



CHAPTER 3

Applying Learning Science to Technology

Learning science can and should inform instruction, whether or not technology is involved. But new technologies create powerful new opportunities to leverage learning science.

What do we have in mind? Let's start with one of the simpler educational technologies: your genial chalkboard (which has mostly given way to your genial marker-friendly whiteboard or high-tech smartboard). We're so familiar with the primitive chalkboard that we rarely think of it as technology—it's just "what teachers used back when."

But it's a mistake to be so dismissive. The humble chalkboard enabled teachers to do things they couldn't do without it. It allowed them to keep notes; to have students come up and do work that the whole class could inspect; to share large, ad hoc diagrams and drawings; and to track student ideas or the flow of a class discussion. It provided a visual complement to the teacher's audio voice-over—in response to student questions and concerns—and offered a reviewable track of material covered in the lesson.



And that's before we encounter the once-remarkable innovation of *sliding* blackboards that drop down one behind another, as in an old-school college lecture hall. These can be used to reveal surprising information, show completed solutions, pose pre-

planned problems . . . hold us back! OK, you might not share our enthusiasm (and maybe we really should get out more). But you get the idea.

Now, consider the smartboard. What do smartboards let educators do that's better or different from what they could do with chalkboards? Well, smartboards allow teachers to pre-store whole series of diagrams or writings, and allow students to interact at the board with their teacher and classmates. They allow teachers to summon new information quickly from the Internet and show it to the class. These are all good and useful things.

But before deciding that the smartboard has upended the classroom, let's consider each of its uses in turn. The pre-storing of slides/diagrams is something that can be done with chalkboards, too: sliding boards do the same thing, just not as easily or well. Smartboards make slides easier to display and manipulate, but teachers have been showing pictures to students for centuries. Smartboards make it easier to put up examples of student work and to do it in real time—but teachers have long showed student essays on overheads or had students solve problems on a blackboard. Smartboards make it easier to summon new information from the Internet, but let's not forget that teachers have long been able to consult an encyclopedia (virtual or not) the night before if they sought a new factual nugget to share.

Don't get us wrong. Smartboards are great. They let educators do things better. It's just that most of what they allow isn't actually new. As Patrick Larkin, assistant superintendent in Burlington, Massachusetts, and a winner of the 2012 Digital Principal Award from the National Association of Secondary School Principals, explains, "We've always done a lot of the things that we're now doing with technology."

Chalkboards or smartboards can be used to execute both good and bad learning solutions. Too many fancy illustrations can overwhelm students, leaving them confused. A teacher might provide too many answers or cues too quickly, preventing students from actually working through problems on their own.

THE FIVE CAPABILITIES OF TECHNOLOGY

Even simple technologies don't automatically help learning. What matters is how the technology is used. Put simply, technology can make a (good or bad) new or old learning solution more *affordable*, *reliable*, *available*, *customizable*, and *data-rich*. Let's take these in turn.

Technology can make the delivery of solutions more *affordable* than before. Indeed, technology has brought tremendous disruption in other industries by completely changing cost structures. Look at the music industry, where record companies struggled to deal with cheap music via iTunes, MP3 downloads, and the rest. Or the challenges faced by a newspaper industry

buffeted by ubiquitous Internet access and the fact that just about anyone can cheaply and easily launch a website.

Technology makes delivery more *reliable*. The best entertainment (music, dance, sports, and more) is now readily available via technology. With recorded performances, there are no schedule hassles, travel problems, or performer illness issues. A digitally mastered version of a concerto or popular song is now available with a mouse-click. Appliances, cars, medical care—all have become much more consistent as a result of technology components that have been designed to invariably do certain things a certain way, repeatedly.

Technology makes more things more *available*. The same machine-engineered parts for a broken-down car can easily be ordered and shipped anywhere in the country. Online customer service is available 24 hours a day. By clicking a button, you can order new electronics on a holiday or check out old episodes of *I Dream of Jeannie* at midnight. Without technology, think of all we'd miss: Up-close viewing of the beluga whale would be the province of a few hardy adventurers or the enormously rich. Few of us would see the World Series or the parachuting Queen of England at the Olympics. We might read about these (although newsprint, too, is a technology) or hear about them from someone who was there, but we'd miss the closer, more visceral experience offered by modern communications, recording, and photography.

Technology makes delivery more *customizable*. Amazon, Pandora, and Google use technology to customize the information and recommendations we receive. Sure, back in the day, the local shopkeeper whom you saw every week would set aside just the right pork chop for you, or keep back your favorite magazine before the new issue sold out. Before Internet-based travel, one of us flew so frequently between Los Angeles and Washington, DC on one airline that the ticket counter folks would print out his boarding pass as soon as they saw him in line. This kind of human-customized touch is now rare for most of us—it's too expensive, and we're too mobile. However, technology can step in and offer a pretty decent substitute that's available, reliable, and customizable based on prior behaviors and choices.

Finally, technology can make experiences more *data-rich*. Think of Amazon customizing suggestions based on your past

purchases. Amazon and similar companies keep learning how to improve what they do because of the rich data at their disposal. Developers accelerate their knowledge of how we use technology by looking at the streams of information that our actions generate. This allows them to learn about what works, what isn't used, and what we're actually doing with our expensive gadgets.

When a great solution is combined with the advantages of technology, great things are possible. Teaching and learning haven't yet had their *Dark Side of the Moon* or *Avatar* moment—an amazing, transforming, technology-delivered, mass experience that resonates through many lives. (OK, *Sesame Street* is nothing to sneeze at, but still.) That's quite normal. When the movie camera was first developed, it was stuck on a stage recording an entire play from a fixed position—useful enough, but it took years before anyone realized the new technology made it possible to tell stories in much richer, more dynamic ways. We're still at the “camera on the stage” phase of technology for learning, but, as we'll see shortly, there are glimmers of possibility in the air.

THE TUTORING CHALLENGE

While we don't think education has yet benefited all that much from the amazing new technologies of the past quarter century, we do think the potential for radical rethinking looms large. What do we have in mind? One-to-one tutoring with a good tutor is about the best way we know to provide intense instruction, real-time customized assessment, and intensive, personalized practice. But it is typically far too expensive to provide at scale.

Technology can help with that. Kurt VanLehn, professor of computer science and engineering at Arizona State University, has reviewed more than 80 studies comparing “intelligent” (e.g., computer-based) tutoring systems to each other and to traditional tutoring, and found that these systems do pretty well.¹ Human tutors seem to be able to move groups of students by about 0.75 standard deviations (remember, this translates to moving the median students from the 50th percentile up to the 77th percentile . . . a pretty good move!). The simplest intelligent tutoring systems, those that provide feedback based on whether students got the answer right or wrong, offer about

half as much benefit—0.36 standard deviations (moving the median student to the 64th percentile). More complex systems that provide guidance at each step of a problem start to get pretty close to the benefits of human tutoring—boosting student achievement by about 0.7 standard deviations (and lifting the median student to the 76th percentile). Interestingly, the most complex systems don't yet seem to provide any additional benefit beyond that.

VanLehn's analysis shows that the best of these systems can nearly match the performance of human tutors when it comes to helping students build skills. This isn't magic: What these systems are doing reflects the tenets of learning science. They provide targeted feedback, repeated practice, pacing matched to the student, a variety of illustrations and explanations as needed, and audio and visual channels of information. They're most likely not going to be as good as the very best human tutors—but they can approximate what typical human tutors do, at scale.

If these tutoring systems aren't any better than human tutors, why bother with them? Because these tutoring systems are always available, don't get tired or sick, never have a bad day, and accurately tell you how things are going. Technology can deliver scalable, cheap-to-deliver *good* solutions that do some things nearly as well as the average human tutor (if not the very best ones). And these systems have the potential to generate large amounts of performance data that can be used to systematically improve them. In short, they can make quality tutoring more affordable, reliable, available, customizable, and data-rich—providing real benefits and real learning solutions at scale.

Think about the practical challenges of tutoring. Houston Independent School District (HISD), for instance, uses hundreds of tutors for its Apollo 20 program. The district pays tutors \$20,000 a year, plus benefits, yielding a total cost of around \$25,000 per tutor.² Each tutor assists about 15 to 20 students a day, working with two students at a time. This means the cost of providing two-to-one tutoring for each participating student is about \$1,000 to \$1,500 per year. The resulting total cost of the program runs to millions of dollars each year to provide tutoring to just a tiny percentage of Houston's 200,000 students.³ If tutoring were extended to serve even one in five students, the program would prove unaffordable.

It's not just the cash. Even with just 20 participating schools, HISD has difficulty recruiting and retaining the many talented tutors it needs. Imagine trying to recruit enough educated talent to serve hundreds, thousands, or millions of children—especially in communities where there may not be enough quality tutors to go around.

Adaptive, intelligent tutoring systems *are* expensive to build—but they suddenly look cheap when compared to the labor costs estimated above. For example, staff at the Open Learning Initiative at Carnegie Mellon University estimate that there's a one-time cost of hundreds of thousands of dollars to build one of its “cognitive tutor” adaptive learning environments to provide customized help for students in a course. Once running, though, the recurring costs are minimal. Contrast that with the millions of dollars *per year* it costs to meet a fraction of the need in Houston.

KNOW WHAT PROBLEM YOU'RE SOLVING

Many years ago, one of us worked in management consulting. Hearing a CEO say something like, “Well, I'm not sure what's wrong here, but let's buy a software package that can fix it,” was a sure sign the company was in trouble. Executives who didn't really understand their predicaments with manufacturing or supply-chain costs would make the mistake of hoping that some fancy software would “get this under control.” Truth is, good solutions have a lot more to do with solving problems than buying a new information management system. If the executives figured the problem out, they could often solve it without the expensive software. Conversely, a focus on buying new technology could easily serve as a distraction.

When decision makers don't understand the problem they're solving, technology-based solutions can waste money—and make problems worse. In 2012, a school system in Huntsville, Alabama, adopted a one-to-one laptop and iPad program and a digital textbook curriculum. But the technology conversion actually made everyday tasks more difficult for students and teachers. Because the system lacked the necessary bandwidth to support the new machinery, one seventh-grader explained, “The websites that the

books are on take forever to load and sometimes kick you out of the program. What used to be 10-minute homework is now two-hour homework.” One parent of a sixth-grader lamented that the digital curriculum could only be accessed on the Internet, saying, “We drive nearly 25 minutes one way to soccer practice at least two times per week. That is two hours that she could have been doing homework, but instead, now, with textbooks only online, that is not possible.” Another parent termed the initiative a “negligent disaster at best.”⁴

The takeaway here is simple. If you could download a “better” operating system for your smartphone but you knew it would restrict your coverage, wipe out important contacts, or reduce battery life, you might choose to stay with your “outdated” system. The same holds when it comes to education technology. Devices, software, and the rest are helpful only if they solve problems without introducing new, bigger ones. This advice seems pretty obvious, but you’d be surprised (well, perhaps you wouldn’t) how often it gets ignored.

Bryan Goodwin, chief operating officer at Mid-continent Research for Education and Learning, echoes this point, “Rather than being a cure-all or silver bullet, one-to-one laptop programs may simply amplify what’s already occurring—for better or worse.”⁵ For instance, the 18,000-student Kyrene School District near Phoenix, Arizona, spent \$33 million on technology and software between 2006 and 2011, or about \$1,800 per student. Yet for all this, student achievement hadn’t budged. Did Kyrene plan to reevaluate or change direction? Nope. It planned to spend tens of millions more over the next several years.⁶

Asked about this, Kyrene Superintendent David Schauer told the *New York Times*, “My gut is telling me we’ve had growth. But we have to have some measure that is valid, and we don’t have that.” He says, “We’ve jumped on bandwagons for different eras without knowing fully what we’re doing. This might just be the new bandwagon. I hope not.”⁷ Imagine if you heard the head of internal medicine at the Massachusetts General Hospital tell the *New York Times*, “We’ve jumped on bandwagons . . . without knowing fully what we’re doing. This [treatment] might just be the new bandwagon. I hope not.” Yikes! Might make you look elsewhere for health care.

TECHNOLOGY CAN HELP WITH THE ELEMENTS OF LEARNING

Last chapter, we ran through the key elements of a good learning environment (objectives, assessments, practice, demonstrations, information, overviews, and motivation support). How might technology help with these?

For starters, technological tools can allow us to store and share any of these elements more easily than if they were on paper. New tools can make it simpler to gather data on how students are doing, to customize their instruction, and to see what instructional approaches are or are not working.

Think how much it can help to simply store instructional resources. If educators can't readily draw on pre-existing materials, they wind up spending hours combing through their files, searching for good illustrations, or hand-crafting a baseline quiz to gauge student understanding. Even now, decades into the "computer revolution," teachers report taking anywhere from two to 10 hours per week designing their lesson plans. Freeing up even half that time would amount to perhaps two or three hours per week, giving teachers perhaps another 80 or 100 hours a year to spend diagnosing individual student needs, talking to students and families, or improving instructional technique.⁸

Technology also makes it easier for teachers to share their handiwork with colleagues. It would be crazy for every teacher to develop his or her own textbook—and no one does. The same principle can be applied across all the elements of learning. For example, when one of us taught high school social studies in the early 1990s, he invested enormous time and energy in developing elaborate simulations (if you're curious, a set of these was later published as the book *Bringing the Social Sciences Alive*⁹). But each of those simulations required 20 hours or more to develop, so devising five or six a year translated to 100 hours or more that couldn't be spent tutoring, mentoring, or responding to written work. Moreover, a single teacher hand-tooling everything inevitably required compromises when it came to quality.

Back then, sharing materials with departmental colleagues required lugging around boxes of instructional materials. Sharing that work with colleagues at other schools, much less those in

other districts or states, was just not practical. Now compare that experience with contemporary online ventures that allow teachers to share instructional units, materials, and lesson plans. Technology can help make exemplary materials widely and freely available.

For instance, Washington, DC-based LearnZillion has built much of its strategy around what cofounder Eric Westendorf terms the “Sunday night problem.” Westendorf says, “A common problem is that a teacher has to teach a lesson in the morning and it’s something that they’ve never taught before or that they don’t know how to teach that well. What do they do? Usually, they scramble to read up on it, e-mail friends for lesson plans, start searching online, and stay up late trying to throw something together. The thing is, there are a lot of great teachers out there who’ve already designed great lesson plans and put together high-quality instructional materials. We can even identify some of those teachers based on student performance.”

So, LearnZillion has issued “casting calls” to identify terrific teachers who can demonstrate success at helping students master particular math and science objectives. LearnZillion then brings this “dream team” together, to craft, share, polish, and capture brief instructional units and the associated learning materials. Each unit features audio of the teacher providing instruction, accompanying video, instructional materials, and a “director’s cut” of the instructor explaining what they’re doing. The technology enables any classroom teacher to easily modify the materials (for instance, by using an app that reproduces the materials in the teacher’s own handwriting), and the units include a script so that instructors can readily rerecord the instruction in their own voice.

Does LearnZillion “replace” teachers? Of course not. Wasn’t it always possible for teachers to share lesson plans, borrow resources from accomplished teachers, or modify a colleagues’ materials? Yep. But LearnZillion has made each of these things more affordable, reliable, available, customizable, and data-rich.

What about the rest of the elements of good instruction? As learning engineers, we tend to talk about these in the order they should be built, which is the reverse of the order they unfold instructionally—engineers start with the end goal and then work their way backwards.

Objectives

Well-constructed objectives define the skills and knowledge that students need to master in long-term memory. A focus on objectives—e.g., on competencies we care about—is a sensible way to make sure instruction, practice, and assessment tackle what matters. Part of the push to shift from a focus on “seat time” to one on “competency-based learning” is an attempt to ensure that students have the time they need to master objectives, and to allow accelerated learners to master new objectives more rapidly.

In an aligned system, objectives become the “hooks” that teachers and curriculum developers use to identify and link content. Knowing how objectives connect to each other—“What do you need to know before you can master this?”—can help organize content, assessment, and instruction.

For example, Kaplan Test Prep has looked in detail at objectives for students preparing for the MCAT exam required for admission to medical school. Many students assume, for example, that organic chemistry is the key to MCAT success. In fact, an analysis of millions of records accumulated over many years shows that physics performance is more important. Kaplan modified its instruction accordingly.

The Pittsburgh Science of Learning Center (PSLC) has rich data about objectives drawn from using computer-based “cognitive tutors” for mathematics students. When objectives are well-written there is a standard shape to the data illustrating how rapidly students master the problems. Some students solve the first problem right, an increasing number show mastery after each subsequent problem, and then the curve eventually plateaus. Sometimes, however, the data look odd; for example, the curve is too flat or bumpy, showing that students are not progressively mastering the objective. PSLC researchers have learned that by digging into the objectives in question, they can improve the instruction and accelerate student mastery (when they’re successful, one result is that the learning curve becomes more “regular”).

Assessments

Many teachers craft homemade assessments. One challenge is that these don’t always test what they’re supposed to (e.g., a math story problem may end up being about reading rather than how to

multiply fractions). Nearly half of the items authored by professional test writers at places like Educational Testing Service or Pearson need to be revised or replaced because they don't "work" well when tested in the field. New technologies can make it vastly easier for teachers to check the data on assessments, to share well-constructed items and assessments, and do all this across the nation as easily as across the hall.

While complex objectives should be evaluated with appropriately complex tasks, this isn't always easy. Technology can make it easier, however, to employ "authentic" tasks. Simulation can allow instructors to have students design and run virtual experiments.¹⁰ Good teachers and tutors can hone in on a student's mastery by asking questions close to a student's capability, saving time by skipping questions that are obviously too hard or too easy. Technology has helped make such assessments more systematic and scalable, making possible computer-adaptive tests that match the difficulty of the next question to an evolving estimate of student mastery. These adaptive assessments can cut testing time in half or less, while providing more meaningful information on student progress.¹¹

Even when two students reach the same correct answer, a good flesh-and-blood tutor can see where a given student may be hesitating or backtracking. If one student stumbles his way to the right answer, it can signal that key skills or knowledge haven't been mastered in long-term memory. That student may need additional demonstrations, practice, and motivational support. Unfortunately, few schools or systems have the skilled staff needed to routinely do this kind of careful evaluation. Research suggests, however, that we can gather evidence on the pace, pattern, and confidence that students exhibit via automated assessment systems and then use that to help guide interventions.¹²

The best teachers and tutors ask a lot of questions and provide hints to help students progress. Historically, assessments lacked the agility, interactivity, or sophistication to help much on this count. Here, again, technology can help. For instance, Neil Heffernan, professor of computer science at Worcester Polytechnic Institute, and his colleagues have created the "ASSISTments" system, which shows how a hinting system within assessments can improve student learning while providing rich data to evaluate progress.¹³ In a randomized controlled trial, they found a moderately large boost

(0.4 standard deviation, moving the median 50th percentile performer up to the 65th percentile) for students using the ASSISTments system instead of traditionally assigned homework.¹⁴ In another trial, students using ASSISTments for a year of math instruction outperformed a control school. Teachers reported that increased use of the system in class resulted in more learning for the entire class, even for those students who didn't use ASSISTments (presumably because the teacher adapted instruction for all students based on the system's results).¹⁵

Practice

Practice is what cements learning into long-term memory. Traditionally, teachers juggling 25 or 35 students have trouble integrating lots of opportunities for practice into hectic classrooms. Textbooks and instructional materials tend to emphasize passive explanation of knowledge and concepts, partly because it's hard to craft books that offer much in the way of dynamic or authentic practice. Technology can help make it easier to provide students with opportunities to practice. Computer-assisted learning can allow a group of students to practice certain kinds of problems while teachers instruct their peers. Meanwhile, it's a lot easier for digital resources than for printed textbooks to incorporate interactive practice.

Good practice is tightly linked to good assessment. Indeed, the best practice often looks a lot like an assessment—but with a premium on explanations and feedback rather than evaluation. This is all fairly intuitive. Good swimmers get better by swimming practice laps, and they're then "evaluated" in races where they swim pretty much those same laps. Driving students practice driving and parking, and they're then evaluated in tests of how well they drive and park. Now, technology can help generate good practice tasks or items, with computer-assisted practice giving learners more opportunities to practice at their own pace. In a classroom setting, time-strapped teachers charged with serving an array of students often feel pressed to move on after a fixed amount of time—especially if most of the class is growing restless while only a few students need more practice and feedback. One-on-one tutoring can help, but that's a pricey option—even when it's available. Technology offers a promising alternative.

Kaplan Test Prep is experimenting with an adaptive homework engine for SAT test prep that adjusts the level of practice based upon a student's progress. This adjustment helps ensure that a student's working memory is not overwhelmed while preparing for class. The engine also suggests how the instructor can break the class into three different group activities related to a given topic, based on student performance. Now we know you're thinking, "Wait a minute, that's nothing that a good teacher doesn't do every day as part of sensible diagnosis and differentiation." Exactly. Remember, technology rarely allows us to do things that are wholly *new*. Instead, it makes it easier to do these things, and lets all instructors do them more reliably.

Technology can help boost the motivation and personalization of practice by matching drills, items, and exercises to student interests and goals. Writing prompts can draw on information about student interests to better match the student with a subject she'll find interesting. This can increase the likelihood that the student will be engaged and take the practice seriously. Again, there's nothing here that creative, hardworking teachers can't do; it's just that the technology makes it more routine and less exhausting. Moreover, computer-assisted practice can more readily encompass banks of essay-writing topics, making things easier for teachers who may not be personally expert in everything that engages their students.

Technology can also make it possible, for instance, to instantly share essays with coaches or respondents across the globe. Remote instructors can provide additional feedback and coaching. Such support can reduce the burden on teachers and perhaps incline them to assign more real writing tasks. Computerized practice items can provide rich data about student learning, enabling teachers to provide additional, customized practice time. This whole process is not that far off from what high-end games like *World of Warcraft* are doing when they modify challenges and customize difficulty level based on player behavior.¹⁶

Indeed, there's a lot of discussion about the value of the "gamification" of learning practice. Well-designed computer games are so engrossing because they provide copious practice while activating our learning machinery in the right way. They succeed because of the "learnification" of gaming.¹⁷ Challenging, popular games

suggest that, when tasks are challenging but doable, learning can be fun. One first-grader told the eminent learning psychologist Seymour Papert, after struggling with a computer programming task, that the experience was “hard fun.” This is a description that aptly characterizes the best games and the best learning.¹⁸

Demonstrations and Information

Demonstrations and information give students conceptual knowledge and examples of what a task looks like when done well. While the best teachers are terrific at demonstrating and providing essential information, there is enormous variability across classrooms. Technology can provide consistent access to well-designed demonstrations that effectively combine audio, text, and visuals. Adding informal, targeted voice-overs to well-designed videos makes a real difference, and more promising developments are on the horizon. A research group at the University of Maastricht experimented with video and voice-overs to train pediatricians. They found that adding circles to the video to highlight areas of interest on an infant helped, but that blurring details outside the area of visual interest worked even better—presumably because the blurring permitted working memory to avoid having to process extraneous information.¹⁹

Tutor.com is a commercially available service that provides live, 24/7, one-on-one tutoring for students in a raft of subjects. Rather than requiring students to wait until the next day to get an explanation of a confusing concept or to see a demonstration of a problem-solving strategy, students can go online and get an immediate response from an experienced instructor. This kind of anytime, anywhere support is something that elite boarding schools with residential tutors have long been able to provide, but that has historically been impractical for most schools and families.

Interactive technologies can begin to blur the distinction between demonstrations, information, and practice, while making it easier to provide more structured demonstrations for students with less background (to avoid overloading working memory) and briefer demonstrations for students who are about ready to engage in practice.

Overviews

Overviews help learners know how the next piece fits with what they've done and what they're going to do. Describing the activities to come creates clarity and explains why the topic is relevant. This reduces potential drag on working memory and can help boost motivation. Overviews with technology-delivered media can illustrate the importance of the objectives for a student's own career or interests, show interviews with experts, depict samples of work, and more. There's an opportunity here to more effectively and reliably combat motivation problems, especially to make the case that what's being learned is important or relevant to their goals.

As with demonstrations and information, technology-delivered overviews don't have to be passive: Questions can be asked and decisions looked for, and learners likely gain from such engagement. Sophisticated data can make it possible to customize overviews for different learners, depending on their background, interests, and personal goals.

Motivation Support

Technology can help support motivation in various ways. For instance, a virtual experience—such as a simulation depicting the impact of water pollution—can help students understand why an objective matters. What's more, technology-delivered motivation supports don't have to be fancy. Even simple efforts to engage students and to focus them on learning can make a big difference.

In one notable study, several hundred students took a four-hour online Microsoft Excel training course. After each one-hour module, some students were asked questions about how they were learning the material. The researchers found that the questions increased student retention markedly. The questions weren't all that dazzling; they consisted only of simple text prompts like, "Have I spent enough time reviewing to remember the information after I finish the course?" or, "Am I focusing my mental effort on the training material?" Nonetheless, the impact on learning was substantial. The performance of students given the prompts improved by 5% on a 15-item multiple-choice measure that included both factual information (such as "which dialog box do

you use to write an If function?”) and procedural knowledge (such as “you have already done . . . and now want to do . . . what is your next step?”).²⁰

Technology can make it easier to record ongoing diagnostic information allowing supports to be targeted. Are students spending less time than expected on a learning activity? Are their assignments getting turned in late? Direct questions about students’ engagement can help complete the picture, too. Once a problem is identified, students get either teacher-mediated or technology-mediated support.

University of Wisconsin-Milwaukee professors have used an approach called Amplified Assistance to target students who need feedback. Instructors use the school’s learning management system to identify students who might be struggling and then use model e-mail templates to provide constructive, proactive assistance. The indicators and feedback are designed to address both motivation and content troubles. These resources make it less likely that faculty will wait until students reach out to them, and more likely they will lend a hand before students get too lost. The templates speed up feedback, offer guidance to faculty who are uncertain of what to say, and make it feasible to communicate with an entire class in the same time it once took to address a handful of students. In an initial controlled trial with more than 1,700 students, the results were promising: The share of students getting an “A” or a “B” for the course in question increased by about 16 percentage points—or roughly 100%!²¹

PUTTING PEOPLE AND TECHNOLOGY TOGETHER

Technology allows people to work better and smarter. It allows them to do more of what they do best—while providing a cheaper, easier way to tackle routine tasks or to provide learning support that teachers can’t provide.

Take the unsexy, low-tech challenge of improving writing, about which there is an established body of learning science.²² One demonstrably effective technique is the one we’ve talked about before, having students write syntheses of good essays they read.

Is this a promising avenue from a learning engineer's standpoint? First, there's high-quality research suggesting it works (usually a good sign). Second, the intuition is consistent with two principles from learning science: Learners need a lot of deliberate practice to get good at things, and they benefit from "worked examples" of complex tasks, where they do some of the hard work and some of it is already done for them. In this case, a previously written, quality essay is a kind of worked example, with much of the research already done for the student. Extracting the argument and key points from the essay and writing those up briefly becomes a manageable, scaffolded project.

Note that this learning technique requires no technology at all. However, rather than stopping there, ask: How can technology help make this more affordable, reliable, available, customizable, and data-rich? For starters, a key problem with writing assignments is the markup and grading process. When instructors are marking papers by hand, it takes too long to get students good feedback rapidly enough for them to rewrite many pieces.

How can technology help? Consider online mediated essay grading services, like those provided by SmartThinking, Inc., an online tutoring service. It's still in the early stages, but even now it can take a block of essays turned in by students and get reader comments back within 24 hours. That lets teachers and students quickly move on to deliberate practice. This can be very exciting for a learning engineer if it can operate under existing constraints on pricing, technology available, and so forth.

There are also services (e.g., the Educational Testing Service's Criterion service, or Vantage Learning's Intellimetric system²³) that provide *automated* essay grading. Automated essay-grading systems spit back a grade plus minor feedback on grammar and spelling. Even if that grade matches how a good teacher would mark the essay, the systems aren't providing the kind of feedback students can dig their teeth into. Now, if the problem is grading large numbers of papers and providing routine feedback, these solutions can be great. However, if the problem is finding a way to give students richer feedback and generate more practice writing based on that feedback, these solutions don't help as much.

There may be additional automated essay marking and grading systems that are better suited to solve the essay practice problem. One of them might be SAGrader, which uses a completely

different method for generating grades and content comments for an essay, and might work well for the synthesis exercise we're talking about. It requires someone, like the teacher or curriculum developer, to install a structured version of the content to be covered in the student paper, and then, using fancy computer techniques such as "fuzzy logic," look for those concepts and terms in a linked structure within the student's writing. It not only provides overall scores, it also offers comments that students may find helpful.

What do these look like? For an example, take an assignment in which "students were asked to (among other things) read a hypothetical life history, identify six concepts related to social stratification, and define each concept."²⁴ The computer feedback listed the correctly identified concepts, noting that the student received partial credit for including most of the six, while indicating that there were still more to identify.

Let's be clear—no one, especially us, thinks that this counts as incisive feedback. But it doesn't have to be, so long as it's useful and allows teachers to focus on something more important than checking whether each student had covered each of the required items. The benefit here, as the folks at SAGrader note, is not just the substantive feedback and the speed with which it's generated, but that the instant feedback seems to increase students' appetite to rewrite. A pilot in which 172 students penned more than 1,100 essays in an introductory sociology course found that students revised 71% of the assignments based on SAGrader feedback. (Anyone who has ever taught high school or college would regard that alone as a pretty heartening state of affairs.) Essays that were not revised by students averaged a score of 87 out of 100. Meanwhile, essays revised by students started with an average score of 61 and ended with an average score of 91.²⁵ In other words, the students who were struggling most seemed to put in the time and effort needed to boost their performance until it exceeded that of their peers.

Technology can free teachers from having to provide some or all of the "broadcast" work, elements like overviews, information, and demonstrations. This allows them to focus their time on coaching, questioning, providing feedback to practice, motivating, and personalizing students' experience. (We'll talk more about this in the context of "flipped" classrooms in Chapter 4.)

PUTTING THIS TO WORK

Today, technology allows a teacher in Seattle to teach students in Syracuse. This entails a certain remove between teacher and student, but also makes it much easier to match students to teachers on the basis of expertise, interest, or style. Social media can enable teachers to connect with colleagues interested in the same topics, students, or challenges. With well-designed assessment tools, groups of geographically dispersed teachers can discuss results and collaborate on new practices in ways that were once simply not feasible. Researchers, developers, and teachers of various grade levels can now cross-pollinate new ideas, sharing what's known about learning, what evidence is accumulating, and how new technologies can matter.

In other words, we've seen the emergence of a wealth of new instructional possibilities. Yet those new capabilities can be used poorly or not at all. To be helpful, a new technology ought to offer discernible benefits somewhere within a learning framework of objectives, assessments, practice, demonstrations, information, overview, and support for motivation. If you can't figure out where, exactly, it makes a difference, then be wary.

Taking full advantage of technology to enhance the learning process requires a willingness to look at proposed solutions and ask tough questions. Next chapter, we'll start to explore how this kind of thinking applies when it comes to school redesign.

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