25. Although there is lots of contradictory evidence on whether this is the case right now, some early signs indicate that schools will adjust. One major independent study was released in June 2007 that suggested test scores were up since No Child Left Behind went into effect. See Amit R. Paley, "Scores Up Since 'No Child' Was Signed," *Washington Post*, June 6, 2007, p. A01.

A significant book that had not been published at the time we were writing *Disrupting Class* notes that a strongly deleterious impact of the No Child Left Behind legislation is that schools, more than ever, are "teaching to the test," rather than teaching critical skills. We recommend this book. See Tony Wagner, *The Global Achievement Gap* (New York: Basic Books, 2008).

From Disrupting Class: How Disruptive Innovation Will Change the Way the World Learns by Clayton M. Christensen, 2008.

Chapter 3

Crammed Classroom Computers

Maria and her friends rise in the stands to cheer as Rob knocks the ball behind the opposing team's goaltender.

"Goaaaaaaaalllllllllllllllllll!" they yell as they clap and hug each other. The team is destined for at least another boys' soccer county championship as long as Rob can remain academically eligible, and, lately, Maria's been pretty optimistic about that.

After the game, Rob and Maria walk home together. They have another chemistry assignment tonight, but Rob is confident about this one: all they have to do is use Microsoft Excel to make a graph of some data. Then, for extra credit, they can write short papers about chemists by using the Internet for research. Then they will present the papers in small groups.

"Cake," Rob says to Maria, still jubilant with victory. She agrees, and they part at the corner of his street and hers.

Later that evening, she is finishing up the extra-credit portion of the assignment when her mother comes into the study where Maria does her homework.

"Whatcha doin', kiddo?" her mother asks.

"Biography of Marie Curie," Maria says absently as she types her citations.

"Really? I did that for Mr. Alvera when I had him," her mother says. "Your grandmother called Uncle Dan, and I grabbed the encyclopedia. We felt so smart."

Maria looks up at that, but her mother has already gone into the kitchen. It figures that even though she was practically born playing computer games, she's still doing the same assignments her mother did 20-some-odd years ago, when Mr. Alvera was a rookie teacher. Maybe college will be better?

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Despite the widespread presence of computers, Maria's school experience isn't too much different from her mother's experience a little over two decades earlier. Whereas her mother did the research through reference books, Maria now does it online; and whereas her mother typed out her project on a typewriter, Maria types it using a word processor. Why haven't computers brought about a transformation in schools the way they have in other areas of life?

In 1996, President Bill Clinton announced a transformative vision for computing in schools. He called for: (1) modern computers and learning devices available to all students, (2) classrooms connected to one another and the outside world, (3) making educational software an integral part of the curriculum and as engaging as the best video game, and (4) having teachers ready to use and teach with technology.[1]

Personal computers have been around for three decades. Schools are well populated with them—largely fulfilling the first two of President Clinton's mandates. But the second two are as distant as ever. Classrooms look largely the same as they did before the personal computer revolution, and the teaching and learning processes are similar to what they were in the days before computers. As we say in the Introduction, the billions schools have spent on computers have had little effect on how teachers teach and students learn—save possibly to increase costs and draw resources away from other school

priorities. They haven't brought schools any closer to realizing the promising path of building students' intrinsic motivation through student-centric learning.

The reason for this disappointing result is that the way schools have employed computers has been perfectly predictable, perfectly logical—and perfectly wrong. As we show in this chapter, schools have crammed them into classrooms to sustain and marginally improve the way they already teach and run their schools, just as most organizations do when they attempt to implement innovations, including computers. Using computers this way will never allow schools to migrate to a student-centric classroom. If school administrators will change course, however, and first implement computer-based learning in places and for courses where there are no teachers to teach, then computer-based learning will, step by step, disrupt the *instructional* job that teachers are doing in a positive way, by helping students learn in ways that their brains are wired to learn *and* by allowing teachers to give students much more individual attention.

❖ DEPLOYING DISRUPTIVE INNOVATIONS AGAINST NONCONSUMPTION

Recall from the last chapter how Apple disrupted Digital Equipment Corporation (DEC) and the minicomputer companies. When Apple introduced its personal computer, it created a completely new market for computing by selling its model Apple IIe as a *toy* for *children*. Apple didn't attack the existing markets where minicomputers already were being used, nor did it frame its main competition as being DEC. Because it targeted applications where in the past computers had been too expensive and complicated to be used, Apple didn't need to make better computers than DEC to delight its customers. All it had to do was make a product that was better than the customers' other alternative, which was no computer at all.

Had Apple tried to cram its personal computer into the existing market by framing it as a sustaining innovation in the original plane of competition, DEC would have crushed Apple and its personal computer, whose performance was not even close to that of DEC's machines. Any effort to emulate DEC's minicomputer capability at the outset within the desktop computer architecture would have cost billions of dollars over many years, and even then it would have been unlikely to take root. To succeed, disruptive technologies *must* be applied in applications where the alternative is nothing. Indeed, selecting these applications is far more important for the successful implementation of the technology than is the technology itself.

❖ TECHNOLOGY IMPLEMENTATION AND THE LEGISLATIVE PROCESS

In every organization there are forces that shape and morph every new innovative proposal so that it fits the existing organization's own business model, rather than fitting the market it was intended to serve. One way to understand these forces is to visualize how the legislative process works. A congresswoman sees a pressing societal problem and envisions an innovative solution. She drafts the enabling legislation and introduces the bill. Within a few weeks, the labor unions inform her that unless she modifies the legislation to address their concerns, they'll block it. She changes her bill to win their support. A short time later the Chamber of Commerce announces its opposition to the bill unless it is modified in certain ways, so she amends her proposal to address their concerns. Then she learns that a powerful senator from Texas won't support it unless she adds special considerations favorable to Texas, and so on. To win the support needed for Congress to enact the proposed legislation into law, the congresswoman shapes the bill to fit the interests of those with powerful votes; as a result, what comes out at the end of the legislative process looks *very* different from what went into it.

The same forces are at work in every company. Companies shape every innovative idea to fit the interests of the groups in

the company that must support the proposal in order for it to receive funding. Innovative ideas never pop out of the innovators' heads as full-fledged business plans. Rather, they are fragments of a plan. As the innovator tries to sell the idea to the powerful entities in the company, he runs into a set of hurdles that are frightfully comparable to those the congresswoman encountered. He realizes that the sales force won't support his idea unless he adapts the innovation to appeal to the customers with whom the sales force already has relationships. Then he learns that unless he changes his estimates for pricing and gross margins, the finance department will veto the idea; and the head of engineering warns that unless he agrees to reuse certain components from earlier product designs, the engineering department will oppose it; and so on. To win the support of all the powerful entities within the organization whose endorsement is critical to getting the innovation funded, the innovative idea morphs into a concept that fits the business model of the organization, rather than the market for which the innovator originally envisioned it.

In the language of disruption, here is what this means: unless top managers actively manage this process, their organization will shape every disruptive innovation into a *sustaining* innovation—one that fits the processes, values, and economic model of the existing business—because organizations *cannot* naturally disrupt themselves. This is a core reason why incumbent firms are at a disadvantage relative to entrant companies when disruptive innovations emerge. And it explains why computers haven't changed schools.

Histories of Nypro, an injection molding firm; Merrill Lynch, an investment management company; and RCA, an electronics firm, illustrate this problem and show how a manager can solve it. We've picked illustrations from such diverse industries to show how pervasive the challenge of deploying disruptive technologies to compete against nonconsumption is. Schools, in other words, are not unique in how they have implemented computer-based learning.

Nypro's Novaplast Machine

Nypro, Inc., is one of the world's top precision-injection molders of plastics. The business model that leads to Nypro's success focuses on producing parts for its customers' products in volumes numbering in the millions, to tolerances as precise as plus-or-minus 2 microns. Nypro's plants span the globe. Each operates as a profit center. Through multiple mechanisms, Nypro's CEO, Gordon Lankton, has created a system of ranking the plants' financial performances against each other. This motivates plant managers to adopt any process innovation that helps them achieve the best financial performance among Nypro's plants.

In the mid-1990s, Lankton saw fundamental changes coming in his market. He saw it shifting away from customers needing millions of units per product and moving toward customers demanding a broader variety of parts with much shorter run lengths and much faster turnaround. To respond to this shift, Lankton initiated development of a small, radically disruptive molding machine dubbed the "Novaplast." The Novaplast could mold parts to the same degree of precision as the huge, inflexible machines Nypro historically had used. But engineers could set up the Novaplast to run new parts in a few minutes instead of a few hours. And the molds it used were much simpler and cheaper to make because molding pressures were low. These innovations were critical to help Nypro compete in the emerging market for fast, customized variety.

Consistent with his established practice of allowing his plant managers autonomy to adopt those innovations they thought would help them compete more profitably in their markets, Lankton offered each plant the opportunity to lease, rather than buy, Novaplast machines from corporate headquarters. Most of his plant managers agreed to lease the machine because the technology was exciting and seemed disruptive. To Lankton's dismay, however, all but two of the plants returned their Novaplast machines to corporate headquarters as soon as the terms of the lease allowed it. The reason? The plant managers uniformly responded that there was no market for fast, customized variety.

Only two plants kept their Novaplast machines. Both, it turned out, were producing thin-walled plastic liners that fit inside the casings of AA batteries that one of Nypro's biggest customers made. This liner had to be manufactured to *very* tight tolerances in high volumes. For a host of reasons, the part ran better on the Novaplast machine than on the company's traditional machines.

What was going on? The votes in Nypro's "legislative" process were clear. Novaplast didn't fit the business model of the plants, so the plant managers rejected it. Nypro's plants were wedded to a process whose economics mandated production of huge volumes of a few products. This was critical to keeping overhead costs low. Likewise, the salespeople for each plant made much higher sales commissions on high-volume products. Low-volume products were simply antithetical to Nypro's plants' formula for making money. Novaplast was, in other words, a disruptive innovation relative to the business model of these plants—and an organization cannot disrupt itself. It cannot implement an innovation that does not make economic or cultural sense to itself. The plants that were able to put Novaplast to productive use implemented it as a sustaining technology. It helped them produce a standard high-volume part even more profitably than before.

For Nypro to address the market Lankton had seen (which history now confirms he saw with farsighted acuity), he would have had to implement Novaplast in factories whose process economics were tuned to the market for fast, customized variety. And this plant would have required a sales force whose compensation system rewarded, rather than penalized, the pursuit of such business. While Nypro's existing plants could not have done this, had Lankton set up a new, independent plant complete with its own sales force, Nypro could have implemented the Novaplast disruptively.

Merrill Lynch, Charles Schwab, and Online Brokerage

In the late 1990s, firms such as E-Trade and Ameritrade began disrupting the stock brokerage market with online trading. In the language of our research, these firms led a new-market disruption that enabled a much larger population of people to manage their own diversified portfolio of stocks. Two of the incumbent firms, Charles Schwab and Merrill Lynch, announced their intention to counter the disruptive attack by initiating online trading as well.

Schwab created a separate business unit to conduct online trading and made a masterful transition to the computer-centric investment management world—ultimately phasing out its original broker-based business unit. How? To make money at heavily discounted prices per trade, the new unit operated at much higher trading volumes and significantly lower costs than those characterizing the traditional business.

Merrill Lynch also implemented an online trading system for its clients. But rather than creating a distinct business unit whose economics were appropriate for the opportunity, it instead chose to attempt building an online trading business within its core broker-centric business. The result? Like the Novaplast machine in Nypro's two plants, Merrill Lynch implemented its online system in a way that helps its well-compensated brokers get better information faster so that they can do a better job serving the needs of their high net-worth clients. The system had the same disruptive potential as did the E-Trade, Ameritrade, and Schwab systems. But because Merrill Lynch's core business unit implemented it, Merrill used it in a way that sustained the current business. The technology didn't transform anything—and we could expect nothing else. An organization simply cannot disrupt itself. But as the Schwab example shows, a manager who sits one level up from the organization she wants to disrupt can set up a new organization with different resources, processes, and priorities and successfully disrupt the old, internal organization. Merrill Lynch could have done the same, just as Lankton and Nypro could have.

The Impact of Transistors on RCA and Sony

In almost every case, when disruptive innovations emerge, the industry leaders *see* the disruptive change coming. The personal computer was not news to DEC; Nypro's Lankton saw the burgeoning market for fast, customized variety; and Merrill Lynch could see online trading. But their instinct was to utilize their existing business infrastructure and sell the disruptive products to their existing customers. We call this phenomenon "cramming." The reason why the established industry leaders instinctively cram disruptive technologies into the established market is that they need to serve their existing customers. Furthermore, these are big companies, with big needs to grow even bigger. Disruptive markets are by definition small at the outset because disruptive products compete against nonconsumption. Within established companies, the firm's "legislative" system, or resource allocation process, shapes every proposal to serve the existing customers better and thereby generate substantial growth—even if the proposal is more suitable for a disruptive approach.

Cramming what should be a disruptive innovation into an existing marketplace is fraught with expense and disappointment because new disruptive technologies never perform as well as does the established approach in its own market. When companies cram disruptions into head-on competition against the existing approach, it costs extraordinary sums as the leaders incessantly work to improve the technology. At the same time, entrant firms are exploiting the technology in new markets where the alternative is nothing at all. To see how and why this happens, we recount a third case history, in which we chronicle the way Sony disrupted the Radio Corporation of America (RCA).

In 1947, scientists at AT&T's Bell Laboratories invented the transistor, the technological building block of what became known as *solid-state electronics*. Transistors were disruptive relative to vacuum tubes, the established technology at the time, because while they enabled smaller, less power-hungry devices, transistors could not handle the power that the electronic products of that age—tabletop radios, floor-standing televisions, and early digital computers—required. All the vacuum tube companies like RCA saw the transistor coming and licensed it. They then framed solid-state electronics as a technological challenge because the transistor could not handle the power required to build big televisions and radios. Adjusted for today's dollars, they spent upwards of $1 billion in research and development trying to make the transistor work in the market as it existed at that time.

While RCA's engineers were in their labs working to improve the technology, the first commercial application of the transistor appeared in 1952. It was a little hearing aid, where the transistor's lower power consumption was highly valued. A few years later, in 1955, Sony introduced the first battery-powered, pocket transistor radio. In comparison with the big RCA tabletop radios, the Sony pocket radio was tinny and static-laced. But Sony chose to sell its transistor radio to nonconsumers—teenagers who could not afford a big tabletop radio. It allowed teenagers to listen to music out of earshot of their parents because it was portable. And although the reception and fidelity weren't great, it was far better than their alternative, which was no radio at all. The pocket radio was a big hit for them.

While it made a profit on this simple beachhead application, Sony continued to improve the technology. In 1959, Sony introduced its first portable television using the transistor. Again, Sony's TV won a welcome market reception because it competed against nonconsumption. Sony's transistor enabled a whole new population of people, whose bank accounts and apartments had been too small, to afford a TV. By the late 1960s, solid-state electronics had improved to the point where the transistor could handle the power required to make larger products, and, just as happened to DEC a few decades later, all the vacuum-tube companies, including RCA, vaporized.

This is a punishing but predictable tale. The only way RCA's customers could have used transistors was if solid-state

electronics were more cost- and performance-effective in the markets that RCA served. In the 1950s and early 1960s, this was a *very* difficult technological hurdle for RCA to surmount. But because Sony deployed the transistor against nonconsumption, all it had to do was make a product that was better than nothing. And that presented a *far* less ambitious technological hurdle at the outset.

CRAMMING COMPUTERS IN SCHOOLS

So what do these three cases of attempting to cram disruptive technologies into mainstream markets have to do with how public schools have dealt with computers? The parallels are everywhere. Just as RCA saw the transistor coming, educators have seen computers reinvent many other professions. As a result, they have invested *heavily* in computers. In 1981, there was one computer for every 125 students in schools. By 1991 there was one for every 18; and in 2000, there was one for every five students. Many schools now have a laptop for every child; and if a $100 laptop becomes a reality, they will likely be everywhere. Over the last couple of decades, schools have spent well over $60 billion in equipping classrooms with computers.[2]

Despite these investments, students report using the computers sparsely in their schools. Fifth graders report using computers 24 minutes a week in class and in computer labs. Eighth graders report using computers an average of 38 minutes a week. Because many high schools have begun offering courses in how to use computers and in vocational classes that relate strongly to computers, older students use them more than those in the younger grades. But even then, schools use computers as a tool and a topic, not as a primary instructional mechanism that helps students learn in ways that are customized to their type of intelligence.[3]

Larry Cuban, who has conducted highly regarded studies on this topic, reports that in early-grade elementary school classrooms, computers serve to sustain the traditional early childhood school model. Computers have become just another activity center for children that they can opt to use in the course of the day. At the computer, they can play such games as "Franklin Learns Math" or "Math Rabbit." While these games are popular with the children, they do not supplant traditional teaching; instead, teachers use them to supplement and reinforce the existing teaching model. As such, computers add cost while failing to revolutionize the classroom experience.[4]

In middle and high school core academic classes in particular, students report that computers have had little to no impact on the way they learn. Teachers still deliver the instruction. Students use computers primarily for word processing, to search the Internet for research papers, and to play games. A small number of middle school teachers—under 20 percent—reported using computers for drill-and-practice software or for math games and the like. High school teachers report having made good use of computers to make better lesson plans and to communicate more with parents through e-mail and blogs. But again, as Cuban concluded, "In the end, both supporters and critics of school technology (including researchers) have claimed that powerful software and hardware often get used in limited ways to simply maintain rather than transform prevailing instructional practices."[5]

Some argue that even where education technology *has* been used, the results have been no better than teacher-based instruction.[6] One might conclude from this that the software just isn't good enough yet, which then implies that if school leaders, software companies and educators just keep working on the technology with a few billion dollars more, the impact will materialize.

We don't think so. To see why, consider the case of Jaime Escalante. Escalante began teaching math at Los Angeles' Garfield High School in the late 1970s. In a school where drugs, gangs, and violence were daily realities, against all conventional wisdom Escalante offered Advanced Placement (AP) Calculus to a few students in 1982. At the end of the year all

these students passed the AP exam. The Educational Testing Service (ETS), which administers the AP exams, thought they must have cheated. It was simply implausible that 100 percent of the students from the class in Garfield High would pass AP Calculus. The students retook the exam and passed again. It was a testament to the students, but also to Escalante and his ability to teach and motivate. By 1991, when Escalante left the school, 570 Garfield High students were taking AP exams.

Escalante was an exceptional teacher. Why not capture Escalante's instructional magic on film and make it available to schools anywhere? Sure, it's not the same as having Escalante there himself (nor are we arguing that this would offer the potential of customizing an education through the power of computer-based learning), but if he is that good, why narrow his impact to one classroom in one school? People have in fact done this with great teachers of Escalante's caliber. But these sorts of films have had little impact because they were simply crammed into classrooms as a tool on top of the traditional teaching methods.[7] Not surprisingly, never has a calculus teacher announced to the class, "Kids, today is a great day. We have these films of a teacher in Los Angeles, and you just need a technician to run the projector. You don't need me any more."

The sum of these assessments is that traditional instructional practices have changed little despite the introduction of computers and other modern technologies. A class does not look all that different from the way it did a couple of decades earlier, with the exception that banks of computers line the walls of many classrooms. Lecturing, group discussions, small-group assignments and projects, and the occasional video or overhead are still the norms. Computers have not increased student-centered learning and project-based teaching practices. The implementation of computers has not caused any measurable improvements in achievement scores.[8] And, most importantly for the purposes of this book, computers have made almost no dent in the most important challenge that they have the potential to crack: allowing students to learn in ways that correspond with how their brains are wired to learn, thereby migrating to a student-centric classroom.

Understanding how schools have spent so much money on computers only to achieve such little gain isn't so hard. Schools have crammed the computers into the existing teaching and classroom models. Teachers have implemented computers in the most common-sense way—to sustain their existing practices and pedagogies rather than to displace them.

So how could schools implement computer-based learning in ways that transform teaching and learning? We illustrate how by first recounting the phonograph's commercialization—and then its ultimate disruption of live music.

HOW TO IMPLEMENT COMPUTER-BASED LEARNING: LESSONS FROM RACHMANINOFF

Through the 1870s, people had few options for listening to music. They either had to provide the music themselves or arrange for a local musician to play. People were of course limited by their particular repertoire and skill. Rarely could you hear the music you wanted to hear where and when you wanted to hear it—and most of the time you couldn't hear music at all.

Thomas Edison began to change all this when he invented the phonograph in 1877. Suddenly you could hear music in places other than those where it originated. And you could now hear more than just the local instrumentalists. As people recorded the great musicians like Rachmaninoff, you could hear the best musicians' brilliance right in your living room. But imagine what would have happened if RCA Victor, which pioneered the ability to record music with Edison's technology, had made a recording of Rachmaninoff playing his second piano concerto and then sold tickets to a concert in Carnegie Hall where people could listen to Rachmaninoff—but instead of the real person playing the music with a live orchestra, the

concert's promoters had rolled a Victrola phonograph onto the stage and played the recording into a microphone. The same people who would have been delighted with the quality of the recording when they were listening at home in Poughkeepsie, New York—where it was infinitely better than nothing—would have been deeply disappointed when the recording was pitted in head-on competition, against the real people in the real place.

Fortunately for the recording industry, RCA Victor didn't attempt the Carnegie Hall stunt. It instead sold its phonographs and recordings to people who couldn't go to Carnegie Hall, and its customers could play them whenever and wherever they wanted to hear music. It took about a century for the technology to become good enough that listening to the recording was nearly as good as hearing the music live. Today, nearly everyone, from the casual music listener to music connoisseurs, hear the majority of their music through recordings, not live.

Imagine the outcome if the early recording industry had marketed its products to be played after the intermission during live symphony concerts to allow the performers to go home early. Or what if it decided it couldn't commercialize Edison's technology at all, and kept working on it in laboratories until it was quality-competitive with the best live musicians? The industry would have spent billions and achieved little. Success with disruptive innovations always originates at the simplest end of the market, typically competing against nonconsumption. Then, from that base, the technology gets better and better until, ultimately, it performs well enough that it supplants the prior approach.

If the recordings of Rachmaninoff found a welcome market by *not* competing directly with the live musician himself, why should people pit the recordings of teachers like Escalante in direct competition with teachers? Just as no one would pay to go to Carnegie Hall to listen to a phonograph recording, we should not expect teachers today to use a recording of Escalante to teach when they can use their own skills. The technology childhood school model. Computers have become just another activity center for children that they can opt to use in the course of the day. At the computer, they can play such games as "Franklin Learns Math" or "Math Rabbit." While these games are popular with the children, they do not supplant traditional teaching; instead, teachers use them to supplement and reinforce the existing teaching model. As such, computers add cost while failing to revolutionize the classroom experience.[4]

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Some argue that even where education technology *has* been used, the results have been no better than teacher-based instruction.[6] One might conclude from this that the software just isn't good enough yet, which then implies that if school leaders, software companies and educators just keep working on the technology with a few billion dollars more, the impact will materialize.

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It's not just the recording industry and the Sony pocket radio. Virtually *every* successful disruptive innovation took root similarly—competing against nonconsumption—so that people were delighted to have a product, even if its capacities were limited. Cisco's router, with its 4-second latency delay, couldn't be used to switch voice calls at the outset. So it was used to transmit data over the Internet. But today, Cisco products route phone calls over the Internet through VoIP (Voice-Over-Internet Protocol) with aplomb. IBM and Kodak attacked Xerox's high-speed photocopiers head-on in the 1980s, got bloodied, and withdrew. But Canon attacked nonconsumption first by deploying small table-top copiers in locations and in small companies where a high-speed Xerox machine wasn't economical. Once in that market, Canon improved its copiers one step at a time until most companies no longer needed costly Xerox machines in their high-speed photocopy centers. Google and craigslist are disrupting advertisements in newspapers in the same manner. And on and on.

In the next chapter we discuss how school districts can actively deploy computer-based learning in schools in a disruptive, rather than cramming, mode. By migrating instruction delivery to custom-configured vehicles able to meet individual students' needs, schools can realize the dream of transforming the classroom from a monolithic one into a student-centric one where all students can learn in the ways their individual minds are wired to learn.

NOTES

1. U.S. Department of Education, *Getting America's Students Ready for the Twenty-First Century: Meeting the Technology Literacy Challenge* (Washington, DC: June 1996) quoted in Larry Cuban, *Oversold & Underused: Computers in the Classroom* (Cambridge, Massachusetts: Harvard University, 2001), p. 16.

2. These numbers come from a variety of sources in which the authors did their own calculations. In particular, see Evan Hansen, "Public Schools: Why Johnny Can't Blog," CNET News.com, November 12, 2003, http://news.com.com/2009-1023-5103805.html. The article cites statistics from Quality Education Data. See Cuban, p. 17. And see *America's Digital Schools* (The Greaves Group and The Hayes Connection, 2006).
3. Cuban, pp. 72 and 90.

   A Department of Education report gives further evidence of how education technology is used mostly to support instruction and as a tool rather than to deliver the instruction itself. *Effectiveness of Reading and Mathematics Software Products: Findings from First Student Cohort*, report to Congress, U.S. Department of Education (National Center for Education Evaluation and Regional Assistance, March 2007), p. xiv.
4. Cuban, pp. 52–67. Also, because of their activity-center structure, K-4 classes tend to be more student-centric, so the lack of transformation is arguably not as big a deal as perhaps it is in the later grades. It is also important to develop many different intelligences and learning styles for children at this younger age, according to Howard Gardner and others.
5. Cuban, pp. 72–73, 90–91, 95, and 133–134. Even though Cuban's studies were published in 2001, not much has changed in the seven years since. Our own observations traveling to schools around the country confirm his observations, as do interviews and a specific case study of the Arlington, Massachusetts, school district that Josh Friedman conducted for a Harvard Business School independent study report for Clayton Christensen in the 2007 winter semester.
6. *Effectiveness of Reading and Mathematics Software*, p. xiii.
7. Cuban has also done research on how other technologies have been implemented in the past. In the 1950s, instructional television was hailed as the answer to a looming teacher shortage; but by and large this, as well as instructional films, first developed in the early part of the twentieth century, have sustained existing practices and been used to give teachers breaks, for example, rather than to overturn how instruction was delivered in schools. Cuban, pp. 137–138.

   In an example of video-taped lectures having an impact, BAR/BRI, the standard for bar exam studying, creates videos of professors to accomplish this teaching purpose for students studying for the bar exam. For example, a group of students can study for the New York Bar Exam in Toronto and receive the best instruction possible. They assemble daily and pop in a BAR/BRI video that has a different professor lecturing on a different bar exam topic each day.
8. Cuban, pp. 90–91, 95, 133–134, and 178.

   A *New York Times* story followed up on a U.S. Department of Education report about the effectiveness of computer-based learning with a story on the Liverpool, New York, school district giving up on laptops. In the article, it references Mark Warschauer, an education professor at the University of California at Irvine and author of *Laptops and Literacy: Learning in the Wireless Classroom* (New York: Teachers College Press, 2006). Warschauer also found no correlation between the use of laptops and test scores, but he also said, "Where laptops and Internet use make a difference are in innovation, creativity, autonomy and independent research." Winnie Hu, "Seeing No Progress, Some Schools Drop Laptops," *New York Times*, May 4, 2007, http://www.nytimes.com/2007/05/04/education/04laptop.html.

Chapter 4

Disruptively Deploying Computers

The next day, as Maria files into the guidance counselor's office to register for next semester, she really, really hopes that college will be better than this. Prompted by interests in religion and international security, she's been reading about the growing importance of Arabic and its popularity as a subject of study in the United States. Dr. Allston had told her that there was an outside chance that there would be a class at Randall next term, but now, flipping through the offerings in the guidance office's booklet, Maria sees that she won't have the option. She frowns at the booklet when it's her turn to talk to the counselor. Instead of registering for class, she makes an appointment to meet with Allston to see if she can get the principal's special permission to attend an Arabic class at the local university.

But the appointment is unnecessary. Allston wanders in the doorway of the guidance office.

"This young lady just made an appointment to see you," says Rachel Hudson, the guidance counselor.

"There's no Arabic," Maria says in response to the principal's raised brow. "I thought I could go to Randall University."

Oddly, Allston's face lights up. "There wasn't enough demand," she says. "But we came up with another way for you to do it. Why don't you just come into my office?"

Maria pads down the hall toward the principal's office. She's already grumpy at the idea of a commute to the local university, but she wants to study Arabic now—not two years from now. The principal gestures at a chair in front of her desk, and Maria plops down. Allston, still standing, rifles through a pile of mail on her desk.

"Aha," she beams. "Here."

She hands an envelope to Maria.

"This is the pilot program of a state-accredited Arabic class, offered only online. You can take it with all the other kids in the county who are interested in Arabic. Just go down the hall to the computer lab in the library, go to the Web site referenced in the packet, and follow the directions."

"Wow, that simple?" asks Maria, amazed.

"Yep, that simple," Allston says. "Your own pace, your own schedule. The program will even customize for how fast you learn. A live teacher would have been great, but you're the only one here who wants to take the course. There are two kids at Spencer Circle, and three at Matthew Key—together, you're enough for the district to try this. I'm hoping to offer Japanese next year, if those of you taking Arabic do well."

Maria offers a hasty thanks, and then she's on her way to the library.

■ ■ ■

Up until this point in time, student-centric technology in the form of computers hasn't had much impact on mainstream public education. But as is the case with all successful disruptions, if you know where to look—competing against nonconsumption—computer-based learning is methodically gaining ground as students, educators, and families find it to be better than the alternative—having nothing at all. Despite skepticism and pessimism from many that the lack of an open market means that schools would not implement this computer-based technology in disruptive fashion, things are

changing. Public education enrollments in online classes like the one for which Maria signed up are exhibiting the classic signs of disruption as they have skyrocketed from 45,000 in 2000 to roughly 1 million today.

How has this happened? At first glance there is little nonconsumption in U.S. schooling, and one therefore might expect to see the disruption occurring only in developing countries where education is not universal; after all, children are required to attend school in the United States. On the contrary, looking at the class level within U.S. schools reveals many areas of nonconsumption where computer-based solutions can take root. Some of the opportunities where the alternative is nothing at all include: Advanced Placement (AP) and other specialized courses; small, rural, and urban schools that are unable to offer breadth; "credit recovery" for students who must retake courses in order to graduate; home-schooled students and those who can't keep up with the schedule of regular school; students needing special tutoring, and prekindergartners.[1] Computer-based learning has already planted itself in these foothold markets. It is gaining "market share" at a predictable pace. Like all disruptions, it first appears as a blip on the radar, and then, seemingly out of nowhere, the mainstream rapidly adopts it.

If the history of these types of innovations can serve as a guide, the disruptive transition from teacher-delivered to software-delivered instruction is likely to proceed in two stages. We call the first of these stages *computer-based learning*. In this stage, the software will be proprietary and relatively expensive to develop; and it will be monolithic, with respect to students' types of intelligence and learning styles. The instructional methods in this software will largely mirror the dominant type of intelligence, or learning style, in each subject. Computer-based learning is not as completely monolithic as the teacher-delivered mode is, however. Today's software accommodates different paces of learning, and some allows students to choose different pathways to learning the material.

The second phase of this disruption we term *student-centric technology*, in which software has been developed that can help students learn each subject in a manner that is consistent with their type of intelligence and learning style. Whereas computer-based learning is disruptive relative to the monolithic mode of teacher-led instruction, student-centric technology is disruptive relative to personal tutors. Tutors today are largely limited to the wealthy; and for those privileged few, good tutors come as close as possible to helping students learn each subject in ways that match the way their brains are wired to learn. Like all disruptions, student-centric technology will make it affordable, convenient, and simple for many more students to learn in ways that are customized for them.

NEW-MARKET DISRUPTIONS TAKE ROOT

Let's explore just a few of the most significant areas of nonconsumption in which these computer-based courses are taking root. One of these is AP classes—college-level courses offered to high school students. There is vast nonconsumption of AP courses in most high schools. Thirty-three percent of schools nationwide offered no AP classes in 2002–2003.[2] Those that provide AP courses offer only a fraction of the 34 courses for which AP exams are available, because there is inadequate demand and resources to hire more AP teachers. More generally, many schools are unable to offer courses for gifted students or the appropriate enrichment classes for special-needs children. Students who want or need to take these courses currently have no option in many schools.

Some schools have more difficulty offering this sort of breadth than do others. For example, bigger schools have more teachers, resources, and students, which result in more supply and demand for a wide range of courses; smaller schools have less of all three, which means they have more problems offering this breadth. Rural schools tend to be smaller, so this disproportionately affects them. And even those rural schools that

are larger and have more funding available for more teachers often find that they cannot recruit qualified faculty to the needed locations. Under No Child Left Behind's regulations requiring districts to have only "highly qualified" teachers for each subject, compliance may further limit the offerings. For example, in a small town, a teacher trained in physics, but who formerly taught biology and chemistry as well, may no longer be allowed to teach anything except physics. The school might have to cut the other two classes entirely, even if they are state-required courses, because finding or hiring a new teacher or two is not easy to do or to afford. Smaller schools are therefore often the perfect places for computer-based learning to take root.

Urban secondary schools, especially in low-income areas, are a third ideal market for computer-based learning. Some of these schools are as resource-constrained as the rural schools are, and many struggle to find highly qualified teachers who are committed to working in such challenging environments. As society has raised the stakes on testing in the core subjects, as we discuss later, schools have responded by allotting proportionately more resources and attention for these tested subjects. A casualty of this resource allocation has been many of the "nice-to-have" courses—in the humanities, languages, arts, economics, statistics, and so on. Diminishing supply in such courses means growing nonconsumption in these areas. In an odd way, this is good news actually. Computer-based learning is a welcome solution when the alternative is to forgo learning the subject altogether.

Homebound and home-schooled students are another ideal market application for computer-based learning. Homebound students are those who cannot go to school for a variety of reasons, from those who have been suspended, to severely ill students, to students who cannot attend school for the full day because of other commitments. The home-schooled population presents a similar ideal market, and it is growing rapidly. According to the U.S. Department of Education, in the spring of 1999 there were 850,000 home-schooled students in the United States. Some home-schooling research groups estimate that the number of home-schooled students now has surpassed 2 million.[3] In the past, both home-schooling advocates and critics have expressed concern that the range of subjects and the depth of learning available to these students were limited by their parents' own knowledge. The online world solves this problem. This is a classic foothold market for disrupting traditional schools; and the advent of this computer capability has fueled, in part, the recent spurt in home schooling.

Another big nonconsumption opportunity is students who need to make up credits. There is a large block of students in this group, as the credit recovery problems plague students from the rural Midwest to many urban school districts.[4] For a variety of reasons, there is not always a remedial class available for students who fail a course. This creates big problems as students move toward their senior year in high school, and this creates a need for an alternative to nothing at all before it is too late. Computer-based learning can fill in the gaps. And its modularity means that students do not have to waste instructional time on concepts they've mastered; they can simply take the modules with which they struggled in order to pass the class—or at the very least breeze through the parts they already understand or that come easily to them.

There is a host of other areas of nonconsumption where student-centric online technology can make a big impact. Private tutoring and prekindergarten offer big zones of nonconsumption. For example, 43 percent of children ages 3 to 5 do not enroll in any prekindergarten program—this includes day-care centers, Head Start programs, preschool, and so forth. Children from wealthier families attend these programs more than do those from poor families. As we increasingly recognize the importance of early childhood development's impact on future learning, a movement is growing to universalize prekindergarten. Student-centric technology has a revolutionary opportunity here. We address these specific areas in

Chapters 5 and 6, as this chapter focuses more on disruptions currently taking place within public high schools.[5]

❖ MEETING THE DEMAND

Together, these venues of nonconsumption constitute a booming market in which school districts can welcome computers as the primary delivery platform for learning—in contrast to the way they are now deployed in mainstream classrooms. Some evidence: Apex Learning, founded by Microsoft cofounder Paul Allen, is a for-profit company. Apex began by developing a product that allows secondary schools to offer more AP courses to more students by placing the courses online. So Apex's strategy was to market courses that schools cannot offer. In 2003–2004, enrollments in Apex AP classes were 8,400; by 2006–2007 that number was 30,200—a compounded annual growth rate of over 50 percent. Apex allows school systems to aggregate the demand for AP courses over an entire school district where there is insufficient demand in individual schools to merit having a dedicated teacher—or where budget cuts have slashed these offerings. Over its history, Apex has had more than 1 million student enrollments[6] and has served over 4,000 school districts. It has expanded well beyond AP courses by offering core classes for secondary schools as well. These often target students needing to make up credits or needing remediation in certain subjects as well as students who are home-schooled. This has fueled Apex's growth.[7]

Apex is far from the only online AP course provider. For example, at UC College Prep, a postsecondary provider of online courses for high schools, AP course enrollments more than doubled, from 797 in 2005–2006 to 1,872 within one year. The state of Florida's virtual school, Florida Virtual School, offered only one AP course in 1997; it now offers 11, and enrollments have doubled in the last two years. At Virginia's virtual school, Virtual Virginia, enrollments have quadrupled in the last two years.[8]

More than twenty-five states have supplementary virtual schools. The aforementioned Florida Virtual School (FLVS) is perhaps the best known of these. Begun in 1997 as a pilot project with two school districts, FLVS has had wide appeal. Under the motto, "any time, any place, any path, any pace," FLVS today offers over ninety courses, which span the traditional staples like algebra and English to the noncore ones like AP and business technology courses. Under this guiding light, FLVS has attracted students who otherwise would be nonconsumers of various classes for a variety of reasons, from not being able to be in school during certain hours to having difficulty completing their full course load. By the 2006–2007 school year, FLVS was serving 52,000 students in 92,000 individual course enrollments—throughout and outside of Florida.[9]

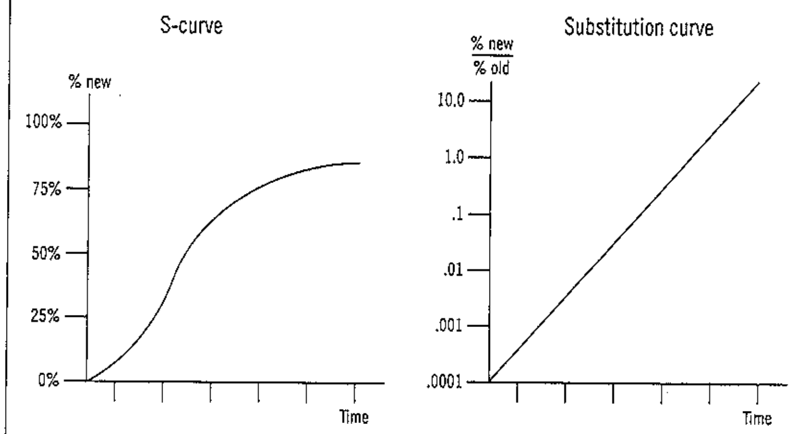
FOLLOWING A DISRUPTIVE PATTERN

All disruptions share a pattern. Disruptions first compete against nonconsumption in a new "plane of competition." In that plane, the technology improves, and the underlying cost declines. The technology begins drawing applications from the original plane of competition into the new one—in this case, from the traditional monolithic classroom to computer-based learning and then, shortly, to student-centric technology.

But this transition is neither abrupt nor immediate. When a new approach or technology substitutes for an old one because it has a technological or economic advantage over the old, the substitution pace almost always follows an S-curve,[10] as depicted on the left side of Figure 4.1. Here the vertical axis measures the percent of the market for which the new approach accounts. The S-curves are sometimes steep; other times they are gradual. But disruptions almost always follow this pattern: the initial substitution pace is slow; then it steepens dramatically; and, finally, it asymptotically approaches 100 percent of the market.

A consistent problem emerges for the industry leaders when one of these substitutions occurs, however. When the nascent

FIGURE 4.1 Patterns by which the new substitutes for the old



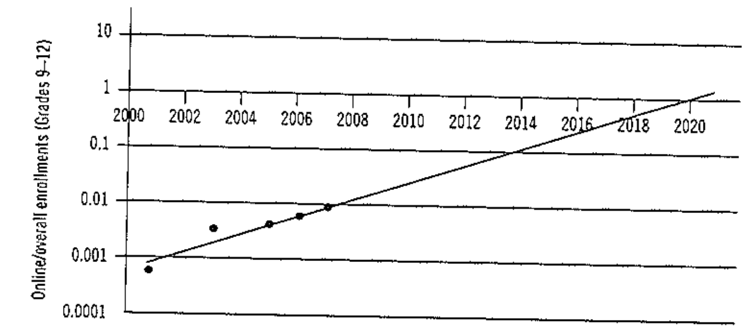
technology accounts only for a tiny fraction of the total market (when it is on the flat part at the bottom of the S-curve), the leaders project linearly into the future and conclude that there is no need to worry about the new approach because it will not be important for a long time. But then the world flips fast on them and cripples the established companies. For example, after a decade of incubation on the curve's flat portion, digital photography flipped on the film companies *very* rapidly. The result? Polaroid is gone. Agfa is gone. Fuji is seriously struggling. Kodak alone caught the wave—but even here it's been a rough ride.[11]

You might think that companies would learn from this experience, but the S-curve adoption pattern does beg a vexing question. If I'm on the initial flat portion of the curve, how can I know whether the world will flip on me next year, in 10 years, or at all?

It turns out there is a way to forecast the flip. First, as shown on the right side of Figure 4.1, one must plot on the vertical axis the *ratio* of market shares held by the new, divided by the old (if each has 50 percent, this ratio will be 1.0). Second, the vertical axis needs to be arrayed on a logarithmic scale—so that .0001, .001, .01, .1, 1.0, and 10.0 are all equidistant. When plotted in this way, the data always fall on a straight line. If the first four or five points do not lie in a line, it is a signal that there is no compelling driver for substitution. But the line is always straight if a disruption is occurring. Sometimes the line slopes upward steeply, and sometimes it is more gradual. The reason the line is straight is that the mathematics "linearizes" the S-curve. When the substitution pace is plotted in this way, one can tell what the slope of the line is even when the new approach accounts for only 2 to 3 percent of the total. That makes it easy to extend the line into the future to get a sense of when the innovation will account for 25 percent, 50 percent, and 90 percent of the total. We call this line a "substitution curve." Whether it's the substitution of 5.25-inch for 8-inch disk drives, VoIP (Voice-Over-Internet Protocol) for circuit-switched telephone calls, or the substitution of women's sportswear for dresses, the slope is so clear within the first few years of the substitution that people can make reasonable estimates for when the innovation will achieve increasing percentages of the market.

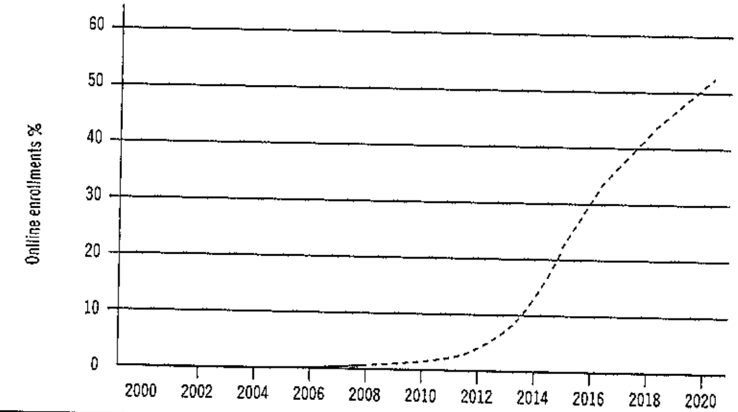
Although the data are hard to aggregate on a consistent basis, Figure 4.2 gives our best sense for the pace of substitution of online-delivered learning for live-teacher instruction. From 45,000 enrollments in fully online or blended-online[12] courses in the fall of 2000, that number had grown nearly 22 times to 1 million by the fall of 2007. Roughly 70 percent of these were for high school students. A significant 43 percent of rural schools already provide students with access to online courses that would not otherwise be available.[13] Even with this rapid growth, however, online courses[14] accounted for just 1 percent of all courses in 2007. Not much change is on the horizon if one projects linearly into the future. But when viewed from the logarithmic perspective, the data suggest that by 2019, about 50 percent of high school courses will be delivered online. In other words, within a few years, after a long period of incubation, the world is likely to begin flipping rapidly to student-centric online technology.

FIGURE 4.2 The pace of substitution of computer-based learning for monolithic learning*



*Calculations are based on data from the North American Council of Online Learning and the U.S. Department of Education statistics. There are other numbers floating out there as well. In June 2007 the Washington, D.C.-based think tank Education Sector released a report titled, "Virtual High Schools and Innovation in Public Education." Written by its chief operating officer, Bill Tucker, it said that roughly 1.5 percent of all school enrollment is online today, but it has doubled in the past three years. The report says that, "Virtual schooling is driving the same sorts of transforming changes in public education as Apple's iTunes has been producing in the way people collect and listen to music." Virtual schools are, "personalizing student learning and extending it beyond the traditional school day." (http://www.educationsector.org/usr_doc/Virtual_Schools.pdf)

The graph when converted to an S-curve will look like the following:



This substitution is happening because of the technological and economic advantages of computer-based learning, compared to the monolithic school model. Online technology provides accessibility for those who previously would not have been able to take the course. It provides convenience for a student to fit the course into his or her schedule at the time and place that is most desirable. To varying degrees, it is simpler because it offers comparatively greater flexibility in the pace and learning path. And when it is software-based, it can scale with ease. Economically, it is often less expensive than the current model, even at today's limited scale. Estimates of the costs vary depending on circumstance, but on average, online courses cost between $200 to $600 per course. At the low end of this range, that is considerably less expensive than the present model; at the high end it is comparable.

Factors That Will Accelerate the Substitution

Four factors will drive the substitution. First, computer-based learning will keep improving, as all successful disruptions do. It will become more enjoyable and take full advantage of the online medium by layering in enhanced video, audio, and interactive elements. Currently, according to reports, computer-based learning works best with the more motivated students; over time, it will become more engaging so as to reach different types of learners. Software developers must also take full advantage of the medium to customize it by layering in different learning paths for different students. Figure 4.2 suggests that the "flip" in the substitution curve will begin in about 2012—just four years from now. In the subsequent six years, the technology's market share will grow from 5 percent to 50 percent. It will become a massive market.

A second driver of this transition will be the ability for students, teachers, and parents to select a learning pathway through each body of material that fits each of the types of learners—the transition from computer-based to student-centric technology.

The third factor that will likely fuel the substitution is a looming teacher shortage. In the past, shortages have been in specific subjects or school types and mostly attributable to the revolving door of teacher turnover. And while many have forecast mass doom-and-gloom teacher shortages before, this is now more likely to happen. The baby-boomer generation of

teachers will start retiring en masse soon, even as the student population, which is the highest it has ever been, will not decline in any proportional way. In 1999, 29 percent of teachers were over 50 years of age. In 2007, it was 42 percent, which suggests that a decade hence there will be a wave of teacher shortages across the country. Unless computer-based learning has been honed in the foothold markets described above, it won't be ready for the mainstream when school districts will need the accessibility that it brings.[15]

The fourth factor is that costs will fall significantly as the market scales up. Different industries have characteristic "scale curves" that allow executives to estimate quite accurately the degree of cost reduction per unit produced each time the scale of the market doubles. In assembled products like automobiles, the downward slope of this scale curve is .85—meaning that each time the quantity produced doubles (from 1 to 2; 2 to 4; 4 to 8; for example), cost per unit declines by 15 percent—to 85 percent of what it used to be. In the semiconductor industry, costs fall by 30 percent at each doubling; and in chemical plants, the scale curve slopes downward at a 40 percent pace of reduction for each doubling of scale.

Developers keep trying to improve their products so that more people will buy them. Improving computer-based learning technologies to become student-centric is likely to be quite expensive. And the costs of managing an organization as its market scales up also are significant. In addition, teachers will always remain in schools, as we note in Chapter 1—increasingly functioning as one-on-one tutors rather than teaching monolithically—and computer-based and student-centric learning will enable a teacher to oversee the work of more students. All of this means that the cost per student per course over the next 10 years is likely to decline by 15 percent for each doubling of volume, so that the cost will be one-third of today's costs, and the courses will be much better.

Local government budget crises will add further fuel to this transition. In 2004, the Government Accounting Standards

Board issued new rules that require public agencies to disclose, starting in 2008, the future costs of all postemployment benefits. The effect will be staggering. The unfunded liabilities for retiree health-care costs have been mounting unnoticed for years because many state and local governments have not made allowances for these liabilities in order to "balance" their budgets. JPMorgan estimates the present value of unfunded government employee health care and other nonpension benefits to be between $600 billion and $1.3 trillion, with the result that many state and local governments could go bankrupt—or at the very least plunge more deeply into debt to meet the costs. As a result, already tight public education budgets, of which state and local governments fund roughly 90 percent, will most certainly face cuts.[16]

The result of these four factors—technological improvements that make learning more engaging; research advances that enable the design of student-centric software appropriate to each type of learner; the looming teacher shortage; and inexorable cost pressures—is that 10 years from the publication of this book, computer-based, student-centric learning will account for 50 percent of the "seat miles" in U.S. secondary schools. Given the current trajectory of substitution, about 80 percent of courses taken in 2024 will have been taught online in a student-centric way. Given how long some have been in the trenches of school reform, this will be quite a breathtaking "flip."

The Sequence of Substitution

Veterans of the battles of school reform with whom we've consulted for this project have been uniformly skeptical about these predictions, primarily because, as evidenced by their battle scars, the teachers unions will not allow it. While not minimizing the self-protective power that these institutions can wield in political processes,[17] if the substitution is managed disruptively, it will happen.

Because most organizations have limits on their resources, they allocate their priority resources to those customers whose

business is most critical to their continued prosperity—or, in the language of disruption, they focus up-market. And they under- or disinvest in those less-profitable products or services whose sales actually pull profit margins down.

The evidence shows that school districts are doing something similar.[18] Recall from Chapter 2 that political or societal importance determines the metric on the vertical axis of the disruption graph in public education. School districts are responding to the scarcity of resources by investing in what they judge to be most important. The overriding concern among school leaders is to improve the test scores in the subjects on which schools will be judged. Schools are doubling up on reading and math at the expense of other subjects. The Center on Education Policy released a survey in March 2005 that showed 71 percent of the nation's school districts are spending more time on math and reading to the exclusion of other subjects.[19] The core subjects on which standardized achievement tests are administered is where priority resources are being focused.

To do this, schools are disinvesting in those "nice-to-have" courses that are less critical to the mandates of improving test scores and leaving no children behind. A darkening budget picture could make this focus on the core even more dramatic. The good news for managing the transition to student-centric learning is that as schools stop teaching certain courses, it creates a vacuum of nonconsumption—the ideal place for student-centric online technology to be deployed. Schools should greet these pressures as opportunities to implement a long-range plan to shift the instructional job to student-centric technology step by step and course by course. Disruptive innovation requires targeting not those courses that the public schools *want* to teach in-house. They must instead focus on courses that the public schools would be relieved *not* to have to teach, but do feel the need to offer. If officials target computer-based courses at the core curriculum, however, it will elicit intense opposition by the teachers unions.

The growth path for computer-based learning providers such as Apex is to figure out how to teach more courses more effectively. As schools face more budget pressures and the need to axe another course that lacks a critical mass of students, computer-based learning providers want to say, "Hey, that previous course you outsourced worked so well. Let us do this one for you, too." The online providers would be motivated to add the very course the school would be motivated to drop. And these courses will keep improving as districts cut more offerings. Through a rational and incremental process, schools would outsource more and more of the instructional job to virtual providers. One day, schools will find themselves using most of their resources to do the noninstructional jobs that *cannot* be done online and find themselves teaching fewer and fewer courses through traditional monolithic instruction.

Officials must not spoil the technology's long-range economic advantage through well-intentioned but flawed funding formulas that penalize per-pupil funding of schools when a student takes an online course. Doing so has been shown to evoke a competitive response to kill the computer-based learning. This has happened in several states when online learning reached into the mainstream in the form of virtual chartered schools, perhaps most notably in Colorado and Pennsylvania.[20] One of the most consistent findings in our studies of innovation is that while consumers are typically reluctant to pay higher prices for product "improvements" that they don't need and can't use, they generally are very willing to pay for improvements that *do* matter.[21] Recall, for example, that in the early years of the disruption of the music distribution industry, owners of early MP3 players could download and share music for free. But it was time-consuming and inconvenient. When Apple introduced its iPod and iTunes music store, millions of people gladly paid significant prices in order to get exactly what they wanted and none of what they didn't want as conveniently as possible. We suspect that during the initial period

of substitution many students' families would react similarly if they were asked to shoulder some of the cost of courses taught in a student-centric way.

❖ THE FUTURE CLASSROOM

If student-centric technology remains on this trajectory, what might the classroom of the future look like? Students filter into their room. Chemistry workbenches, complete with such things as test tubes, reagents, pH meters, and a bomb calorimeter greet them. The students conduct experiments in which they measure the effect of changes in the pressure, volume, and temperature of gases. They record their experiments in their lab workbook, and the teacher grades them and returns it to the students.

This might not sound too different from the everyday happenings many of us recall from chemistry class, but there is a big difference. This all takes place in the Virtual ChemLab. The classroom of the future is, in this case, present and accounted for.

Begun by a chemistry professor at Brigham Young University, the Virtual ChemLab serves some 150,000 students seated at computer terminals across the country. The professor took 2,500 photographs and 220 videos, and, along with some video-game designers, created a simulated laboratory to allow students to do all the above and more. While it is not as good, perhaps, as doing the experiments hands-on (some have pointed out that these students could enter college science courses without having used a real Bunsen burner), the virtual lab allows students to try experiments that would be too costly or dangerous to do at their local high schools. What is more, it is infinitely better than many students' alternative—nothing at all. For resource-constrained schools in isolated rural areas or impoverished urban ones, this is a big improvement. And as technology improves over time, who knows how good the virtual re-creation of a lab might become? Maybe one day the students will be able to feel the heat from the Bunsen burner and smell the chemical reaction.[22]

In another classroom, students are learning Mandarin grammar. The students are wearing noise-canceling headphones and working with laptop computers. The teacher is kneeling beside a particular student. The student is directing the work of a brick mason on his computer screen by having him assemble a sentence in the same way that he would construct a wall—block by block. There are stacks of blocks with words on them in the background of the screen, each colored for its potential role in the sentence. The student has been directing the mason to pick blocks out of the appropriate stacks to put them in the correct order of a Mandarin sentence. When all the required blocks have been assembled in the proper sequence, the Mandarin word replaces the English on each block and the student joins the brick mason in reading the sentence (which is written phonetically in the Roman alphabet). When the student doesn't get the pronunciation right, the brick mason looks pained. The mason then repeats the correct pronunciation, and when the student gets it right, the brick mason gives a high five. Mandarin is a tonal language, so the blocks then tilt to help the student see and feel the tones.

Another student in the same classroom is learning the same material from the same software program by rote memorization—listening to a native Mandarin speaker and then repeating the sentences, in a mode of learning familiar to her parents' generation. Both students are learning to put together sentences that they'll use in a conversation together in front of the rest of the class—some of whom are using the same learning tools as these two, but many of whom are learning Mandarin in other ways that are tailored to the way they learn.

In contrast to the Virtual ChemLab, this Mandarin classroom is indeed a classroom of the future—we've not seen it yet. But it can emerge, provided the technology is introduced disruptively.

Where do teachers fit in this futuristic classroom? One, of course, is the teacher who developed the Virtual ChemLab.

Another, in the room with the Mandarin students, was walking from student to student, helping each one, individually, to stay focused and to master the material in a way consistent with each student's way of learning.

As the monolithic system of instruction shifts to a classroom powered by student-centric technology, teachers' roles will gradually shift over time, too. The shift might not be easy, but it will be rewarding. Instead of spending most of their time delivering one-size-fits-all lessons year after year, teachers can spend much more of their time traveling from student to student to help individuals with individual problems. Teachers will act more as learning coaches and tutors to help students find the learning approach that makes the most sense for them. They will mentor and motivate them through the learning with the aid of real-time computer data on how the student is learning. This means, however, that they will need very different skills to add value in this future than the skills with which education schools are equipping them today. Since customization will be a major driver and benefit of this shift to student-centric online technology, increasingly teachers will have to be able to understand differences in students and be able to provide individual assistance that is complementary to the learning model each student is using.[23]

There is another potential benefit for teachers. Because student-centric technology allows for far more personalized attention from a teacher, we can do something counterintuitive in education—increase the number of students per live teacher. Facilitating this disruption of instruction has the potential to break the expensive trade-offs in which school districts have been trapped so that individual teachers can do a better job and give individual attention to *more* students. As a result, there potentially will be more funds to pay teachers better.[24]

❖ THE FUTURE OF ASSESSMENT

With the change to student-centric learning, assessment—the art and science of testing children to determine what they have learned—can and should change, as well. Student-centric learning should, over time, obviate the need for examinations as we have known them. Alternative means of comparison, when necessary, will emerge.

In the past, testing has been used to do two jobs for students, teachers, and administrators. The first has been to determine the extent to which students have mastered a body of material and are ready to progress. The second job is to compare students against one another. Student-centric technology can fulfill both of these purposes.

The conventional teacher-administered examination doesn't do the first job well. Regardless of whether students have mastered the material in a unit, they all move on. Teachers don't find out what students have actually learned until an exam is administered and graded, which tends to be some time after the unit or class is already complete. If students haven't mastered all the material but know it well enough to get a passing grade, the students still must move on. And even if they fail an exam, the students typically must move on, because moving on is inherent in the model of monolithic instruction. This teacher-administered examination tells teachers and administrators only what percentage of the students has demonstrated mastery of what percentage of the material. The amount of time in which to learn the material is fixed, but the amount of learning varies significantly.

In his upcoming book *Chasing the Rabbit*, Steven Spear, a senior lecturer at MIT, recounts an experience that has helped us frame the trap of monolithic instruction that we've gotten ourselves into in public education. While doing research in 1996 as a doctoral student studying Toyota's famed production system, Steve took temporary jobs working on an assembly line at Toyota and one of the Detroit Big Three plants at the passenger-side frontseat installation point.

At the Detroit Big Three factory, the worker doing the training essentially told Steve, "The cars come down this line every 58 seconds, so that's how long you have to install this

seat. Now I'm going to show you how to do it. First, you do this. Then do that, then click this in here just like this, then tighten this, then do that," and so on, until the seat was completely installed. "Do you get how to do it, Steve?"

Steve was quite certain he could do each of those things in the allotted time, given that he had earned a master's degrees in mechanical engineering from MIT. So when the next car came down the line, he confidently picked up the seat and did each of the preparatory steps. But when he tried to install it in the car, it wouldn't fit. For the entire 58 seconds he tried to complete the installation but couldn't. His trainer had to stop the assembly line to fix the problem. He again showed Steve how to do it. When the next car arrived, Steve tried again but didn't get it right. In an entire hour, he installed only four seats correctly. One reason why it historically was so important to test every product when it came off the end of a production line like the Detroit Big Three's was that there were typically hundreds of steps involved in making a product, and the company could not be sure that each step had been done correctly. In business, we call that end-of-the-line activity "inspection." In education, we call it "assessment" or "testing."

When Steve went to work at the same station in Toyota's plant, he had a completely different experience. First, he went to a training station where he was told, "These are the seven steps required to install this seat successfully. You don't have the privilege of learning step 2 until you've demonstrated mastery of step 1. If you master step 1 in a minute, you can begin learning step 2 a minute from now. If step 1 takes you an hour, then you can learn step 2 in an hour. And if it takes you a day, then you can learn step 2 tomorrow. It makes no sense for us to teach you subsequent steps if you can't do the prior ones correctly." Testing and assessment was an integral part of the process of instruction. As a result, when he took his spot on Toyota's production line, Steve was able to do his part right the first time and every time. In fact, Toyota had built into its process a mechanism to verify immediately that each step had been done correctly so that no time or money would be wasted fixing a defective product. As a result, it did not have to test its products when they came to the end of the production process.

What a contrast between the two methods for training Steve Spear. At the Detroit Big Three plant, the time was fixed, but the result of training was variable and unpredictable—just as it is in the public schools' assessment systems. The "exam"—installing the seat—came at the end of Steve's training. At Toyota, the training time was variable. But assessment was interdependently woven into content delivery, and the result was fixed; every person who went through the training could predictably do what he had been taught to do (while Toyota's instructional methods might not be customized for the way Steve learns best, the point of this anecdote is to focus on the end implication for examinations). Toyota follows that principle in all its training, for every activity in the company.[25]

We note in Chapter 1 that through the 1800s there was little monolithic instruction in public schools because students of many ages were in the one-room schoolhouse together. Most instruction occurred at the individualized level at individualized rates. Educators borrowed the concept of monolithically processing students in batches, with a fixed time spent in each stage of the process of assembling an educated person, from the concept of batch processing in industry so that they could cope with the burgeoning student population in the early twentieth century. Just like Steve Spear's experience at the Detroit Big Three plant, schools similarly acquired the character of "fixed time, variable learning." Just as manufacturers had to test each product when it came off the end of the production line because they couldn't predict which products had been made correctly, educators had to test their students because they couldn't predict which of those in each batch had learned what. Repair, rework, and rejects became costly elements of both systems. Just as a professional discipline of inspection emerged in industry, a professional discipline of assessment has emerged in education.

This shift from individualized instruction to monolithic content delivery targeting batches of students changed the teacher's job. We estimate that at least 80 percent of the typical teacher's time is now spent in monolithic activity—preparing to teach, actually teaching, and testing an entire class. Far less than 20 percent is available to help students individually. A profession whose work primarily was in tutoring students one on one was hijacked into one where some of the teacher's most important skills became keeping order and commanding attention.

When students learn through student-centric online technology, testing doesn't have to be postponed until the end of an instructional module and then administered in a batch mode. Rather, we can verify mastery continually to create tight, closed feedback loops. Misunderstandings do not have to persist for weeks until the exam has been administered and the instructor has had time to grade every student's test. Rather than a fixed time to learn with variable results student by student, the amount of time to learn can vary, but the resulting learning can be much more consistent. In other words, assessment and individualized assistance can be interactively and interdependently woven into the content-delivery stage, rather than tacked on as a test at the end of the process. And the software makers can also use the feedback loop to learn how to improve their product for different kinds of learners.

We mention above that the second job for which examinations are used is to compare students—and there are lots of sound reasons why we want to compare students. College admission decisions are built around test scores. The evaluation of which schools and districts are doing satisfactory jobs educating their students depends upon standardized exams. Even the assembly of honor rolls—whose purpose is to compare students—is largely based upon performance on exams.

As student-centric online technology becomes dominant, we can fulfill this need to compare in different ways. Since learning will no longer be as variable, we can compare students not by what percentage of the material they have mastered, but by comparing how far they have moved through a body of material.

If we indeed want to begin teaching subjects to students in ways that correspond to how their minds are wired to learn, it means that the science of assessment will need to evolve significantly. If we want to teach chemistry differently to people like Rob James, who struggles with conventionally taught math and science but was blessed with bodily-kinesthetic intelligence, then we'll need to find ways to compare his mastery of a body of material with the mastery demonstrated by someone whose intelligence is in the logical-mathematical realm.

Maurice Maeterlinck, the Belgian Nobel Laureate in literature once observed, "At every crossway on the road that leads to the future each progressive spirit is opposed by a thousand men appointed to guard the past." Educators, like the rest of us, tend to resist major change. But this shift in the learning platform, if managed correctly—which means *disruptively*—is not a threat. It is an opportunity. Students will be able to work in the way that comes naturally for them. Teachers can be learning leaders with time to pay attention to each student. And school organizations can navigate the impending financial maelstrom without abdicating their mission.

The disruption of instruction by student-centric online technology that we chronicle in this chapter has been driven, to date, by its having taken root in competition against nonconsumption. Online learning already has transformed instruction where the alternative has been nothing at all. We've noted that this is how all disruptions start. And we've shown that, given the shape of the substitution curves, this transition is likely to pick up substantial momentum in the coming years. The budgetary economics of states, cities, and towns will drive part of the substitution. The improving technology will drive much more of it.

This chapter paints a picture of the first phase of the disruption, which we have labeled computer-based learning.

We've also mentioned the second phase, student-centric technology, in this chapter. At the end of the second phase of a disruption, the landscape often looks very different from what preceded it. Much of the opportunity for student-centric technology to take root and transform the learning landscape is outside the present K-12 public education system. This is an exciting opportunity, which we detail more in the next chapter.

NOTES

1. A report by Anthony G. Picciano and Jeff Seaman shows the precise instances of how and why schools would use online learning and confirms what the theory predicts. This provides a solid grounding for many of the assertions throughout the chapter on why school districts are motivated to use these courses as well as what the potential and pitfalls are for these solutions. Anthony G. Picciano and Jeff Seaman, *K-12 Online Learning: A Survey of U.S. School District Administrators*, Hunter College-CUNY, Babson Survey Research Group, The Sloan Consortium, 2007.
2. Mark Schneider, *The Condition of Education 2007*, U.S. Department of Education, National Center for Education Statistics, May 31, 2007 briefing.
3. *The Condition of Education 2005*, U.S. Department of Education, National Center for Education Statistics, 2005, http://nces.ed.gov/fastfacts/display.asp?id=91. Brian D. Ray, "Research Facts on Homeschooling," National Home Education Research Institute, July 10, 2006, http://www.nheri.org/content/view/199/.
4. Interview with Richard Siddoway, founder of Utah's Electronic High School, interview by Michael Horn, November 26, 2007.
5. *The Condition of Education 2007*, U.S. Department of Education, National Center for Education Statistics, 2007, http://nces.ed.gov/fastfacts/display.asp?id=78.

   Also, there are many opportunities further outside the school system for student-centric technology to make a positive impact. Marc Prensky, a noted thinker and author on the impact technology can have in learning, calls the space outside the school system "after-school." After-school education is whatever students learn when they are not in class or doing their homework or preparing for tests. From science and robotics clubs to blogging, social networking, and playing video games, children spend lots of time learning outside of school. There are lots of areas of nonconsumption here to make a positive impact and revolutionize how we think about learning. Because the focus of this book is on our schools, we do not have the opportunity to