

# Copyright

Published by Robinson

ISBN: 978-1-47213-912-2

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Robinson  
Little, Brown Book Group  
Carmelite House  
50 Victoria Embankment  
London EC4Y 0DZ

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## ***Introduction: The Adventure Begins***

Learning is an adventure—and as anyone who’s survived an adventure will tell you, that’s not always a good thing. It can be a long, rewarding process that changes the way you experience the world and reveals capabilities you never knew you had. But in the retelling adventures are extolled only by the victors. For every adventurer who’s slain an educational dragon, there may be dozens lying in caves and ditches nearby, smoldering in their armor, ruining the day they made their attempt.

My closest scrape with outrageous educational misfortune came at the Indian Institute of Technology, Kanpur. The moment stands out in my memory with uncanny clarity, as though it had been filmed at double the standard frame rate, as in Peter Jackson’s somehow-too-vivid *Hobbit* movies. It happened my final year at university.

Actually, to be technical, it was the summer after my final year. Although I had entered university firing on all cylinders, at some point my straight As gave way to curvier letters, and finally, just before what should have been my graduation, I managed to flunk Controls, a course required for my engineering degree.

That meant summer school: one chance at redemption. In most of India, summer means the monsoon season. In Kanpur, it’s wetter than it is hot—and it is as hot as anywhere I’ve ever lived. The dormitories weren’t air-conditioned, but the rooms did have French doors that opened onto a small terrace, and so, like every other sucker lucky enough to be taking remedial summer courses, I pushed my bed close to the French doors, so that at least my upper half could enjoy the occasional breeze. My worldly goods—my trunk of clothing, books, a stash of sweets I’d brought from home—went at my feet, at the other end of the room.

One morning, I woke up at eight or so, bleary eyed. Something was amiss.

Or rather, something was looking at me. Something with an impressive set of teeth.

I don’t know if you’ve ever experienced the rapid transition from drowsiness to abject terror, but I don’t recommend it. Every part of my body froze except my eyeballs, which swiveled on their bearings to take in my visitor. Staring back, fangs bared, was a rhesus macaque.

Too late, I realized my error: I had situated myself between my stash of sweets and any passing hungry simians.

Monkeys, in my opinion, are cute only on the other side of a television screen. They can be mischievous in all the worst ways, even violent, and they sometimes carry rabies. We stayed like that, face-to-face, for what felt like minutes. I pictured my obituary: *Once-Promising Student Mauled at Summer School*.

Five years earlier, in high school, no one who knew me would have predicted such an ignominious fate. Together with about 70,000 of my peers—the comparable number today is on the order of a million—I had sat for the Indian Institutes of Technology’s entrance exam. It was, and remains, perhaps the most competitive exam in the world. With some variation by year, only the top 2 percent of test takers are accepted to any of IIT’s campuses, which means for every fifty would-be dragon slayers, only one prevails. When my cohort’s scores came in, I learned that I had placed among the top five hundred students in the country. The news came as a major relief. Though I had won the neonatal lottery in the sense that I had been born to educated parents who prized learning and independent thought, we were far from wealthy, and they had made it clear to me that if I were ever going to make something of myself, academic excellence would be non-negotiable. After I saw my name on that board, it seemed my adventure was off to a promising start.

But at some point at university, the going became a slog. It became difficult to figure out how and why the abstract coursework I was supposed to be learning mattered in the larger scheme of things. It wasn’t my professors’ fault; I was being taught by some of the better professors in India, and plenty of other students were doing just fine. And it wasn’t that I didn’t *want* to care about the material. I wished desperately, in fact, for the stuff I was being taught to fit into my head as effortlessly as it had in my childhood.

But instead, for the first time in my life, learning had become difficult. In a way, I almost envied the monkey slaving at the end of my bed. All he had to do was wander along the row of dormitory windows and take whatever food was on offer. To him, my university was a buffet, filled with treats just waiting to be discovered. It should have been that way for me as well. I could see some of my friends partaking in the spread of knowledge, but I couldn’t force myself to eat. In a very real sense, the monkey was better adapted to my university than I was.

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Today, more than thirty years later, I’m happy to report I survived the most dangerous part of my educational adventure. The macaque at the end of my bed scampered away, permitting me to spend the rest of the summer forcing down the curriculum of my Controls course (and reading J. R. R. Tolkien’s entire *Lord of the*

*Rings* cycle). If I hadn't been given that second crack at that course, however, or if something else should have come between me and my studies that summer, I shudder to think about the later educational journeys I would have missed out on.

Instead, today I find myself in a unique position: not just engaged in my own lifelong pursuit of knowledge, but also the lead guide for many others. I head the Open Learning effort at the Massachusetts Institute of Technology, where it's my job to fling open the doors of the MIT educational experience and extend aspects of it to as many people as might conceivably benefit.

My quest is hardly unprecedented. Many others across time and space have made similarly ambitious attempts: geniuses, visionaries, disciplinarians, anti-disciplinarians, administrators, philosophers, gurus, *literal saints*.<sup>\*</sup> Some failed, some succeeded with certain types of students in certain conditions, and some saw their ideas spread nearly worldwide, only to recede. And so it would not be unreasonable to wonder what I, and the groups that I represent, bring to the equation that is so new and different. It can't be just my experience as an educator, although, if I may be so immodest, I am a good one. And it can't come down just to the transformative new education technologies being created at MIT and elsewhere. After all, would-be reformers have overhyped education tech for well over a century. To William Rainey Harper, who taught Hebrew at Yale University in the late 1800s, the transformative technology was the United States Postal Service, which he claimed would facilitate correspondence coursework "greater in amount than that done in the classrooms of our academies and colleges." In 1913, Thomas Edison voiced similarly high hopes for the motion picture, which he thought would render textbooks "obsolete." Next came radio, which was supposed to become "as common in the classroom as the blackboard," then television, which 1950s-era technophiles referred to as "the 21-inch classroom." In 1961, *Popular Science* predicted that by 1965, half of students would rely on automatic "teaching machines" for their instructional needs. By the 1970s and 1980s, computers had become the new top contender. And indeed, although they did soon become "a significant part of every child's life," as the MIT educational technology pioneer Seymour Papert foresaw in 1980, they have yet to live up to his 1984 prediction that "the computer will blow up the school." Far from it: Despite the onrush of technological changes that have come to education since the middle of the nineteenth century, most of us still teach and learn in classrooms that remain remarkably similar to those of 150 years ago.

And so, when I ponder what education could become, I find my thoughts wandering less to hypothetical, technological futures than to my own past: to my university dormitory and that monkey, for whom the physical architecture of standardized education spelled nothing but opportunity. In the course of my own journey, I would come to realize that those same sorts of educational structures—encoded not just in architecture but also in software, laws of the land, traditions,

organizational rules, and unspoken norms—had ceased to function as a playground for my mind, and had begun to constrain my ability to learn. Many others had it worse. My most critical moment of distress had arrived late enough in my education that, with plenty of family support and few responsibilities of my own, I'd managed to muddle through. I had been one of the lucky ones.

## ENTER THE EDUCATIONAL WINNOWER

I'm hardly the first observer to note that standardized educational structures, ostensibly put in place to nurture learning, can in fact impinge on it. In fact, a surprisingly wide variety of education reformers find common ground not just in their broad antipathy to the educational status quo, but also in how they describe it—which is to say, by analogizing schools to factories. As Alvin Toffler wryly noted in his 1970 book *Future Shock*, “the whole idea of assembling masses of students (raw material) to be processed by teachers (workers) in a centrally located school (factory) was a stroke of industrial genius.” Today, you can find reformers of virtually all stripes inveighing against the so-called factory model, from the free-marketeers at the Clayton Christensen Institute (“The factory-model system” processes “students in batches”) to the left-leaning Century Foundation (“The ‘factory’ model ... tends to alienate teachers on the front lines”). Centrists, such as the Learning Policy Institute, have echoed the metaphor, and so has the arch-libertarian John Taylor Gatto, who describes school as “a kind of halfway house” preparing youngsters for “service to a mind-destroying machine.” Tech evangelists, too, have hopped on the bandwagon: As Salman Khan, an MIT alumnus who created the Khan Academy educational video series, has said, “There is no need to continue the factory model inherited from 19th-century Prussia.”

To the credit of all these critics, the standardization of school does indeed come with serious drawbacks. And yet, for all its prevalence, I still don't think the factory metaphor provides the best illustration of what mass-education-as-we-know-it does to learners.

For one thing, education reformers have been leveling similar complaints for a very long time. As the historian Sherman Dorn has pointed out, even as early as the decades leading up to the Civil War, American schools were replete with many of the supposed sins of today's “factory model,” including mass-produced textbooks and a tradition of learning by rote. A wide wave of reforms took place, and yet, by the tail end of the nineteenth century, a new generation of reformers was already issuing complaints remarkably similar to those of their predecessors. This process repeated itself again and again, in the Progressive Era and throughout the twentieth century. In many respects, then, to rail against “factory-style” schools today is merely to slap a fresh metaphor onto an age-old struggle against repetitive, perfunctory instruction.

But still, it's easy to see why the factory comparison is so tempting. School, at a glance, appears to take in raw materials—human beings, in all their variety—only to produce a sea of similar-seeming graduates. It would only be reasonable to assume, then, that a shaping, molding process must be taking place between matriculation and graduation: clay, formed into dinner plates; gold, cast into bars; trees, whittled down to toothpicks.

Nowhere is the resulting homogeneity more apparent than in college admissions. In recent years, elite colleges in particular have found themselves with the strange problem of differentiating among students who, on paper, are essentially clones—at least in such still-important terms as their SAT and ACT scores and grade point averages. The product of the supposed “factory,” at least when viewed through its preferred lens of standardized metrics, is undeniably consistent.

But molding isn't the only process capable of churning out such homogeneity. To the extent that the output of educational systems around the world differs from the input, it seems to me that a different procedure is just as responsible, perhaps more:

*A winnowing.*

By blowing air through a column of crushed seeds, a winnower can separate seeds from their shells, or grain from chaff. Small winnowers can take up as little space as a vacuum cleaner and can be kept in the corner of a bakery or coffee roasting shop. Large ones can be the size of a warehouse: an entire factory devoted to producing near-identical grains on an industrial scale not by molding or shaping, but by eliminating deviance. When building such a device, the question is always what level of error is acceptable. How much good grain is worth throwing out in order to achieve next to no chaff in the final product?

It's hard to pinpoint precisely how much raw human potential the global educational winnower routinely sacrifices for the sake of a consistent product, but there's every reason to believe the wastage is vast: a world's worth of attrition parceled out most visibly in rejection letters and underwhelming test scores, but also in less obvious forms: courses never taken, applications never sent, examinations never sat for, books never read.

Once you realize how education systems are set up not just to nurture, but also to cull, you begin to see it everywhere. We winnow in how we test, and we winnow in how we teach.

We also winnow, for that matter, in *who* we teach—and where, and when, and for how much. Take the widest possible view and try to imagine everyone in the world who might want to learn something via formal educational channels. Right from the start, a whole slew of access-related factors cut short educational journeys before they even begin. Maybe you'd like to take some higher-ed courses, but you live too far away from a college or university, or maybe you're “too old” to

go to school. (No such thing, but on the other hand, holding down a day job certainly makes it harder to get to classes during the workweek.) Maybe you're a stressed-out parent, or someone with intensive eldercare responsibilities. Maybe you live in a region of the world without great schools, or your local schools won't admit people of the "wrong" race or caste or social position. In some countries girls are denied full access to education; in others, girls seem to zoom ahead in grade school only to be stymied later in their journey, or shunted toward stereotypically "feminine" fields while the boys get to play with robots. You might not belong to a family that expects you to go to college, or you might not belong to a community where higher education is the norm. As the economists Caroline Hoxby and Christopher Avery demonstrated in a 2012 study, a large number—"probably the vast majority," they write—of low-income, high-achieving American students simply never apply to a selective college or university, despite the increasing availability of generous financial aid packages.

And because not everyone is granted generous financial aid, the cost of education itself only adds capriciousness to an already ruthless winnower. Since the early 1980s, the full "sticker price" of college tuition has increased year in, year out, at more than double the rate of overall inflation. There are a number of reasons why, including the substantial administrative and physical-plant costs posed by major research efforts, declining government funding, and the economic fact that as salaries in high-tech fields rise, "high-touch" fields like teaching and healthcare must keep pace if they hope to stay in business.

But perhaps the most straightforward explanation for tuition's rise is the most persuasive: Simply put, the average undergraduate degree is still well worth the cost. As the MIT economist David Autor demonstrated in a 2014 paper in *Science*, pursuing a college degree remains one of the smartest financial decisions you can make, leading to a median lifetime benefit of roughly \$500,000. One slightly jaundiced way to look at the mismatch between college's cost and value, then, is to recognize that the sticker price could, if anything, be worse, since the market would largely bear it. Indeed, one intriguing, model-based analysis, created by the economists Grey Gordon and Aaron Hedlund, supports this idea. They argue that broad, continuing student demand may be the *primary* driver of tuition increases: Because more students than ever want to go to desirable colleges and reap the college wage premium, while the number of seats at said colleges has remained largely stagnant, the price has gone up. (Meanwhile, at lower-tier colleges whose degrees don't confer much of a wage premium, you'd expect to see declining enrollment—and that's precisely what's happened in recent years, a trend that has hit for-profit colleges particularly hard.)

Despite the rise of needs-blind admissions and the best efforts of colleges and universities to provide significant financial aid, the cost factor still winnows away lower-income students with callous efficiency. The relationship between family



income and college attendance is almost absurdly strong, as a team led by Harvard's Raj Chetty showed in 2014, with 25 percent attendance at the lowest income rung rising straight as an arrow up to 95 percent attendance at the highest income level. Worse, the lower your family's income, the less selective the institution you're likely to attend—a consequence not of differences in aptitude but rather of such concerns as the need to be close to home to help family members, or difficulty jumping through all the hoops required to put together a top-tier application package. Although in raw terms, less-selective colleges account for more of the U.S.'s income mobility than elite schools, elite schools have the edge on a per-student basis, and tend to offer better financial aid and support resources to boot. "Ironically," Stanford's Hoxby has said, lower-income students "are often paying more to go to a nonselective four-year college or even a community college than they would pay to go to the most selective, most resource-rich institutions."

Any plan to expand the learning horizons of people everywhere must involve recalibrating the educational winnowing to be more inclusive, so that we stop turning away learners for such access-related reasons as income, geography, and timing. Necessarily, such a plan would involve adding "seats," be they physical or virtual, to the world's top-notch classrooms, for which demand is already high and growing. One force at odds with adding seats, however, is the all-too-prevalent idea that for a school to be top-notch, it must be "selective"—meaning it turns away most of its applicants. And therein lies a conundrum.

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In fact, selectivity itself, and how we go about enforcing it, represents one of the more powerful, pernicious ways that our educational winnowing squanders human potential. Slotting the best students into highly sought-after seats is, in its way, an admirable goal—after all, we should make the most of our limited resources. But the way we pursue that goal is built on a set of glaring assumptions: that our potential as learners is both knowable and fixed, more or less for life, perhaps starting as early as birth. These ideas, though highly debatable, comport with how most of us think about intelligence: If you're smart now, you'll still be smart in ten or twenty years. Or, as Lewis Terman, the father of American intelligence testing, wrote in 1919, "the dull remain dull, the average remain average, and the superior remain superior."

The *original* inventor of the intelligence test, the French psychologist Alfred Binet, disputed this sentiment. Binet was convinced of intelligence's fungibility. In fact, the whole point of his test, which he invented in 1905, was to identify members of the population whose intelligence might benefit from intervention. Soon, however, his test was coopted by Terman and like-minded thinkers, who

approached the topic with a worldview steeped in the deeply unfortunate tradition now known as “scientific racism.” Such scientists, in constant search of evidence that could prop up their prejudices, considered it a given that human intelligence was “chiefly a matter of original endowment,” as Terman put it. “We must protest and react against this brutal pessimism,” Binet lamented in 1909, to no avail. Within a decade, such pessimism was quite literally on the march. IQ tests, given to 1.7 million U.S. Army servicemen in World War I, led to the development of a National Intelligence Test for schoolchildren. By the 1930s, schools were testing for IQ and aptitude as a matter of course. They often started young; Terman insisted that “the limits of a child’s educability can be fairly accurately predicted by means of mental tests given in the first year” of school, and “accurately enough for all practical purposes by the child’s fifth or sixth year.” Schools used the results to sort students into tracks: the high road being the “college track” or “academic track,” as opposed to lower “general” or “vocational” tracks. Upper-track kids applying to college then found themselves facing yet another cousin of the wartime testing program: the Scholastic Aptitude Test, known today as the SAT, which began classifying students according to their supposed aptitude in 1926.

To give aptitude tests like the historical SAT their due, they can and do deliver a subset of learners from the jaws of the winnow. For generations now, by establishing a point of comparison across high school students, they have helped make admissions less contingent on personal connections (even if that transformation remains incomplete, given the extra consideration commonly granted to, say, legacy applicants). A good test score, meanwhile, can encourage students to give college a shot who otherwise might not. (Indeed, when the state of Maine began requiring students to take the SAT in 2006, 10 percent of students who would have otherwise skipped the test ended up attending a four-year college.) And, despite scientific racism’s formative role in aptitude testing’s history, a well-aimed aptitude test can actually expose racial bias in schools. In 2005, for instance, when Florida’s Broward County introduced a universal, aptitude-based screening program to fill its third-grade “gifted” classrooms, instead of relying on parents’ and teachers’ nominations as in years prior, the Black and Hispanic populations of those “gifted” classes tripled.

But there are also problems galore to be found with intelligence and aptitude testing. It’s impossible to gauge intelligence directly, so IQ tests attempt to sketch its outline by sending test takers through a battery of challenges, the combined results of which supposedly reflect one’s cross-cutting intellectual chops. Some psychologists doubt that there really is a deep, generalized factor undergirding performance on all these sorts of subtests. IQ skeptics also like to point out that intelligence testing almost inevitably comes with blind spots and biases. Starkly drawn test questions fail to assess such virtues as creativity and interpersonal

skills, for instance—and then there’s also a long history of test makers coming up with questions that favor test takers of higher socioeconomic status (for example, “Define *regatta*”).

But let’s suppose, for argument’s sake, that these caveats don’t matter much: that IQ scores really do paint an accurate picture of one’s ability to learn. Even then, the predictive power of IQ scores still comes up short, because IQ is not, as Terman supposed, fixed for life. Rather, Binet was right: IQ is alterable, fungible, contingent on your surroundings and experiences. Sorting students by IQ-style tests, then, can be a recipe for winnowing out students for their environmental circumstances, not their intrinsic aptitude. In fact, speaking in aggregate, the lower a family’s socioeconomic status, the more variable (and therefore less heritable) IQ tends to be within that family—which implies that environmental factors wield particularly disproportionate influence over IQ scores in lower-status populations. Such external factors can be either helpful or harmful. Pollution, for instance, such as lead in drinking water or in the air, can take a lasting toll on IQ, as can childhood malnutrition, as well as childhood abuse and neglect. More temporarily, lack of sleep and acute stress can take a severe bite out of the cognitive processes required for good performance on IQ and other standardized tests. On the bright side, education can boost IQ: On average, every additional year of schooling you complete will garner you between 2.7 and 4.5 IQ points.

So malleable is intelligence, in fact, that the simple act of teaching students that it can improve—leading them toward what the psychologist Carol Dweck calls a “growth mindset”—can, in specific circumstances, cause noteworthy achievement gains. Perhaps the most obvious sign, however, that tests of intelligence and aptitude measure something fluid, not fixed, is the sheer scale of the test-prep industry that crops up whenever the stakes of such exams are sufficiently high. As the education historian Carl Kaestle has written, “Generations of affluent people buying test preparation to improve their children’s ‘aptitude’ would prove the naïveté of calling the SAT a measure of ‘aptitude.’ ” In the summer of 2019, in an attempt to mitigate such distortionary factors, the SAT-issuing College Board briefly announced that it would begin contextualizing its scores with information about test takers’ neighborhoods and schools of origin, before walking the plans back a few months later. The tentative step would never have been necessary had SAT scores adequately represented aptitude in the first place.

Despite the continued influence of the SAT in college admissions, starting in the 1980s the American education establishment began to lurch away from aptitude exams and toward subject-matter-specific “achievement” exams, which test not for intelligence but rather acquired knowledge and skills. As these customs changed, a wave of bowdlerization washed over aptitude’s remaining

edifices. In 1993, the College Board changed the name of the SAT from “Aptitude Test” to the redundant “Assessment Test,” and then, in 1997, did away with the words behind the letters entirely; SAT now stands for nothing in particular. Meanwhile, high schools’ “college” and “general” tracks have slipped into a suit of subtler terminology: Advanced Placement and “honors” courses now form the rails of a college track that exists in all but name.

I wish I could reassure you that backward-facing achievement exams winnow away learners far less arbitrarily than forward-looking aptitude tests, but it’s not clear they do. Acute stress, for instance, impairs cognitive processes that are indispensable for both sorts of exams. And then there’s the matter of stereotype threat: the well-supported theory that negative stereotypes can provoke unfair distractions, doubts, and anxiety in students belonging to disadvantaged groups, harming their performance on high-stakes tests. Take, for instance, a group of boys and girls who, in 2013, posted identical scores on the Specialized High School Admissions Test, the sole criterion for entrance to eight of New York City’s most selective public high schools. The following year, the girls went on to earn significantly higher GPAs than the boys, a sign that something about the entrance exam had disproportionately depressed the girls’ scores. Perhaps the issue was that they were less willing to guess at answers than the boys, but it was just as likely that stereotype threat had erected an asymmetric distraction during the test—occupying girls’ cognitive resources at precisely the moment when they needed them most.

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If a learner’s personal circumstances act like a thumb on the scale determining whether she’s worthy of educational investment, and the biased methods used to sort students act like another, then there is, improbably enough, a third thumb (or perhaps a big toe) at work as well. It has to do with how we expect students to learn.

In even our best-intentioned attempts to shovel information into students’ heads, educators routinely violate principles found throughout the research disciplines collectively known as cognitive science, from higher-order psychology down even to the molecular level. Every one of these violations—often the unintended consequence of scholastic norms and structures—comes at the cost of learning adventures delayed, diverted, or cut short.

Put simply: In our efforts to standardize education, we’ve made learning too damn hard. This unfortunate state of affairs harms students across the board, and may be especially fraught for disadvantaged groups who arrive in classrooms already stressed, especially vulnerable to the worst effects of biologically and psychologically unsound instruction. One powerful way to save vast swathes of the

world's unduly winnowed learners, then, may be as simple as making learning more user-friendly, by identifying and eliminating unnecessary cognitive fetters.

Happily, I'm here to report that there are many feasible ways to do precisely this—not by watering down the knowledge and skills we hope to impart, but rather by deliberately rethinking how we teach, and how students might strive to learn. Such an approach would certainly not resolve deep, systemic biases, but nevertheless it stands to mitigate some of the excesses of our overzealous winnower. Tailoring education to meet the specific, often surprising demands of the equipment between our ears will permit us to *increase* the depth, breadth, and rigor of learning—for a far wider population of students than currently benefits.

### TO TEACH—OR TO SORT?

It's fitting that the modern science of learning may help pull us out of our current predicament, because its forebears certainly helped shove us into it. During the first few decades of the twentieth century, many of the emblematic features of contemporary mass education entered into widespread use while others, predating that era, were put to work in newly standardized ways. Abetting and inspiring this infrastructural sprawl was the young field of experimental psychology, which had begun to draw sharp, quantifiable edges around the once-gauzy phenomenon of learning.

In 1898, the experimental psychologist E. L. Thorndike declared to the world that learning came down to principles of mental association. He argued that when people—or, in the case of his original experimental subjects, hungry cats—do something that results in a desirable outcome, they become increasingly likely to repeat that action. In such instances, he maintained, a mental association forms: between a lever on the door of a cat's cage, say, and a tasty meal outside. As I'll explore in chapters ahead, using such fundamental building blocks, it's possible to posit an entire, freestanding theory of how human learning works, including in the classroom. (Instead of “lever” and “cat food,” for instance, students might associate “5 times 7” with “35.”) By chopping up learning into manageable, measurable chunks, Thorndike's theory created a scientific rationale for the standardization of schools, and his theories came with certain other attendant assumptions as well—about students. His model was, in essence, a new take on the old notion of the mind as blank slate, shaped by experience as opposed to innate predispositions. Thorndike's version, however, came with a near-Orwellian twist: Although all slates were born blank, some appeared to be more blank than others—or at least better able to absorb and parse incoming information. Like his contemporaries in the IQ-testing game, he believed this capacity to be both genetically determined and set for life, an idea that added considerable heft to the twentieth century's obsession with testing and sorting students. (Indeed,

Thorndike and Terman worked together on both the Army's IQ testing program and the follow-up National Intelligence Tests.)

And so, even while some of his contemporaries were arguing that the purpose of education was to improve intelligence, Thorndike saw things differently. "The one thing that the schools or any other educational forces can do least," he told his students at Columbia University, was develop "powers and capacities." In a world where intelligence wasn't improvable, he recommended that schools focus their limited resources on those students best able to make the most of what they were given. It was imperative that schools winnow the chaff from the wheat.

It's hard to overstate the degree to which such assumptions became woven into the fabric of mass education in the United States, and much of the rest of the world, as the twentieth century wore on. Even today, many schools begin sorting students as early as the end of elementary school, as though their promise as learners were both set for life and entirely knowable. (It's neither.) We attempt to fill them with facts as though their heads are an empty bucket. (The better metaphor, as I'll explain later, would be a growing tree.) We spur them to learn with carrots and sticks like GPAs and test scores. (Instead, we could focus on building natural interest and curiosity.) Finally, at the end of this process, a very specific sort of student is left standing—someone who is in no way undeserving of further educational investment, but who is also in no way representative of the full scope of human potential that went in.

Even as mass-education structures crystallized around Thorndike's point of view, however, the field of cognitive science continued to advance, creating a gap between the leading edge of scientific knowledge and the increasingly outdated assumptions frozen at the core of standardized education. The issue wasn't that Thorndike was wrong. Rather, his theory of learning turned out to be reductive: an oversimplification of what we now understand to be an extremely complex process. In fact, the learning mechanism that Thorndike theorized bears more than a passing resemblance to today's most commonly accepted neuroscience model for how information is represented among the brain's synapses—a remarkably prescient finding. What he failed to anticipate, however, was that his model might compose only the ground floor of what many cognitive scientists now think of as a high-rise of sorts, with individual neurons and their synapses supporting the activity of specialized regions of the brain; the physiological brain supporting psychological processes; physio- and psychological processes both contributing to what we think of as the conscious mind; and above that, multiple minds interacting with each other in classrooms and beyond. At every one of these levels of organization, researchers have uncovered processes that turn out to be absolutely critical to successful learning—and which, when interfered with, can quickly bring an educational adventure to a grinding halt.

Many of our inherited education practices, with their hundred-plus-year-old

underpinnings, sit uneasily with these newer findings. If my mission to foster learning far and wide is to have a prayer of a chance, it must avoid replicating these same old mistakes on a larger scale. Rather, we must first undertake a cognitive reckoning of sorts. Based on what we now know about the levels of the learning brain and mind, what—as teachers and learners both—can we do to make the act of learning more user-friendly?

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Perhaps the most obvious impediment to making learning easy is the pervasive notion that learning *should* be difficult. This idea is as prevalent at MIT as anywhere—perhaps more so. As an informal slogan, MIT’s undergraduates have adopted the initialism “IHTEFP”—short for “I Hate This F\*\*\*ing Place,” intoned usually (but not always) with a rueful smile—which gives you one good benchmark of how taxing they find their coursework. Challenging students to develop rigorous, deep, and readily activated bodies of knowledge is essential. Imposing onto this already difficult undertaking additional, *unnecessary* hardship, however, is both cruel and arbitrary—like requiring Olympic sprinters to first qualify in a karaoke competition.

And yet, another of MIT’s cherished tropes hints at precisely this sort of needless difficulty. It’s long been a point of masochistic pride that learning at MIT is like drinking from a high-pressure fire hose. Our students, this bit of campus lore suggests, are smart and tough enough to gulp down a flow of information capable of stripping paint. And so, in 1991, when a group of pranksters set up a water fountain on campus that literally dispensed drinking water from the tip of a fire hose, MIT made it into a permanent exhibit. The fire hose fountain now graces the entrance to the Ray and Maria Stata Center, the building where most of MIT’s computer scientists live, with a commemorative plaque explaining about high-pressure learning. Every time I walk past it, I grimace, because the sculpture suggests two misguided ideas. First, that apparently learning is a difficult endeavor at MIT. That’s strange, considering that as the world’s premier institute for technical education, blessed with an utterly fantastic student body, you’d think we would find it easier to teach. (And in fact, we are *far* better at teaching than the fire-hose metaphor suggests.) And second, it implies that people who, for whatever reason, are unable or don’t care to sip from the stream of pressurized truth don’t belong at MIT. Indeed, perhaps advanced education is not for them. Perhaps *knowledge itself*, beyond what they catch as it flies by in the news and on social media, is not for them.

Or more likely: We’ve been thinking about learning all wrong. We’ve internalized the idea that learning is meant to be an ordeal through which students must persevere or fail. I’d like to step back and ask why. Human beings

are built to learn. It would not be too overdramatic, in fact, to argue that our learning ability is our birthright as a species, hard won through eons of natural selection. The difficult part should be over. When did the abstraction of useful knowledge from the world around us become attainable only through bitter perseverance? When did learning become not the fun sort of adventure story, but a grim slog against the odds?

In an education system set up in part to sort the supposed elect from the unworthy, any unnecessary impediment to the act of learning itself will inevitably push a subset of students toward the latter category: a flunked exam here, a denied college application there, diminished educational prospects overall. More troublingly, there's every reason to believe that that subset—the winnowed—will disproportionately consist of students who arrive at school pre-burdened with the sorts of social and economic disadvantages I've already discussed. One obvious, worthy response to such problems is simply to fix them: to lead a full-frontal attack on poverty and racism and sexism and all the other things that keep good people down. In fact, if we ever hope to live in a more just society, such a direct approach is simply non-negotiable.

But even in a world miraculously without such obstacles, learners would still be hamstrung by cognitively clumsy instruction. To truly make education as equitable as possible, it is imperative that we shed the myth that serious learning must be difficult, and find ways to make instruction far more cognitively user-friendly. Such an approach would save students from undue winnowing while helping others achieve new heights of academic excellence.

And if we can save a few students from the ruthless machinery of the educational winnower, then perhaps we can also multiply that effect, taking our new and improved approaches and making them accessible to a wider world of learners. This is where new instructional technologies come in. As the peddlers of earlier technologies discovered the hard way, a hot new instruction medium alone—even one capable of reaching vast numbers of students—isn't likely to drastically change how most people learn. The idea of using educational technologies as a vehicle for a more brain-friendly mode of education, though promising, isn't exactly new, either. But as I explore in the pages ahead, both our understanding of how learning works and the capabilities of new instructional media have reached a point where their combined potential raises possibilities too promising to ignore.

Let me say this before we go any further: I believe the best education is still a human-to-human education, and I don't see that changing anytime soon. We're only now, however, starting to see what great human teachers can accomplish while wielding truly powerful education technologies—especially when given the freedom to act outside the inherited, often procrustean structures of traditional mass education.



The need for more user-friendly, accessible learning has never been more urgent. Admittedly, in saying this, I'm guilty of the long-standing, unfair practice of dropping off the world's problems at the classroom door for educators to solve. But the fact is, the current moment does present a suite of issues that demand uniquely *educational* solutions. From the perspective of learners, the pace of technological change is altering the rules of work, even as careers are growing longer than ever. We need better, time-and-energy-efficient ways for busy midcareer workers to keep current or change tracks as needed. Meanwhile, at a time when intergenerational income mobility has been stagnant for decades, we need new ways to bolster one of the few forces capable of helping individuals vault free of their parents' circumstances: a college education.

And then there are the broader problems faced by entire societies: climate change perhaps most existentially, but also such concerns as pandemic disease, the medical and caregiving costs facing countries with large aging populations, income and wealth inequality, and finding ways to reattach gains in living standards to economic growth, among many others. Unfortunately, we're devoting only a small portion of our collective brainpower to the sort of innovation we'll need to solve such pressing issues. Only a small fraction of people is ever even given the *chance* to innovate. In an attempt to probe who gets to participate in technological innovation, Raj Chetty of Harvard and his team have shown that the vast majority of patent-holding inventors fit an alarmingly narrow profile: mainly boys from wealthy families and rich neighborhoods. "These findings suggest that there are many 'lost Einsteins,' " they write, "individuals who would have had highly impactful inventions had they been exposed to innovation in childhood—especially among women, minorities, and children from low-income families." This innovation imbalance equates to less income for those underrepresented groups and less innovative energy devoted to solving the unique problems they experience. Just as alarming, it means that in terms of the gigantic, urgent challenges facing societies around the world, we're fighting with one hand tied behind our back.

Scientists, meanwhile, are making their most groundbreaking discoveries later and later in their careers, likely because in any growing area of research, it takes each generation longer than the last to get up to speed. We need ways to hasten students' journey to the cutting edge of research, and we need people from more diverse backgrounds taking part.

One answer to both problems is to make learning easier: more user-friendly and far more accessible, for all different sorts of people, all around the world.

One way or another, learning is going to be an adventure. It can be a story of Herculean perseverance or it can be a voyage of joyous discovery. By erring on the side of the fun kind of adventure, we may help more people learn, and realize more human potential, than we've ever seen.

My lucky position at MIT has given me insight into how this could happen, and now it's my pleasure to share it with you. In the chapters ahead, you will meet the scientists, educators, and engineers who are changing the way we're thinking about learning, on MIT's own campus and beyond. If learning is an adventure, then learning *about* learning may turn out to be one for the storybooks.

*Part One*

**LEARNING IS SCIENCE AND  
SCIENCE IS LEARNING**

## THE LEARNING DIVIDE

It was the last day of February 2017, and Amos Winter, an assistant professor of mechanical engineering at MIT, was warning the group of sophomores in his afternoon lab section about the destructive potential of their batteries. Though supposedly safe, in the unlikely event of a sudden discharge, each of the lithium polymer batteries scattered on the conference table possessed enough energy to maim, even kill.

How much energy, exactly? “Go ahead—slam it into a calculator,” he said. After approximately ten seconds, anyone who had worked it out was keeping the answer to herself, so Winter bounded over to a whiteboard. You know the capacity of the battery, he explained, which came labeled in units of milliampere hours. “You basically just add in time to figure out energy in joules,” he said, and in short order, the answer was on the board: 13,320 joules. “That’s the equivalent to lifting a Honda Civic ten meters off the ground,” he said. “Imagine a Honda Civic falling on your hand”—that’s the kind of damage an exploding lithium polymer battery could inflict. If the casing on such a battery begins to bubble, he said, chuck it in one of the lab’s many sand buckets and run in the opposite direction.

In the absence of any such catastrophes, however, class would continue to hum along as it had for the first few weeks of the semester. In addition to the batteries, sitting on the table in front of each student was a simple robot—two wheels and a skid designed to drag along the ground—which would serve as a sort of training vehicle, in anticipation of the more complex robots the class would build later in the semester. On these practice bots, which Winter dubbed “Mini-Mes,” the students would learn mechanical engineering principles ranging from simple to complex. They would start by learning to code a microcontroller (that is, a very small computer) to run an electric motor; later, they would instill in their Mini-Mes the capacity to navigate the world autonomously like rudimentary self-driving cars. Along the way, they would learn not just robotics knowledge and skills, but how to think like designers and engineers. They would come to understand how to approach a task creatively, to spot issues before they become serious problems, and, perhaps most important, to gain a level of trust in their own ability to guide a project from early phase, when there are innumerable paths to a desired solution, to late, when there’s only one best way forward.

That was the learning progression in theory, at least. In practice, some of Course 2.007's students were coming to it with more engineering experience than others. Some had competed in high-school robotics tournaments. (The best-known extracurricular robotics organization, FIRST Robotics, had actually spun out of MIT's original version of Course 2.007, back in 1989.) And the rumor mill had already made it known that one student, Alex Hattori, had competed on BattleBots, a televised contest known for its metal-on-metal violence. He and his teammates had sent a buzz-saw-wielding robot the size of a manhole cover into a gladiatorial arena, to wage war on opponents with names like SawBlaze and Overhaul.

To the other 164 students who lacked such head starts, these advantages were cause for real concern. In MIT's charged academic atmosphere, stress among students is a perennial issue, and unnecessary competition, usually over grades, does not help. Most of the time, the Institute works hard to dampen this instinct—for instance, by abolishing grades in the first semester of freshman year. But Course 2.007 is different. Competition is baked into it at a deep level, and is the reason why it is arguably MIT's most famous undergraduate offering. At the end of every spring semester, the course culminates in a robotics showdown, which draws hundreds of spectators from across campus and beyond. The winner achieves lifelong bragging rights, entering MIT Valhalla while notching one heck of a résumé bullet point.

Brandon McKenzie's gaze slid to his lab mates seated around the table. A varsity swimmer who had competed in the Division III national championship as a first-year and would return to the championship series later in the semester, he had thus far maintained a perfect 5.0 GPA despite spending eighteen-plus hours per week in the pool. He was not used to the sense of falling behind, and yet there was no shaking the feeling that others were several lengths ahead of him in the race to build serious, competition-worthy robots. He had come to 2.007 with next to no practical robotics experience, and there were a few others in the same predicament—Amy Fang, for instance, at the other end of the table, and Josh Graves, Brandon's roommate, teammate, and all-around co-conspirator, at his right elbow. But then there were folks like Jordan Malone, seated directly across from Brandon, whose computer-aided-design prowess Winter would later describe as a "super power." (And that wasn't even the most impressive thing about him: Although he never brought it up unbidden, everyone knew that Malone, a short track speed skater, had brought home Olympic medals from Vancouver and Sochi, prior to enrolling at MIT at age thirty.) And there was Zhiyi Liang—Z, for short—a joyful mad-scientist-in-training who seemed to come to class every week having produced a new mechanical marvel in his downtime. Brandon expressed no animosity toward his fellow students; indeed, he would become the lab's most reliable source of fist bumps and backslaps in the weeks to come. But then again,

any theory taught in class can and must be immediately applied—after all, if you don't apply it, your opponents will. In part because students thrill to the experience of seeing their knowledge translate into real-world engineering powers, and in part because there's glory on the line, the course's ability to motivate learning is second to none. Even students with a long history of doing the bare minimum\* wind up inspired despite themselves, spending far more time in the lab than is strictly necessary, screwdriver in hand, notebook computer open. In the space of a single semester, the course launches experienced hobbyists and the uninitiated alike toward professional mechanical engineering in a way that is sometimes imitated but never, in my completely biased opinion, exceeded.

Today, when I contemplate the task before me, my thoughts never stray far from 2.007. At minimum, any education scheme worth its salt must not only deliver knowledge, but do so in a way that is highly engaging—and then activate that knowledge, so its owner can do real work in the world. Course 2.007 vaults these bars with plenty of clearance.

The problem is a matter of access. Course 2.007 is extremely expensive to offer, costing MIT far more per student than each would pay in tuition, even without financial aid factored in. This owes in great part to the costs of keeping the laboratory up with the cutting edge of fabrication technologies while still safe for novices, which equates to a lot of highly trained personnel.

Pragmatically speaking, anyone hoping to provide an educational experience of this caliber to vast numbers of people either must be mind-bogglingly rich or else find a creative way to pull it off at scale. After all, you can't put a billion people through Course 2.007; even if you somehow found enough teachers and built enough laboratories, according to one back-of-envelope calculation I've done, it would still cost more money than exists in the world.

It's certainly possible, however, to disseminate knowledge on that order of magnitude for far less: Wikipedia alone has done that, for instance, to great and deserved acclaim. So has MIT, in our own, smaller, way: Starting in 2001, through our OpenCourseWare initiative, we've made essentially all of our course materials freely available to anyone with an internet connection. But making information available is not the same as providing an education. And so you might reasonably ask: Can a scaled-up education scheme ever replicate what a skilled teacher in a traditional classroom can achieve, let alone the motivating, contextualizing effect of Course 2.007? Will its students ever truly make the jump from understanding calculus to *thinking using calculus*?

## TEACHING MACHINES, TEACHING HUMANS

Would-be innovators have dreamed of distilling and mass-producing the secret sauce of education for well over a century. As early as 1912, the psychologist E. L.

Thorndike, already well on his way to reshaping how America thought about learning, mused: “If, by a miracle of ingenuity, a book could be so arranged that only to him who had done what was directed on page one would page two become visible, and so on, much that now requires personal instruction could be managed in print.” In 1953, the Harvard psychologist B. F. Skinner, in many respects Thorndike’s intellectual descendant, attempted to realize this science-fictional notion by building a series of “teaching machines.” One of them can still be found at Harvard, tucked away on the ninth floor of the university’s William James Hall. The wooden, rectangular machine would have covered most of a student’s desk while she worked at it, making her way through the series of questions printed around the edge of the paper disk inside. A small rectangular window in the machine’s bronzed lid displayed a single question at a time as well as the answer to the previous question, and a nearby aperture let the student scrawl her answer longhand on a strip of paper tape that emerged briefly from the machine’s innards before plunging back in. She would compare each written response to the correct answer and, by pulling a lever, mark herself correct or incorrect. (Teachers could check students’ answer tapes for inconsistencies after the fact.) Once she’d answered every question on the disk, it would then spin more freely, stopping only to re-pose those questions she had initially gotten wrong, a process that would continue until she had answered every question correctly. Students would move along at their own pace, advancing from one disk to the next. The education revolution, Skinner believed, would thus be personalized. As one student memorably put it, “The eggheads don’t get slowed up; the clods don’t get showed up.”

Just to the right of the window where students recorded their answers, the bronze surface of the teaching machine on display at Harvard is worn down to the underlying gunmetal: the result of a decade’s worth of wrists rubbing the same spot. As the 1960s gave way to the 1970s, however, the hype, too, faded from teaching machines, and Skinner’s invention vanished from both schools and the national conversation. They had proved less effective in the wild than in the lab, many in the public found them creepy, and much of the buzz surrounding the mechanical devices was finding its way over to electronic ones: computers and the nascent field of educational software. But still, neither the original teaching machine nor its computerized equivalents have ever transformed the classroom as promised.

And why not?

Perhaps most egregiously, teaching machines and their immediate electronic descendants were *boring*. Once the novelty wore off, many students said they hated the things—a major indictment of Skinner’s entire project. Although it can feel momentarily gratifying to get answers right, and it’s often good to move at your own pace, Skinner’s approach proved overly simplistic: blind to larger

concerns like motivation, contextualization, and social isolation. Like his predecessor E. L. Thorndike, Skinner was a reductionist, seeking to explain learning in terms of its most fundamental constituent parts. To his credit, reductionism done right is one of the most powerful conceptual tools available to scientists; it's what allows us to understand chemical processes in terms of atomic physics, for instance, or the concept of temperature in terms of the average kinetic energy of molecules. But "done right" assumes that the fundamental particles and processes you've isolated really do explain the workings of the larger system in question. When reductionism goes wrong, however—when scientists and engineers underestimate the complexity of a system—disaster can result: airplane crashes, stock market crashes, and everything in between.

Somewhere on the continuum between Skinner's reductive teaching machines at one extreme and the relatively holistic approach of Course 2.007 at the other, something important clearly gets lost. And that wouldn't be much of a problem—except for the fact that the structures of standardized education, guiding and confining students and teachers both, happen to be built of the same intellectual bricks as Skinner's teaching machines. In fact, I'd go so far as to claim that, to the extent that traditional classrooms today successfully help their students develop deep, contextualized, activated knowledge, it's due mainly to the skill of teachers working *despite* the limits imposed on their medium—many of which can be traced straight back to Skinner's intellectual godfather, E. L. Thorndike.

What's so striking, looking back, is how at the very same time that Thorndike and his allies began pursuing the research thread that would undergird and justify the form mass education took in the twentieth century, a separate research thrust, built on a wildly different scientific ethos, offered an alternate path—one far closer in spirit, as it turns out, to Course 2.007. In fact, although the story of education at the turn of the twentieth century features enough characters to rival the greatest hits of Russian realist fiction, the story of the science *behind* the education is a much tighter narrative, boiling down mainly to a contest between two figures in the nascent field of educational psychology. It did not end in a draw. As the education historian Ellen Condliffe Lagemann has written, "I have often argued to students, only in part to be perverse, that one cannot understand the history of education in the United States during the twentieth century unless one realizes that Edward L. Thorndike won and John Dewey lost."

Although the more obvious set of battle lines that formed between the two scholars concerned educational practice, their higher-level disagreement on how to conduct and apply science itself will hold the greater significance for our journey in the pages ahead. If we ever hope to usher in a vision of education at scale that is not reductive but rather *expansive*—closer to 2.007 than teaching machines—we must first plumb the scientific divide that separated Dewey and Thorndike.



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