Technologies to Meet Workforce Education Needs

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Summary

The Question: This paper focuses on the question: What are the lessons from learning science and new technologies that could make online education, including workforce training, more effective?

Our current workforce education system faces many gaps, from underinvestment to a deep disconnect between the still-separate worlds of work and learning. However, new models for workforce education delivery are developing to help fill these gaps. New educational technologies, the subject of this paper, are high on the list of new delivery models that we must consider.

The coronavirus disease (COVID-19) introduces a new driver. It has particularly harmed the poor and working class, who have lost jobs or are filling riskier face-to-face “essential” jobs, as opposed to safer, at-home, “knowledge” work. It has underscored the need for a better workforce education system to create better quality jobs. The virus also seriously damaged some key sectors of the economy, where many jobs will not return any time soon. There is now a major need to make workforce education a policy priority, to upgrade skills for those being left behind, and to help others shift job sectors to areas where there will be work. The scale of the current workforce education system is not up to the job. To meet the needed scale, online education, which has been growing in recent years, could be a key tool. But online education is a very different medium than the traditional classroom, and there are lessons from learning science only now being understood that will apply to it in different ways. For online workforce education to work and to scale, it will have to be a better system, incorporating learning lessons and advanced technologies to optimize the new medium.

The world has also been going through a prolonged and unprecedented period of training in the use of digital education. According to UNESCO, 1.6 billion students were displaced in the spring of 2020 as COVID-19 forced social distancing. This left hundreds of millions of students and teachers to rapidly deploy digital tools. Some children didn’t have them, and they were left out. Parents, too, have been exposed to this modality—whether helping their children or scouring the internet looking for resources. Anecdotally, this seems to have informed millions of parents about the affordances of online education—both good and bad. Many working adults, meanwhile, were forced to attend training sessions,

conferences, and events over videoconferencing, further deepening the penetration of online modalities. While online education rescued many schools, the cost of COVID-19 in lost tuition and revenues will likely lead to the demise of many colleges and institutions. At the very least, it will lead to a rethinking in others about the need, role, and purpose of online education.

What are the learning science lessons we need to apply? They include better pedagogical practices, such as:

- providing learning in segments, in 10-minute chunks rather than in lengthier lectures by talking heads;
- creating "desirable difficulties" in learning where the learner has to struggle a bit with the material; using frequent testing;
- using "spaced practice" so that learning occurs or is reiterated over a period of weeks and months;
- using interleaved content that alternates problems and topics rather than teaching a single topic in a single block;
- using periodic assessment and feedback;
- and providing scaffolding that helps the learner with supporting materials as well as coaching.

All of these ideas can be systematically introduced into online courses and workforce training modules. Online learning can also include computer gaming and simulations that encourage more creative problem-solving as a learning task evolves. And online can offer collaborative tools where fellow learners help each other by providing coaching and practice.

Hands-on, active approaches to learning can provide benefits, and can be furthered by simulations, software prototyping, and incorporating new technologies like virtual and augmented reality into online offerings. These advances will be particularly critical in providing workforce skills, which must emphasize hands-on aspects. Artificial intelligence (AI) is still an evolving technology in education, but potentially can be applied to enable digital tutors and personalized coaching tools. Natural language processing (NLP) has led to chatboxes for responding to student questions and, combined with AI, may lead to virtual teaching assistants.

Digitally certified credentials and certificates can be developed to recognize learning achievements and workforce skills, although these have been proliferating at a rate that makes them difficult for employers and workers to understand. MIT is working with a group of universities to apply blockchain technology for such certificates to assure their validity, to make them readily accessible to the student or worker, and to enable much more detailed information than a simple grade sheet about particular skills acquired.

Workforce education is a direct beneficiary of online education developments. Online will be a critical technology in enabling a new scale of workforce education to meet growing needs. However, it will not scale unless it provides quality training, and to do this the lessons being acquired as summarized above from learning science must be incorporated.

Introduction: The New Education Technology

There is a series of significant problem points in current workforce education. They include:

- disinvestment in recent decades by both government and employers in workforce education;
- U.S. Department of Labor training programs that have limited focus on higher technical skills and incumbent workers;
- U.S. Department of Education programs that have large gaps in filling workforce needs and are not linked or complementary to the Department of Labor programs;
- a vocational education system in secondary schools that has largely been dismantled;
- publicly supported community colleges that are underfunded and lack the resources to provide advanced training in emerging fields with too low completion rates;
- colleges and universities that are disconnected from workforce education and the other participants in the system;
- a general disconnect between the still-separate worlds of work and learning; and
- a missing system for lifelong learning.

However, new models for workforce education delivery are evolving that help fill the gaps identified above. These include programs to improve community college completion rates; short 10- to 12-week programs at community colleges to upskill underemployed service-sector workers into better jobs; regional efforts across clusters of employers to share the risk and cost of development of new training programs; and engaging colleges and universities to provide better workforce preparation. But it will take time to adopt these reforms, and meanwhile the need is significant. Advancing technologies are imposing significant upskilling requirements on the workforce so the education need is growing. New educational technologies, the subject of this paper, are high on the list of new delivery models that we must consider.

Is workforce education an American policy priority? One painful lesson from the coronavirus is that the poor and working class have suffered more. Income inequality and its consequences are now more apparent than ever, and there is a massive economic and jobs fallout problem. Entire economic sectors that have been major sources of jobs were hit by the coronavirus pandemic, from retail to restaurants and hospitality, to travel and tourism, to aircraft manufacturing. As of May 2020, there are 36 million unemployed and some of those jobs, particularly in hard-hit sectors, will not come back. These workers will have to find new skills for new jobs. One significant policy to address this will be workforce education. A short-term task will be to help with the job resorting that will be needed. An overall goal will be to bring more of the working class into education and skill levels where they can obtain higher-quality jobs. The pandemic has moved workforce education closer to the top of the pile of needed policies.

Part of new workforce delivery systems will be an expanded role for new education technologies. The workforce education system problem is massive—we need to greatly expand and improve a limited and problematic system. With the ongoing upskilling in the workforce, and now with the coronavirus disruption, there is a major problem of scale. The system needs not only reforms, but also the ability to reach many more, more effectively. This scale problem is: How can a reformed but undersized system operate to reach more incumbent, new entrant, and underemployed workers? One major new element that will need to be deployed to meet the scale required involves new online educational technologies, which have great potential for solving scale. But these technologies will only scale if the learning system behind them significantly improves.

Online education has been evolving for many years—but with the widespread availability of broadband technology through laptops and cell phones, it reached an inflection point in 2012. That year, growing numbers of Massive Open Online Courses (MOOCs) were developed at many colleges, and universities across a number of nations offered MOOCs on the for-profit platforms of Coursera and Udacity, and on the non-profit edX platform jointly created by MIT and Harvard. By June 2012, some 1.5 million people had enrolled in MOOC classes offered on the three platform providers[1], and those numbers have continued to grow, now totaling some 100 million. MOOCs have been seen to offer a number of education benefits including: increasing higher education access, offering an affordable alternative to existing higher education institutions, providing flexible learning schedules so that learners with job or family commitments can participate, and creating a place for online collaborations. Criticism of MOOCs includes: Participants must have basic digital literacy to manage courses; MOOCs work primarily for motivated students so the already-educated predominate; the completion rate for MOOCs is low, with typically fewer than 10% of initial viewers completing courses; MOOCs are utilitarian and undermine holistic education; and content once generated must often be frequently updated, particularly in technical areas.

However, because most of the world now has access to broadband internet either through cell phones or laptops, online education is proving to be a remarkable engine to approach education at a scale impossible with established education institutions. Producing online education material also needs to be understood as occurring in a very different medium from in-person classes. It resembles the difference between making a movie compared to a stage play; very different rules apply. Getting the new rules right for the new online medium is still a work in progress.

Effect of the Coronavirus

As we noted earlier, online education saw a massive increase during the 2020 coronavirus pandemic. The internet, originally built with Defense Advanced Research Projects Agency (DARPA) sponsorship as a resilient emergency communications system, enabled colleges and universities to move their education tasks online. Without it, as well as the accompanying videoconferencing apps, learning management systems, and experience with MOOCs, higher education would have been in the same state of collapse in 2020 as hotels, airlines, and restaurants, with students dismissed and faculties laid off. While not necessarily optimally used, it kept schools open. While many colleges and universities had been reluctant online education adopters, the pandemic-induced switch to online created an online cascade from which there is probably no going back. This means, too, that its utility as a workforce education option can be accelerated.

The pandemic, then, forced a massive education experiment where nearly all of American higher education was forced to shift from classrooms to online. This, in turn, created a massive learning laboratory. Here, online teaching professionals found that faculty who already had created or worked on a MOOC—one that embodied lessons from learning science for online education—could draw on that content and those lessons for the urgent online shift during COVID-19. But institutions and faculty without online experience—a MOOC or other deliberate online initiative—found themselves jury-rigging a new education experience in the face of the pandemic.

Online education has been gradually learning a series of lessons from learning science about how to assemble online materials that are more optimal for learning. It has not been easy because lessons from three separate fields that did not naturally interact—technology, cognitive psychology, and learning research at education schools—had to be brought together and reinterpreted in a new online context. Because of the pandemic, many faculty who suddenly had to go online with their class lectures have found the transition difficult. So, while the coronavirus forced an online shift, those who were prepared, as was the story with so many other facets of the pandemic, were better performers. Others were building online courses without the learning science lessons. While the fact that schools could continue providing education online was almost miraculous, an unthinkable technological advance from a decade ago, there has been a backlash in some quarters against online education as a result of the coronavirus. Undergraduates, in general, missed the social experience of being on campus, and being online was not an adequate substitute. It was a particular problem when students faced mediocre material because too many faculty were unprepared and unaware of the best practices and lessons for online learning. But online education was shown to be a resilient system—now there is no substitute for it. The coronavirus provided an opportunity for many to use online education and underscored the need to optimize it. If online education is mediocre, however, it simply will not grow. There are critical lessons about learning that must be incorporated for it to work well.

Applying Learning Science Lessons to Workforce Education

So far, this discussion of online education has been a story about education not training. MOOCs and their platforms were formed for colleges and universities not for workforce education, and little workforce content is offered there. Yet, there are workforce online offerings through companies like Tooling U-SME and 180 Skills in manufacturing, and in the computing area through tech firms like Cisco. The military has already shifted much of its training to online simulations. Online offers a great opportunity to scale up workforce education to those now out of reach of education institutions. Virtual and augmented reality provide an opportunity to introduce hands-on content, which is so critical to training, into online training. Just as with the education side, effective workforce training will have to apply new lessons for learning in online content for it to be accepted and work well.

What are those lessons? A video of an uninterrupted talking head, for example, promotes mind wandering and provides quite limited learning value for viewers. It must be interspersed with content for assessments, participatory discussions, or feedback loops. Rules for content include: It must be offered in bite-sized chunks, learning can be enhanced by creating certain desirable difficulties, offerings must be spaced to adjust to optimal learning patterns, different kinds of content should be interleaved, and ongoing testing and assessment/feedback loops can be critical to effective learning. Below, we turn to a review of the learning lessons now being understood to apply to online education. The same lessons will equally apply to workforce education. One overall lesson should be kept in mind in the discussion below: Optimal education remains blended education, combining face-to-face and online, where each can do what each does best.

Examining Content, Pedagogy, and Modality

An increasingly agile workforce deserves an equally agile system for learning. This is placing new demands on our existing systems for workforce training and education in general. Education is a complex field. But for the purposes of this discussion, we will view it in terms of three pieces: the content, the pedagogical approach, and the modality by which it is delivered. Each of these has undergone changes due to advances in technology—and this has caused a new interest in educational technology, also called EdTech.

While partitioning them is convenient, content, pedagogy, and modality are not entirely unconnected to each other. Different content forms require different pedagogies, and often different delivery modalities. Consider how machine learning might be taught, for example, and compare it with teaching a nurse to use a new ultrasound machine: One involves algorithms and data, the other hands-on equipment. Yet, a central aspect of the opportunity in mainstream education is the fact that good pedagogical practice—applying what we know about how people learn and how to be effective in education—has often taken a back seat to convenience, scale, tradition, and regulation in the development of our education systems. This is true not just in the United States, but worldwide as well. Much has been written about the evolution of the school and college systems, which we will not repeat here.[2] But the summary is that the need for better learning points toward a significant redesign of existing education systems; and happily, we posit, the optimal system would in fact be more agile, and therefore more in tune with today's labor market, than the systems in place today. So, with this view of the importance of pedagogy, we begin our exploration of EdTech with a discussion of pedagogy.

Better Pedagogical Practices

Insights about how the human brain gathers and stores information, and develops facility with new material, have been accumulating for over 100 years, beginning with the seminal work of Hermann Ebbinghaus.[3] Unfortunately, our education systems were well in place by that time, and the runaway train could not be rerouted. Since then, we have learned a great deal more, and it has been widely studied.[4] For example, it appears that we are more likely to learn when we are curious, because curiosity triggers a dopaminergic circuit.[5] Socrates presciently said, "Wonder is the beginning of wisdom."[6]

So, material that inspires a student to become curious about a topic is well worth the effort. Unfortunately, this is hard to achieve in a standard classroom setting without exceptional educators—the ones many of us remember from our own experiences. But not every teacher can be inspiring—many may have a better grasp of the material without the same level of charisma. And yet today, our one-size-fits-all model limits our efficacy at a time of great need for a revolution in learning. This is where technology can, and is, playing a part. We explain more below.

BITE-SIZED CHUNKS

We can learn in about 10-minute chunks.[7] This appears to be related to the way in which we form short-term memories in the brain. If learning exceeds that time, the mind seems to enter a state of mind wandering.[8] Therefore, lectures need to be extremely short to be effective—a lesson a parent probably recognizes instantly, though the insight applies equally to adults. Courses, then, should use 10 minutes of lecture segment, switch to another learning mode (e.g., an interactive group discussion, a demonstration, or an assessment), then return to a 10-minute lecture segment, and so on.[9]

Impact of educational technology on the lecture: Distance education, be it by correspondence, radio, or cassette, has been around for decades. But it should not be confused with modern online education. *Online, on-demand video* has unquestionably made a massive impact on learning by enabling students to access content on an on-demand basis. Content creators such as Khan Academy, Minute Physics, and MIT

OpenCourseWare have millions of subscribers on platforms such as YouTube. Content creators and learners have naturally gravitated toward shorter videos, perhaps without explicit knowledge of the cognitive benefits. Furthermore, the ability to pause, rewind, and speed up video has made for a very adaptable and vibrant approach to the distribution and consumption of content. Transcripts can be generated automatically or manually to make the videos accessible and to give viewers search options. We tend not to think of YouTube as educational technology, but we argue that it is probably the most important EdTech product out there.

In the 2010 decade, as noted above, a new technology format became prevalent: MOOCs. Combining the short video format with computer grading, which we will discuss later, and forums where students can help each other as well as get help from teaching assistants, MOOCs have become a major force in education. Of the three largest MOOC providers, edX and Coursera offer certificates, micro-credentials, and full master's degrees at the time of this writing. Udacity offers certificates and "nanodegrees."

Finally, it is worth mentioning that automatic lecture capture of the traditional lecture is still an interesting technology. By tracking the lecturer, these cameras can generate 4K video with very little operator effort. A lapel mike can be used for sound. These systems make traditional lectures available for asynchronous viewing, where the viewer can pause or rewind the lecture, and for edited distribution internally and externally.

Videos of traditional lectures don't reflect the learning science lessons we need to apply; it's like filming a stage play not a movie. But these videos can be readily developed at low cost, then edited into segments and combined with other elements to fit learning science rules. This can increase their educational value, and their availability outside the classroom itself is useful. We will elaborate on the value of asynchronous video later.

These online, on-demand technologies hold great promise for education and for workforce education in particular. Unlike a classroom, they can both operate at great scale and offer new education opportunities. Because it will often involve operating equipment and physical activity, workforce education is inherently more "learning by doing." So online, with its capability for repetitive and visual engagement, can fit better than a classroom. The benefits of online programs are many, but one of the most important is the ability of working people to educate themselves without interrupting their work and careers. This is particularly helpful to individuals who have families, or have other reasons that make traditional place-based education difficult. Online is already reaching the workforce side, for example, through new commercial firms such as THORS, Tooling U-SME, 180 Skills, and others, although universities and community colleges have been slow in applying online to meet emerging workforce needs.

DESIRABLE DIFFICULTIES

Students often reread material, thinking it helps learning. Unfortunately, it is not effortful, and causes the illusion of learning. In fact, a surprisingly consistent result from learning research is learners' overconfidence about their own learning, and the importance of a realistic sense of one's personal competence.[10] A series of findings shows that *effortful* approaches (i.e., in which the learner struggles with the material a little) unintuitively lead to better, more durable learning. Elizabeth Bjork and Robert Bjork call these techniques "desirable difficulties"—difficulties that lead to better learning by increasing the processing of material rather than being distracting.[11]

First, when a learner is *tested frequently* about the material that she has just learned, learning is better.[12] This is called the "testing effect," and the use of it as a learning technique is referred to as "retrieval practice." Together, they are much documented in the literature. An interesting aspect of retrieval practice is the positive effect of effortful retrieval. So, for example, a learner who is given weaker cues for the test, and therefore struggles more, will learn better than one who is given stronger cues.

Second, testing should be *spaced*.[13] Also called, "spaced practice," this concept is related to the findings of Ebbinghaus himself. Spaced practice flies in the face of a prevalent and expedient approach in education today, mass practice, in which a student might address a number of problems at the end of a chapter in a short span of time (rather than spacing them out over days, weeks, and months). Spaced practice applies not just to academic learning but also to sports and motor learning. Ironically, learners themselves feel they have learned better with blocked practice (repeating a single skill over and over) although they may have learned less effectively—recalling the theme of illusory learning.[14] Spaced practice has even been replicated beyond humans in animals such as insects, and now has been explained to some extent down to the levels of the proteins needed for long-term memory.[15] In fact, a key aspect of spaced learning is that relearning material is most effective just before the learner forgets the material. This requires sensing when a learner is getting rusty about the material—a level of attention that a teacher in a classroom cannot achieve at any scale.

Third, content is best *interleaved*.[16] A common, and understandable, practice in education is to practice topics in blocks: multiplication, say, followed by division. The evidence from extensive research points to the benefits of interleaving practice: multiplication problems alternated with division. This is, again, inconvenient in a large classroom in which students are on a march along a complex curriculum. However, the benefits have been replicated in a range of subject areas including mathematics and art. The neuroscientific mechanisms of this desirable difficulty, which results in so-called cognitive interference while learning, has also begun to be understood.[17]

Fourth, the act of *assessing* a student's performance in any interaction with a view to giving *feedback* and the when and how to give feedback are obviously essential in learning. Many have studied the impacts of the amount of feedback, the time delay of the feedback, and the detail of feedback. Depending on context, for example, delayed feedback is a desirable difficulty. But feedback takes time, and pithy feedback may be generally (but not always) more efficient in terms of the allocation of total time in a learning task.[18]

All of these lessons—spacing, testing, interleaved content, and assessment/feedback loops—have direct application to workforce education. All can be fitted into a backdrop of "desirable difficulty" to keep students engaged and challenged. Unlike established classroom approaches, each can be directly incorporated into the way online education instruction is organized. Online's potential for interactive learning can make it much more sensitive than a classroom setting to the best timing for introducing spacing and feedback features, for example, to attain the right level of desirable difficulty.

Educational technology and cognitive science: Traditional lectures with large classrooms are hard-pressed to leverage cognitive science. Technologies such as clickers can engage students, make learning more active, and mimic the testing effect, but the full use of the cognitive science described here requires personalization. For example, since spaced practice would ideally detect when the learner is becoming rusty in the material, a few "probing" assessments are necessary to fine-tune the spacing for each student.

The software application SuperMemo is truly a pioneer in the use of spaced repetition.[19] Language learning apps such as Duolingo also appear to use cognitive science principles.[20] Flashcard software such as Quizlet leverages the testing effect, and can be used to apply spaced repetition and interleaving. MOOC platforms already leverage the testing effect, and have a significant opportunity to incorporate spacing and interleaving. Research is ongoing.[21]

MOOCs' most significant impact was that they changed the state of the art in assessments—a world that was for a long time entrenched in multiple-choice questions. For example, today the edX platform offers dozens of assessment types, including assessing the correctness of software code, circuits, mathematical expressions, and diagrams. What of essays or poetry? There is already software in word processing systems for assessing spelling, grammar, and sentence structure and for detecting plagiarism. MOOC providers like edX go a step further with peer grading, in which students grade each other's assignments. In fact, there is now a rich subfield of research studying the benefits of peer assessment.[22] Thanks to peer grading, MOOC providers have a surprisingly rich slate of courses in the humanities, arts, and social sciences. But a "milestone" challenge still far ahead is AI-based grading and, more importantly, feedback for subjective responses such as essays. This has proved controversial for reasons both philosophical and pragmatic, bringing into focus existential questions about the purpose of universities and the nature of human expertise.[23] It is qualitatively entirely different from assessing whether a student has the right answer to a close-ended question.

Lessons from cognitive science can migrate from traditional education to workforce education. The needs for feedback and testing are profound in skill training, and online technologies can be of significant help in optimizing their delivery. Because subjective responses and essays are less relevant to much of workforce training, current developments in AI-based assessment can already enhance workforce applications.

APPLYING COGNITIVELY FRIENDLY FEATURES IN A MOOC:

A well-assembled online MOOC class consists of a series of 8- to 10-minute segments. Such shorter segments reduce the probability of unproductive student mind wandering. At the end of each segment, short auto-graded questions invoke the testing effect. Moreover, the student can review material before moving on to the next segment, thereby striving for mastery. Teaching assistants and peers provide assistance through the "forum" feature, recreating some aspects of tutoring and deliberate practice at scale. When a student feels she has mastered a segment, she can move on to the next segment.

The questions posed to a student at any point need not be limited to the segment just completed. It is advisable to insert questions on a previously covered topic from a week or even a month ago. This elicits spaced retrieval and encourages retention. The questions need not be similar. For example, when two topics are covered in a segment, it is possible to alternate questions: topic #1, topic #2, topic #1. This elicits interleaved practice—another practice that is "cognitively friendly." Questions can also become sequentially more difficult as the student progress in her mastery of the material. This invokes fading scaffolds.

More recently, MOOC platforms have also integrated live elements through software plug-ins such as Zoom, enabling the recreation of social experience in small doses. Live sessions and breakout groups also create opportunities for discussion and improve engagement.

Problems in MOOCs are not limited to multiple-choice questions. A student might write a circuit and simulate it. Virtual labs are now quite common. A visual problem may involve the rotation of a 3D model of a molecule or dragging and dropping a biological artifact to the right location on a drawing. These are affordances unique to virtual platforms not available in lectures or face-to-face classrooms. If an essay is called for, it can be graded by peers, rather than by the instructor. The act of grading a peer's work is in itself an educational experience

SCAFFOLDING AND TUTORING

The Soviet psychologist, Lev Vygotsky, proposed the concept of a "zone of proximal development" as an optimal difference between a learner and a "more knowledgeable other" who can lead the learner to greater achievement.[24] Too large a difference, he argued, and the learner cannot keep up. Too small, and the learner doesn't learn. More generally, scaffolding is a way to provide the learner support as she gains mastery over the material. The teacher adds supporting material for the student in order to enhance learning and aid in the mastery of tasks by systematically building on the student's experiences and knowledge. In Vygotsky scaffolding, the art lies in calibrating the challenge of the learning to the student's abilities. Anyone who has played tennis with a slightly better player can probably relate to this balance.

The benefits of tutoring in teaching have been known for a few decades. In 1985, Benjamin Bloom published a seminal paper in which he showed that tutoring could achieve a 2 sigma improvement over traditional teaching.[25] But, he argued, since tutoring is expensive, how can we improve scalable education to achieve similar results? And equally, we can ask, what is effective tutoring and coaching? While good tutors and coaches are able to calibrate themselves, not all experts can coach well because they may suffer from what is called an expert blind spot. Also called the "curse of knowledge," this occurs when a person has a deep understanding of a subject and forgets how difficult it was to learn the content initially; he fails to slow down to make sure his students understand each element behind the expertise.[26]

There is a rich body of work on the science of coaching, expertise, and performance. Psychologists have studied what engenders world-class performance in a range of activities from Olympic-level athletics to world-class musicians.[27] They conclude that an expert skill—such as perfect pitch[28]—is not "an immutable" or "God-given" skill. Rather, it can be built by (a) studying and deconstructing the actions of top performers into constituent actions, behaviors, and reflexes; (b) practicing these more atomic actions deliberately; and (c) receiving and acting on precise feedback from an expert coach. The deconstruction of expert behavior into component actions can be informal, as it often is in fields such as painting. One formal framework is *cognitive task analysis*.[29] The approach of deliberately building expertise in this way is referred to as *deliberate practice*. While deliberate practice has been applied to sports and art, it was also famously demonstrated in physics education by the Nobel Laureate Carl E. Wieman.[30]

A carefully scaffolded curriculum design is critical so that students can build the thinking and doing practices of experts. In the last two decades, *Cognitive Load Theory* has helped flesh out a theory of scaffolding beyond the cognitive task analysis described earlier. Novices, researchers say, have fewer predefined schema to digest new information, and so suffer from high cognitive load. The working memory—think of computer RAM—available to learners is limited, and novices have fewer frameworks to "pattern-match" the new information into.[31] Novices therefore benefit from worked examples and "fill in the blank" problems. The extra structure provided in this stage helps novices build their own internal schema. But as the novice becomes an expert, and develops the schema to absorb information, she can be effectively exposed to more open-ended problems.[32] This is consistent with the approach of "faded scaffolding": As novices become experts, unaided exploration becomes valuable.[33] Either way, the key, it appears, is to expend cognitive load on germane as opposed to distracting tasks. In this respect, Cognitive Load Theory and the approach of "desirable difficulties" seem to agree—it is important to avoid undesirable difficulties.

Finally, there is a relatively profound philosophical question embedded in the term "mastery learning." Traditional education across the world is based on synchronous lectures and modest amounts of coaching, and is in fact an unforgiving form of delivery. A student who struggles with a concept or misses a class is easily derailed, and catching up is difficult. The question is: Should the goal of education be to ensure that the student has the opportunity to master the material in a module before moving on, or should it be to see how much of the material the student is able to grasp as, to use a metaphor, the unstoppable freight train of lectures roars past? This latter approach is prevalent today, and summative grading is used to measure the student's uptake of the material. The former approach is called mastery learning[34]—the goal of ensuring that each student advances to the next stage only after mastering the content. Unfortunately, mastery learning often takes a back seat in modern educational systems because the logistics of the more personalized approach are usually deemed impractical. So much so, in fact, that some at MIT have described an MIT education as "drinking from a firehose." But we would argue that the goal of educational systems from all perspectives—the philosophical, the moral, and the equitable—should be to "take every student forward." Equity issues are deeply embedded in this question: For example, students with varied preparations, or those who struggle with language, are more likely to be left behind in the traditional approach. Asynchronous content availability, coaching, and formative assessments are key to the mastery approach to learning.[35]

Education technology and tutoring: MOOC platforms such as edX naturally capture some of the principles described above. First, since immediate feedback is available for a rich range of problem types, students can adjust their mental models at a more granular level. This is not quite the rich feedback that students seek; rather, it is more granular feedback that the technology enables in a formative way. Second, forums "crowd source" coaching. The sheer numbers of students in MOOCs means that students can see both right and wrong answers from other students before a teaching assistant weighs in. Anecdotally, this seems to facilitate the formation of a more nuanced mental model while also avoiding the expert blind spot.

Next, we consider rich, formative feedback at scale. We distinguish such feedback from simpler "yes/no" summative assessments related to grading. An unfulfilled and futuristic aspiration is for AI to provide rich feedback to student responses. In its ultimate incarnation, it might include scanning a student's work on a mathematics problem, say, and providing annotations that show where she made a conceptual error. This aspiration has received the greatest impetus in the research on intelligent tutoring systems (ITSs): computational systems that teach students a subject by modeling the student's cognition of the domain being taught with a scheme for instruction and feedback. In many ways, ITSs have been the holy grail of automated education going all the way back to Alan Turing and B.F. Skinner.[36] Modern ITSs, which model the most recent understanding of the working of the human brain, were pioneered by John Anderson of Carnegie Mellon University, and resulted in the so-called cognitive tutor.[37] ITSs in the ultimate form are also the pinnacle of personalized learning.

But short of that vision, there are approaches that can provide valuable step-by-step feedback in highly granular tasks. For example, Codecademy, a company that offers online computer program courses, provides a highly scaffolded set of coding micro-tasks with granular assessments at each step as the student builds up a larger computer program. Grammarly uses natural language processing and AI to provide feedback in writing. Since these tools are very incremental and rapid, it is easier for a student to infer directionality beyond the simpler "yes/no" feedback. For the foreseeable future though, these tools are best treated as "force multipliers" for real coaches rather than as replacements.

Games are another important area of EdTech related to motivation and scaffolding. So-called "serious games," a term used to contrast with "gamification," refers to games developed for purposes other than entertainment. In brief, while neuroscience is revealing the relationship between gaming and the reward system of the brain, serious games are designed to provide more context and to evoke curiosity in the learner for the material being learned. In doing so, they combine curricular and experiential elements to build a more deliberate learning pathway than video games. An example is World Without Oil, an alternate reality game that leads payers through a post-oil world, forcing them to think about the implications of an oil shock.[38] While the game was much acclaimed, designing a game to ensure well-balanced learning and participation is difficult.[39] Games have been used for education about topics as varied as the environment[40], gender discrimination[41], and STEM topics.[42] "Edutainment" is a different philosophy from serious games, in which gaming is "entrained" into entertainment. However, the value of edutainment has been questioned.[43] A third approach is to neither entertain nor be serious, per se, but to focus on creativity and playfulness.[44] The Scratch system, for example, is an extraordinarily successful example of this approach—students focus on creativity with a graphical programming language, "playing to learn" rather than "learning to play."[45] In the process, they learn computer programming using visual metaphors. Finally, the word "gamification" has been used somewhat loosely, but should really be interpreted as a fourth category. The idea of gamification is to tap into social, potentially competitive networks while also tapping into intrinsic motivation factors similar to those in video games. In some sense, any educational environment can be gamified, but the effectiveness needs to be carefully assessed.[46]

Simulations are a very powerful technique similar to games, but different in that they model realistic situations and teach real skills. The simulation provides real-time feedback and uses this to scaffold the progress of the learning with increasing difficulty as the training progresses. Flight simulators, for example, have long played a major part in training pilots, enabling rapid scale-up.[47] During World War II, the U.S. military used some 10,000 automated Link Trainers to train half a million pilots.[48] Japan, which lacked comparable simulators, was desperately short of trained pilots by the end of the war. Currently, the military is using virtual and augmented reality tools (VR and AR) for the latest generation of simulators applied to a wide range of training needs, from operating aircraft turbines to submarines. Simulators have also been used to teach everything from business strategy[49] to environmental dynamics.[50]

VR/AR AT THE NAVAL AIR WARFARE CENTER TRAINING SYSTEMS DIVISION, ORLANDO

A team of sailors, each wearing a virtual reality (VR) headset, stood in front of a portrayal of a mobile cart—a "huffer"—used to start jet aircraft engines on carrier decks. The cart's control panel doors were open, and a member of the team was flipping by hand the master switch and then the start switch on the touch screen to warm it up.

The huffer is a small auxiliary turbine engine that generates high-pressure exhaust using the same fuel as the real engine. A hose led to the F/A-18 Hornet aircraft's engine, and exhaust air began pushing through its big turbine. Jet engines need substantial airflow before they're started; if turbine blades aren't pushing enough air through the engine to get the RPMs up to the right level, the "hot start" causes overheating and damage. With a $70 million aircraft at stake, the huffer team has to get it right every time.

We watched them flip the next set of switches, first in the correct order and then react to incorrect sequences to test their ability to make rapid corrections. Then we saw it fault out and watched the operators use the system to go through protocols—in the form of instructional videos and equipment system designs that can be cued to pop up for each piece of the equipment—to do an online repair and make it operational again.

This is how the U.S. Navy now teaches sailors to start jet aircraft engines without the jet, and without the safety risks and costs of actually doing so. This technology is now being spread through the Navy's training centers, and also placed on its ships, carriers, and bases. There are also laptop screen versions of the training programs. The military services are increasingly shifting training to online, and using VR and AR (augmented reality) technology. Soldiers and sailors increasingly don't have to leave their ships and bases to travel to a training center—they can master the equipment they need to master on-site.

An emerging trend in online platforms, such as MOOC platforms, is the use of collaborative tools to enable coaching. For example, edX is supporting case-based collaborative tools for online learners. Coursera acquired Rhyme Softworks, which enables, among other things, a coach to work with a novice as she uses a software tool. Finally, group annotation tools, such as that supported by edX, or the standalone software Nota Bene, help students and teachers annotate the same, or versions of the same, document and provide coaching.[51]

Intelligent tutors, games, simulations, and collaborative tools are all highly relevant technologies for workforce education. Each offers new learning capabilities through applying advances in tutoring and scaffolding approaches to learning, delivered from the new technologies that can enhance them. The experiments that are ongoing in education with these technologies need to be incorporated into workforce education.

MENS ET MANUS

The MIT approach to learning is its motto *mens et manus*, Latin for "mind and hand," reflecting its early emphasis for lab-based learning, and indicates a continuing strong preference for *learning by doing*. While Descartes argued that the mind and the body were independent, recent scientific findings seem to bear out the wisdom of MIT's historical credo. It is a credo that is captured by the more current phrase "hands-on" learning, which is tied to a related series of educational approaches. Tactile experience, in which a student physically feels angular momentum, or gestures to capture a phenomenon, has been shown to improve learning.[52] Similarly, Generative Learning Theory posits that learning is better when the agency of the learner is engaged in the generation of new information based on prior concepts.[53] More generally, *active learning* is any instructional approach that engages the student in the learning process—as opposed to passive listening.[54] *Blended learning* is an approach that mixes online, focuses on the information content, and frees up increasing face-to-face time between students and teachers so that the class can be more active and more opportunities for coaching arise.[55] The "flipped classroom" is a term coined by Sal Khan of Khan Academy to describe the use of online courses to leave time in the classroom to do more hands-on, blended activities. Project-based learning, problem-based learning, and task-oriented learning are all techniques to give students more agency and purpose. Integration is another important aspect of learning, which projects and tasks can help enable. Learning through discipline-aligned courses can lead to siloed knowledge. Integration refers to connecting topics across silos and is a central aspect of David Merrill's teaching philosophy.[56] Teamwork is another important element of learning that can also be helped by projects and group activities.[57]

Educational technology that enables hands-on activities: There is a small fleet of prototyping technologies—such as 3D printing, Lego Mindstorms, the Arduino, the Raspberry Pi, the MIT App Inventor, and even the programming language Python—which comprise a form of EdTech that enables hands-on learning. The power at the fingertips of students to actualize their ideas, to learn from the real creation, to seek feedback, and to enjoy the pleasure of achievement is unprecedented—and will increase with time. Competitions such as FIRST Robotics have leveraged such technologies to further increase the reach and power of scaffolded mentoring and coaching. This could be characterized as learning by creating.

What if the topic cannot be prototyped on a benchtop? We have already noted simulation. *Virtual reality* is another step in the direction of creating realistic situations that would be difficult to get physical access to. For example, VR can be used to perform a hands-on, team-oriented task in an undersea environment. *Augmented reality* can be used for on-the-job training. For example, an engineer who is performing a maintenance task may have an expert view the task in real time over an AR headset and provide subtle feedback.

Hands-on learning is clearly critical to workforce education since so much of it requires training for actual hands-on tasks. The suite of related kinds of learning, from tactile to active to blended, are all highly relevant to workforce education. The prototyping technologies for learning by creating are further enablers when applied to a range of skill areas, such as manufacturing. Particularly important for workforce education are blended learning and VR and AR technologies. Blended learning can shift more of the rote learning to online and free up expert instructors for coaching as well as personal and small group problem-solving and instructing. Since displaced and older workers may be less ready for online courses, blended appears critical in reaching these groups.[58] VR and AR enable true learning by doing in immersive environments, which will be ideal for many aspects of workforce education. The military's work on training through these technologies is particularly worthy of note.

NEW DELIVERY MODALITIES

Clearly, as we have discussed above, the internet and computers enable a whole new paradigm for education in ways that will enable us to implement lessons from learning science in dramatic new ways. However, there is an important aspect that we have not discussed: access.

In 2001, MIT made its curriculum free to the world with the launch of OpenCourseWare.[59] To date, more than 300 million downloads have occurred. This spurred a major online revolution that resulted in the launch of MOOCs. Today, the top three MOOC providers, edX, Coursera, and Udacity, collectively boast nearly 100 million enrollments. Joshua Goodman and colleagues' study of the Georgia Tech's computer science master's program presents a useful summary.[60] They describe the advantages of access and scale of the Georgia Tech program, and the opportunities that online programs create.[61] The benefits of online programs are many, but one of the most important, as previously noted, is that working people with family commitments or ongoing jobs can educate themselves without disrupting work or other obligations. Traditional place-based education can be impossible for them. Georgia Tech's computer science master's program reaches this group. New micro-credentials, such as the MicroMasters, enable job-friendly academic accomplishments without the need to attend college. These kinds of online offerings multiply education access.

The edX software is also open-sourced under the Open edX name, enabling any member institution to download and run their own MOOCs. Universities, companies, and entire nations have taken advantage of this facility to create local education ecosystems. Anyone can be a MOOC creator and take advantage of the latest technologies and broadband access that edX has created for its platform. In addition, learning management system (LMS) vendors, such as Desire2Learn and Canvas, have adopted many MOOC-like features which, though not necessarily scalable like the MOOC platforms to hundreds of thousands of users, nevertheless can support university-sized user bases.

Online education does seem to work when done right.[62] However, Eric Bettinger and researchers at Stanford's Center for Education Policy Analysis analyzed a for-profit university and found poorer results from online courses.[63] They also found that online seems to work less well than a classroom for the least prepared students.[64] Many lessons on online delivery clearly are still to be learned; this indicates that there is nuance in using this powerful new medium.

A deep problem for workforce education, then, is access. With a U.S. workforce of over 150 million requiring systematic upskilling and lifelong learning, and a problematic existing delivery system, it is hard to envision how to reach this group without extensive use of the scaling possibilities of online education. New delivery modalities have evolved to expand the reach of online education, from MOOCs to online certificate programs. Clearly online, and the suite of technologies and learning approaches that can enhance it, will be important to workforce education. However, much work needs to be done to adjust online training for the kinds of learning challenges different workforce groups face, including incumbent, displaced, and new entrant workers. One size clearly won't fit all; online training will have to adjust to worker needs.

CONTENT

That leads us to the point that there are three types of content for the working learner of the future: formal, informal, and professional. The technology for each will be different.

In discussing *formal* education, typically academic but also very relevant to workforce, we have already described the pedagogy, the modalities, and the technologies impacting it. In addition, we have stated that there is a cognitive benefit to having learners receive some in-person education. This leads to the opportunity for technologies that support the deeper insights that in-person modalities enable, such as virtual lab equipment. In addition, collaboration software can serve as a middle ground that achieves some aspects of in-person education without physical co-presence. Platforms such as Harvard Business School's HBX online and IE Business School's WOW are examples that enable an in-person experience online.

Informal learning has flourished over the last two decades.[65] Informal education occurs outside formal institutions and either helps students to do better in school or to prepare for standardized tests and certifications such as bar exams. Examples include extracurricular activities such as FIRST Robotics[66] and watching Khan Academy[67] or Minute Physics[68] videos. A significant amount of educational technology innovation has occurred in this sphere, and there is a rich ecosystem of downloadable and web-based testing tools. Recently, companies such as Squirrel Ai claim to have personalized software using AI tools, creating student models as students learn. These companies tend to focus on highly defined topics such as mathematics and seem to be a new generation of intelligent tutors targeting competitive exams. Can such technologies be used to teach a student how to write G-codes for a CNC machine tool?

Professional education refers to yet another market in which EdTech tools have flourished. Professional education either occurs inside companies or in fields that require continuing education, which can be rewarded with continuing education units (CEUs). Specialized corporate learning management systems, such as Skillsoft, Cornerstone, and Pluralsight, enable corporate learning libraries, which allow integration with HR systems. There is even an emerging category of recognizing and rewarding informal education in the professional category. Companies such as Degreed and EdCast let firms provide this informal content—including content libraries and even magazine articles—and keep track of learner progress.

These technology developments in all three types of education are potentially relevant to workforce training. Clearly, professional education enhanced by the new technologies cited here allows firms to provide their own training systems in new ways. But new technologies entering both informal and academic education clearly can carry over to workforce education delivery.

EDTECH AND WORKFORCE EDUCATION – ADDITIONAL TECHNOLOGY STRANDS

Rather than present EdTech as a catalog of separate technology capabilities, we have presented it here in the context of pedagogy, modality, and content. However, this framework leaves out a few capabilities that are best presented holistically. Each has significant promise for workforce education.

Artificial intelligence in education: The idea of using AI in education, and eventually the personalization of education, is very attractive in an era of rapid workforce training. The idea is that smart systems might be able to adapt to and personally guide students, at scale, through a learning journey that ensures better outcomes. However, it is useful to separate what it means to personalize.

First, asynchronous video-based learning lets students slow down, replay, or speed up delivery, and in this sense enables what we refer to as "self-personalization." One can think of this as the human brain acting as an AI system that adapts the learning. AI systems that can model human cognition could eventually augment this process.

Second, the logistics of education can be made smoother using AI and natural language processing (NLP). This includes chatbots to address student questions and requests, and to answer frequently asked questions. The much-reported Jill Watson experiment, a virtual teaching assistant used at Georgia Tech, is a good example.[69] By using NLP and interacting with students over chat, Jill Watson was able to assist students on logistical matters such as class times, weekly announcements, and frequently asked questions (FAQs). While Jill Watson was sometimes misunderstood to be an AI tutor, its value as more of a clerical assistant should not be overlooked. Extensions of NLP to answer more generalized questions from one or many sources have been implemented in research prototypes,[70] and are now making an appearance in commercial voice assistant systems such as Amazon Alexa. It is, we speculate, only a matter of time before systems like Alexa add educational functionality.

Third, the ultimate AI-based personalized system might well be the intelligent tutor we have described before. AI systems like Squirrel Ai, however, offer "adaptive guidance" to students using Bayesian and other learning algorithms, but in the end, involve a human teacher who can provide personal attention. This could help manage the load on the instructor. Perhaps one day AI systems will be able to truly coach the student by understanding their deeply embedded misconceptions and teach new concepts and skills the way a human teacher does. But that may be some years away.

Sensors: There is much research about the human body's response to learning. This ranges from EEG responses[71] to eye tracking[72]. In the future, galvanic skin reflex, expression tracking, and heart-rate variability may also become key measures. While these tools may be useful in certain settings—for example, for monitoring the state of a trainee pilot who is executing a difficult procedure from a safety perspective—there are serious, unanswered ethical questions about their use in education.[73] Overall, there are some correlations between learning and sensor data, but there is limited evidence to date that this is truly informative.

Digital certificates and badging: There has been much work and interest in digital badging to recognize learning achievements.[74] Badges are intended to recognize learner achievements more fluidly, and at a more granular level, than traditional diplomas and certificates. And indeed, innovations in credential systems will be needed for workforce education and lifelong learning. But issues about what particular badges or certificates mean, and proof of their validity, remain. Recently, 12 universities worldwide, including MIT, launched an effort to make digital badging more scalable and prevalent for use in, among other things, online courses. The effort is called the Digital Credentials Consortium (DCC).[75] Digital credentialing, using strong cryptography and blockchain technology, can create fraud-resistant, readily verifiable certificates fully accessible to the credential holder instead of just to the educational institution. These digital certificates can also be much more detailed about the skill content behind the credential.

The deeper implication of digital certificates is that they "liberate" the transcript from education institutions. Today, when students enroll at community colleges or universities to receive diplomas and certificates for programs, they can be left stranded if they don't finish the program. In most of the world, the transcript is generally owned by the institution, and the transfer of credit is difficult and cumbersome, if not impossible.

Institutions such as Southern New Hampshire University (SNHU) offer streamlined ways to consolidate course credits into degrees. SNHU, in particular, recognizes the constituent components—or competencies[76]—within the previously taken courses and enables students to fill the gap with a prescribed set of online courses to complete a diploma. The competency approach divides an education area into manageable components that complement one another and, when combined, enable mastery of a group of topics that allow understanding a field. It entails developing measurable learning targets in specific areas of competency made clear to students at the outset, with students receiving instruction until they fully grasp these concepts and skills, building competency on component after component.[77] This is the approach SNHU is striving for, integrating a competency approach into its course components. By then making these competency-based courses available online along with a comprehensive coaching infrastructure, SNHU has established itself as a leader in education innovation. The approach can recognize the competencies as well as the degree, but the diploma and the transcript are still forcing functions in this scenario.

Digital certificates, on the other hand, put the transcript entirely in the hands of the learner. By being able to refer verifiably to educational achievements from across institutions, learners can construct their own personal stories on résumés, jobs sites, or professional networking sites, such as LinkedIn. This approach increases the diversity of activities that a learner can leverage. The learner might have taken a few courses from a community college, gone through a programming bootcamp, taken a few edX courses, and finished an apprenticeship at a company, all of which can be proudly and verifiably displayed as her personal learning journey.

This approach is also appealing for its immutability when an education institution goes out of business (as will likely occur during the COVID-19 pandemic) or when the individual is a refugee from a region like Syria or Venezuela. The DCC is also working with the World Wide Web Consortium (W3C) on a W3C standard for managing digital identities. Called the Decentralized identifiers (DIDs),[78] these new IDs offer a potential solution to the challenges of identity management and documentation faced by displaced individuals.

Online and Workforce Education

Online education, coupled with a swarm of complementary new technologies and learning approaches, offers a new tool for workforce education. Given the scale of the workforce education task—a workforce that requires ongoing upskilling and lifelong learning—online education's ability to rapidly scale will play an important role. It provides a dramatic new tool to open up access to workforce education. While online education so far is better if it is combined with face-to-face education for "blended learning," it should become a critical element for workforce education delivery.

The complementary technologies will increasingly enhance online education. These include MOOCs, intelligent tutoring systems, computer games, simulations, collaborative IT tools, VR and AR, AI, digital credentialing, and, potentially, sensors. This bundle of new education tools can also further learning. We are starting to absorb lessons in improving the learning process through new pedagogy tools: "bite-sized chunks" (short, focused segments), "desirable difficulties" (through testing, spacing, interleaved content, and assessment/feedback loops), and "hands-on" learning (through tactile, active, and blended approaches). These learning lessons can be boosted in an online context by the new technologies available to help deliver them. New systems and modalities for delivery are also evolving, from MOOCs to the platform systems that support them, to new companies, to digital certificate systems.

Workforce education, with its requirements for learning by doing and hands-on, is a direct beneficiary of this mix of new technologies with our learning about learning. It can also benefit from the new delivery modalities and systems that online has led to. There is much promise here, along with challenges.

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