The Common Wealth Plan

A Blueprint for Revolutionizing Learning

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In the following pages I offer nothing more than simple facts, plain arguments, and common sense; and have no other Preliminaries to settle with the reader, than that he will divest himself of prejudice and prepossession, and suffer his reason and his feelings to determine for themselves; that he will put ON, or rather that he will not put OFF the true character of a man, and generously enlarge his views beyond the present day.

Thomas Paine, *Common Sense*, 1775

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Executive Summary

In the 21st century the true wealth of a nation, our common wealth, will be measured by the education of our children. Today, 88% aspire to get a college degree, yet currently just 40% do. This disparity can be addressed with a new technology of learning that now exists. It can provide the customized curriculum all of our children need to learn more productively and emerge from high school ready and able to succeed in college. Increasing the productivity of teachers, it will lower per-student costs. The transition to this more efficient and effective learning technology is inevitable. But today, we have the unique opportunity to use ARRA[1] investment to accelerate it. By 2012 every student would come to school with a computer and be connected to the internet via adequate broadband access, every teacher would be prepared, and every school would get the new customized technology of learning for every student.

Goals	2009	2020
College Graduation Rate	40%	88%
Technology of learning	Textbooks with static text	Online programs with customized productive practice and interactive visualizations
Classroom	Teacher-centered	Student-centered
Student-Teacher Ratio	15:1	24:1
Cost per Student	$10,000	$7,500

1. **Graduation rates** - 88% of our 8th graders aspire to a college degree according to the prestigious Stanford Bridge Study.[2] This ARRA investment offers the promise that they can all achieve one by 2020.
2. **The technology of education** is changing from the paper, ink, slate, and chalk model that results in one-size-fits-all static textbooks to online computers providing dynamic, customized curricula. This new technology of learning can provide every student with a true IEP[*].
3. **Today's classroom** is focused on group instruction; tomorrow's classroom will be focused on customized learning that makes practice productive and builds flexible thinking.
4. **Student-teacher ratio** in 1960 was 25:1 and cost-per-student in current dollars was $2,670[3]. To provide more individual attention, schools over the past 50 years have driven down the student-teacher ratio to 15:1, raising the cost of schooling to nearly $10,000[4] per student and producing severe shortages of qualified teachers in critical subjects like math and science.[5]
5. **Cost per student –** teacher compensation represents between 40 and 50% of the cost per student, so increasing the student teacher ratio to 24:1could reduce the cost per student to $7,500[†] by 2020, which

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[*] Individualized Educational Plan, required today of all Special Education students, should be an entitlement for all students. This new customized technology of learning can make such a mandate realistic.

[†] In 2009 dollars

would provide the funds for hardware, online curriculum, a substantial increase in teacher salaries, and a lower cost for K-12 education. This reduction can occur without teacher layoffs.

Funding	Cost	Number	Total
Student Computers	$250/student	16,000,000	$4B
Infrastructure	~$10,000/school	100,000	$1B
Staff Development	$1500/teacher	2,000,000	$3B
Custom Curriculum	$50/student	55,000,000	$2.5B
Total			$10.5B

1. **Computers** -- Today netbooks and notebook computers are selling for less than $400 at retail. Since technology prices are dropping and schools can purchase in bulk, we expect that over the next three years such school-ready computers should average about $250 each. These ARRA dollars should be considered a subsidy for those students and schools unable to afford even this price.
2. **Infrastructure** – Through E-rate[6], schools were wired to the internet. This funding would upgrade that system to provide increased bandwidth, wireless functionality, and upgrades to management software.
3. **Staff Development** – With a focus on STEM (Science, Technology, Engineering, Math), reading, and writing, this program would provide support and summer programs to prepare teachers for the new instructional methodologies. Coaches to support teachers and schools could be trained and supported from the ranks of Teach for American and other like organizations.
4. **Customized Curriculum** – Textbooks are typically bought in 5-7 year cycles. This money enables schools to buy new technologies of learning, offering more at comparable prices, to replace textbooks and supplemental materials before those cycles are completed.

Process	2009-10	2010-11	2011-2012
Preparation	Grades 3&4, 7&8, 11&12	Grades 1&2, 5&6, 9&10	
Implementation		Grades 3&4, 7&8, 11&12	Grades 1&2, 5&6, 9&10
Increasing Class Size			Grades 3&4, 7&8, 11&12

1. **Preparation** – includes workshop planning, curriculum planning and testing, infrastructure planning, and administration planning, and planning for coaching both in person and online.
2. **Implementation** – Teachers in these grades would be asked to fully implement the new learning technologies in math, reading and writing, and science. History and Social Studies teachers as well as those in other disciplines may choose to transform their courses as well.
3. **Increasing Class Size** – 9% or 350,000 teachers now leave the profession each year. This churn provides an opportunity to increase class size without layoffs. If we increased average class size by just one student per year, we will take 9 years to reach our 24:1 target, and we would still be hiring nearly 250,000 new teachers a year.

Contents

Perhaps the sentiments contained in the following pages, are not YET sufficiently fashionable to procure them general favour; a long habit of not thinking a thing WRONG, gives it a superficial appearance of being RIGHT, and raises at first a formidable outcry in defense of custom. But the tumult soon subsides. Time makes more converts than reason.

Thomas Paine, Common Sense, 1775

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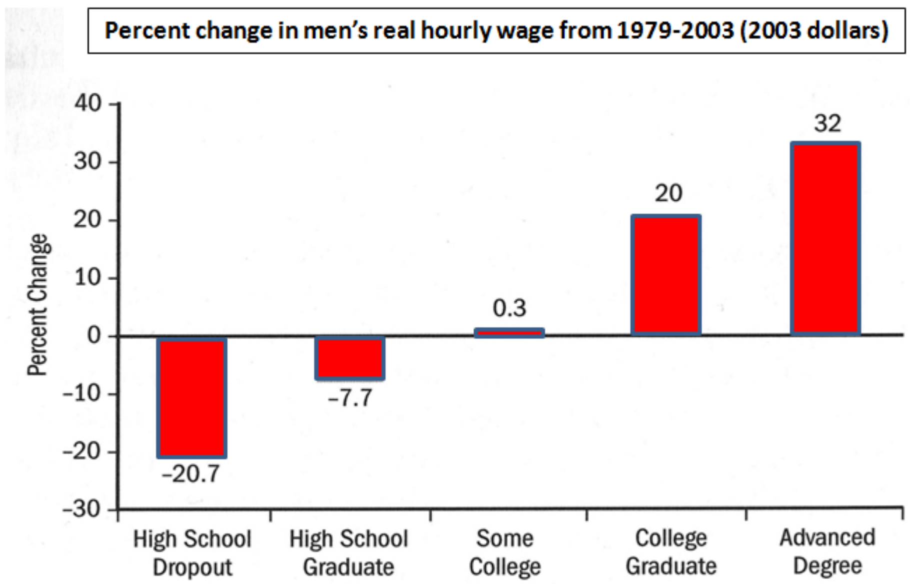
The Problem

The Need – The dreams of our children

In the United States there are in round numbers 5 million students at each grade level. Today, only 2 million of our 5 million 18 year-olds will graduate from college. Today, only 2 million of our 5 million students have any hope of living the kind of lives they or their parents dream of for them.[7] Our 8th graders know the reality that without a college degree the will earn less than their parents. That's why 88% of them told the Stanford Bridge study researchers that they aspired to a college degree. College graduation rates have been rising over the past few years at only about 1% per year, but even that anemic rate of increase is expected to decline[8].



We can get a better view of the scale of this problem by looking at our student population as a normal distribution[9]. IQ, intelligence quotient, is a crude but useful measure that can serve as an effective proxy for this normal distribution to help us understand what is needed to create the 21st century educational system America needs.

IQ is a quotient, a ratio between the score on a test and chronological age. As we get older we are expected to score higher, maintaining our IQ as a constant ratio because our score is divided by our age. Though these tests may purport to have special types of questions that get at "native intelligence", they tap skills, concepts, and vocabulary that children learn over time. Because IQ is a quotient or ratio, it is a rate, a measure of how fast we have learned and not a measure of how much we have learned. And whether we want to think of IQ as a single ratio or as multiple ratios (in Howard Gardner's sense of multiple intelligences), it is a measure of how fast we have been able to learn, process, and use content we have been exposed to. As a proxy for our learning rate, we can use it to ask, "Can we substantially raise IQ through a new technology of learning?"

This is the critical question for both educators and citizens at large, for today we graduate only 40% of our population from college and yet 88% of our children dream of getting a college degree. The upper 40% of the population represents those with an IQ of roughly 105 and above. The top 88% of the population would include students with IQs around 80. Since the mean IQ is 100 and the standard deviation is 15 points, we are talking about a shift of almost two standard deviations for our lowest performing students. Many would say “impossible!” In the fifties and sixties when IQ was a popular school measure, a student with an IQ of 80 would have been considered incapable of even finishing high school much less of earning a college degree. Many would argue that without profoundly diluting the meaning of a college degree, these students are incapable of earning one and should be offered only technical or trade school options.

The reality is far different. We are not in the 1960s anymore. Even so-called trade jobs require the education typically found in a community college AA (Associate of Arts) degree. The reality is we cannot deny any American child the opportunity to get the education he or she aspires to have and live the kind of life that our children dream about. The reality is that in this 21st century there are no longer going to be many well paying jobs that do not require a college degree. And the reality is to be competitive in today’s “flat earth,” we will need most of our children to have college degrees.

Some people believe that the critical barrier to a college education is cost. While the cost of a college education can be for some a formidable barrier, especially at four year private colleges, it is generally not a significant barrier at community colleges and state supported institutions. Between their relatively low cost per credit, scholarships, part-time jobs, and student loans, a college degree is within reach of most students who want to one. The real barrier is academic.

So the obvious question is: “Can we raise the IQ of those at 80 to 105, almost two standard deviations?” Can technology really make our kids smart enough so that 88% of them will learn as fast as the top 40% do today? While we often say that new technologies enable us to work smarter and faster in our work places, is it really possible that this is also true of our kids’ work places? The answer is an unequivocal yes! And we are not talking about this new technology of learning as some esoteric and likely dangerous mental steroid, or about some amazing advanced computer software that will require students to have quantum computers. We are talking about computers on the internet with learning software that exists today.

The Solution

The role of technology in learning

To understand the new role technology will play in learning, it is useful to take a quick look back. Though we usually don't think of the ubiquitous textbook, paper and pencils, and chalk and blackboards as technologies, they are. These technologies of education have been with us in their current form for about 120 years, so long that we tend to think of them as always existing and the natural, indeed the only, way to learn. Neither is the case. The technologies they replaced in our 19th century elementary schools were recitation boards and student slates. Recitation boards were layers of oilskins printed with different lesson elements (alphabet, vocabulary, multiplication tables, history dates, etc.). Teachers, usually in multi-age classrooms, used pointing sticks to direct students' attention to a particular spot on the recitation board, leading them to recite and repeat these lessons aloud. Students had small slates and chalk on which to write words or do calculations. Copy it from the recitation board, solve it on your slate, and raise your hand to respond – this was the dominant classroom activity of the 19th century.

Toward the end of the 19th century, a measure to greatly reform education made textbooks ubiquitous in K-12 classrooms. Readily available, cheap paper along with very fast printing presses enabled the inexpensive textbook to revolutionize schools with standardized single-age classrooms. The textbook provided content that students could study on their own, accompanied by practice exercises that required only cheap paper or workbooks and pencils to do. Students could practice independently of a teacher and were generally expected to do so in the form of homework. In addition, these early textbooks gave students access to the great teachers who wrote those books. They gave average classroom teachers a master set of content to rely on and a demanding sequence of lessons to work through. With the newest technology of the time, the huge slate blackboards lining their classroom walls, they could add their own flavor and conduct the whole class in a homogeneous "lockstep" through a lesson. The learning process became what it essentially remains today: the teacher presents the concept and does a few practice exercises on the board, students do the "homework" problems from the textbook which they turn in the next day, and the teacher later grades and returns the homework.

This technological shift at the end of the 19th century catapulted high school graduation rates from 3% to nearly 80%.[10] Can a new technology of instruction and learning take college graduation rates to 88%? Can it raise IQ by 25 points? Textbooks have certainly changed over the past 100 years. They have gotten much bigger,[11] added large quantities of images and content, changed from black and white to four-color, sometimes incorporated novel pedagogical ideas, and become more and more expensive. But despite a large number of federal innovative projects,[‡] textbooks have not substantially changed their methodology. The 40% of our kids who succeed today can learn from this old technology. They read at grade level and are good at following written directions and assimilating written information. Yet the majority of their peers do not fully master the standard curriculum during 13 years of schooling.

[‡] My guess is that over the past 50 years I have come in contact with as many as 100 such programs.

We recognize the deficiencies of textbooks since we constantly call for better and smarter teachers. We expect teachers to pull our children through. We expect them to make concepts clear and exercises doable. We expect them to help our kids understand the textbook. We expect them to provide the constant feedback and the customized learning that the textbook cannot provide. We hope that they will do at the board what the textbook was supposed to do: motivate, make clear, highlight the patterns, and provide customized practice that makes performance perfect. We are asking our teachers today to do their job as well as the textbook's job.[12] It is no wonder they are exhausted. No wonder that even with much smaller classes they seem to have a harder and harder time knowing our kids as individuals. No wonder it is so difficult for teachers to do a good job that we now try to coerce them with the NCLB tests. We know in our hearts that this old technology of instruction just cannot do what needs to be done, so we place an added burden on teachers to make learning work for all kids. It is a wonder that it works for so many. Even if we can continue to improve this old technology, we are talking about 1 or 2% improvements. Do we really believe that we can improve textbooks enough to graduate 88% of our students from college?

Can this new technology of learning make the difference?

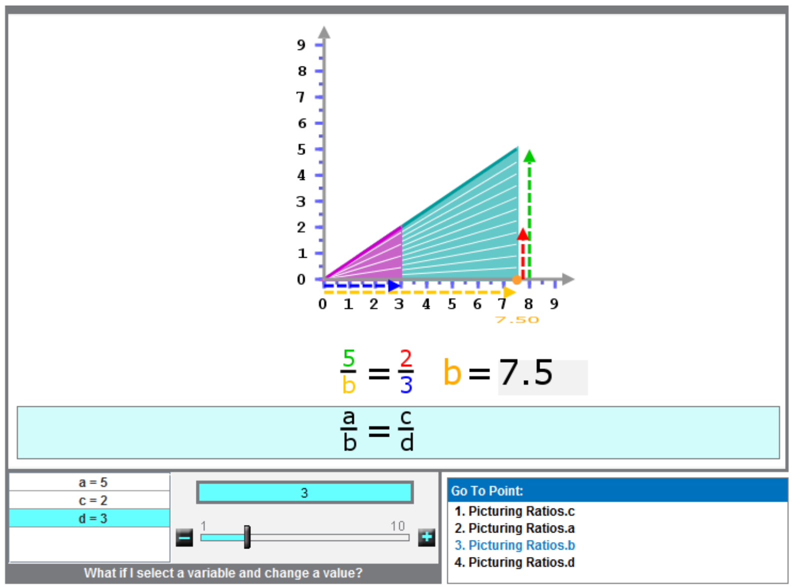
Could a new technology of learning enhance students' learning rates and their ability to understand complicated concepts? Could it substantially increase their facility with problem solving, patternmaking, vocabulary, and other skills traditionally measured on IQ tests and considered foundational for the learning of a wide range of subject matter? Could it lead to higher levels of achievement, especially in the core areas of reading, writing, and math? While the value of this new technology of learning stretches across every discipline it is in these primary languages, English and math, that we need to see much higher levels of achievement and where we have some evidence that we can produce them. And since my own expertise is in math education, I will focus most of my attention on that subject.

One type of test question that correlates with math achievement has to do with spatial intelligence. Students are asked to pick out a shape that is a reflection and rotation of another. Textbooks don't do much to help students learn such visualization skills because all of their images are static. They can't show students how to picture these shapes in their minds and transform them with their brains. And since these skills are not taught in schools today, students have to come to school with strong visualization abilities in order to do well on such questions.

A computer, on the other hand, is a visual medium, not simply a text medium. It is highly interactive and of course dynamic. So it is not hard for us to picture a computer program that lets a student draw a shape, reflect it, or rotate it and then reflect or rotate it again. Even PowerPoint™[13] lets you do this. With a computer, every student, visual learner or not, can practice and transform shapes. Perhaps this is the reason that some research indicates that IQ measured on these tests is already rising.[14] Since math is a visual language and functions are transformations, this ability is not just "nice to have," important for those kids who are going to be architects or engineers, or good for IQ tests; it is vital for every student because it helps them understand important mathematical concepts.

Ratio and proportion are the most difficult and likely the most important ideas in elementary arithmetic. They often determine success or failure in algebra because proportions are the first real reason to solve equations in math. IQ tests focus on proportion because of its importance and because so many students fail to understand this concept. Proportional reasoning has always been a very hard concept for textbooks to teach. The presentation tends to be formulaic: "cross multiply and isolate the variable." It stresses memorization of verbal definitions, such as "A proportion is made up of two ratios that are equal to each other." It tends to shy away from teaching real understanding.

On the computer we can show proportion as the transformation of a pair of right triangles. We picture a ratio as a right triangle, and we picture a proportion as two ratios, a pair of similar right triangles. Similar triangles, as we all learn in geometry, have the same shape but differ in size. As you can see in this static picture, the lengths of the legs of each triangle represent the values of the numbers in each ratio of the proportion. Imagine a student asking the question, "If I make this leg longer, what will happen to this other leg?" and then being able to use a controller to change the value of the legs. This can be very hard for many students to do in their heads, but it becomes easy to picture on a computer screen. What difference would this new ability to play with visualizations make in a student's ability to learn this concept and solve proportion problems?



This visualization of ratio and proportion is not just a cute idea that helps elementary school students to "see" and experiment with an important concept. It is a fundamental. It introduces students to slope and trig[§] functions that are crucial to algebra and calculus. And it provides a foundation for helping students connect ratio and proportion to percentage, motion, and scale so much a part of the skill set they need to understand their 21st century world. So this new technology of learning can help us to understand important ideas and build important skills, ideas and skills assessed on IQ and achievement tests.

Practice -- The old technology

I hear the question repeatedly about math education today: "Why aren't students getting the practice they need?"[15] Most adults over fifty remember math in school as endless practice, and they believe, with good reason, that students today are doing more poorly in math because they do not practice enough. In fact, in my conversations with educators, it is clear that students are getting less practice and more presentation today than in the past. There are several reasons for this. First, the old "drill and

[§] Trig is the study of ratio and uses the right triangle as its foundational image.

kill" philosophy was discredited by both the math profession and by the community at large. Second, teachers have become inundated with so many other tasks that they no longer have the time or energy to grade homework on a consistent basis, and what is not graded is not done. Finally, the challenges of keeping up with the new mathematics requirements as embodied in the state and NCTM[16] Standards are overwhelming most teachers. So to "get through" the material, they "show and tell," because teaching through practice is a slow and demanding process. By *practice* in math, I mean the work that students do: homework.

There is good reason for these attitudes about practice. The existing technology of practice is enormously wasteful and good teachers know it. First of all, many students do assignments at night when they are tired, distracted, and lack concentration. We don't learn without concentration. Second, they get little feedback as much homework is not even graded and very little is graded in time to make a difference. Imagine practicing golf by hitting balls in the dark or trying to learn the piano wearing earplugs. Practice has little value without immediate feedback. Third, every student gets the same assignment – "Goldilocks assignments" – with a third of the problems being too hard, a third too easy, and only a third just right. So 2/3 of the problems students do don't help them learn. And fourth, even if a student strives to be diligent, how does he or she get help at 10 at night? The example the teacher worked out step-by-step on the board in class made sense then, but in the textbook or in the notes it becomes just one big blob.

The "cram and forget" learning, based on today's emphasis on testing and the necessary repetition of content both within and between grades, is a sign of the existing technology's inefficiency. Sure it worked for some students in the past and continues to do so today. But more and more we can see that this inefficient system has been overwhelmed by the demands placed on teachers, students, and on the school day. These new demands, to learn and teach more in the same time frame, to substantially raise IQ, mean that we can no longer afford an inefficient practice system. We need a new practice system that builds the fluency all of our children require.

Practice – The new technology of learning builds fluency

Imagine providing immediate feedback for every student on every problem. Imagine giving students assignments in which each problem is adapted to their individual learning level. Imagine that students can go to interactive and dynamic examples whenever they need them, and that these examples let a student step-through the solution, just like the teacher did it in class. Imagine them being able to change the values and then go through the example again. Imagine that they can query the visualizations, asking "What if…" questions by changing the length of a line or transforming a shape or graph. And finally, imagine that an assignment is considered complete when the student has mastered its concepts to the point of fluency. These are the advantages a new technology of learning can bring to practice. It can make practice much more effective and efficient, and thus a more productive experience.[17]

This new technology of learning is student-centered. It puts the student in control of the learning process through customized practice. Rather than doing an arbitrary number of problems, each student does just enough, at just the right level of increasing difficulty, to master the concept or procedure. Students have a good reason to concentrate and to work carefully, so as to do as few problems as possible to complete an assignment. When assignments are shorter because all of the problems are "just right," then students save time and energy and no longer feel that they are doing "busy work." And when students master concepts the first time and do not have to repeat them again and again, they gain the powerful confidence needed to build concentration.

But perhaps the most important result of a technology that makes practice productive is that it can substantially speed learning. Less drag, less repetition, quicker access to help, fewer holes, and generally shorter assignments mean that students can do more and learn more. How much more? Teachers today generally spend about a third of each year going over the previous year's content. Our experience indicates that textbook assignments are generally 1/3 longer than computer mastery-based assignments because they have to fit the needs of the whole class. (Textbook assignments in math are generally 30 problems long. We find that most students complete our EnableMath™[18] assignments to mastery in 22 problems[19].) The typical student, then, should be able to cover the same amount of content as she could with the old technology with 2/3 the work and in 2/3 time! If she – or her teacher – chose instead to accelerate her progress through the standard curriculum, she could cover between one-and-a-half and two years worth of material in a single year.

For the students who fall behind today, the potential of the new technology is even greater. Textbook technology provides few ways of catching up. If a student misses a foundational concept, his errors and misconceptions continue to interfere with learning new material, so he falls further and further behind. The new technology of learning permits continuous progress, beginning at the student's current level of understanding and filling in holes when necessary. It can substantially increase the fluency of students of all abilities and do so in less time and with less effort.

Understanding – Using the new technology of learning to build flexibility

For the past 100 years education has been a battleground between two great demands, content and concept. Each generation uses its own labels and thinks it is fighting a new battle. Should we teach our kids to *do* or should we teach them to *understand*? Should we teach facts or ideas, basics or new math, phonics or whole language, procedures or critical thinking, workforce skills or 21st century skills[20]? I like to think of this battle in less polarized terms as the choice between fluency and flexibility. By *fluency*, I mean command of the facts and processes of a discipline. By *flexibility* I mean the ability to think critically, to solve authentic problems, to work creatively, and to know the principles of a discipline. An efficient technology of learning should enable students to develop both – in an integrated way.

The NCTM Process Standards[21] for math education in America are communication, problem solving, reasoning, connections, and representation. How do you incorporate communication into a textbook? What do you do: have a problem that suggests students communicate to answer it? You can do that easily with the new technology. How does the textbook help students gain problem solving skills? Problem solving is a process and needs to be taught as a process that is rarely linear. Textbooks are linear; they cannot easily show branching processes nor can they teach them. Computers are built for branching and for following processes through multiple paths at the same time. Textbooks cannot help students find connections. Textbooks are not updatable. The Web is a connection machine and new programs that feature making new connections are arriving almost daily. Can you build multiple representations of concepts on a printed page? Not easily, and probably not without interfering with the flow of your presentation or argument. The computer – with its hyperlinks, multimedia capacity, and interactivity – can enable students to see, play with, and even construct multiple representations.

With a productive practice technology providing more time to build fluency and with new tools that open the door to flexibility, a new technology of learning can finally make peace between these warring factions. The computer connected to the internet is a natural communications device. It can enable students to work together, to work with others outside of schools, and to work with teachers on problems and projects. It overcomes much of the friction in the current system that inhibits project-based learning. It enables students and teachers to transmit not only verbal but visual messages, not only a static "I did this" page but dynamic "It works this way" screens. It can include tools so that students can edit or create their own screens and portfolios so that they can save, write about, and share their work.

This new technology, with the great wealth of knowledge on the internet, enables students to find and build connections between concepts, disciplines, or ways of thinking. The internet offers students today the opportunity to connect just about anything in the world together. And new programs[22] that help build patterns and connections are now coming to even further enhance this wealth. Students can use real data to learn statistics. They can make connections and inferences and test them. They can create new knowledge. Working individually or with partners in their classroom or across the globe, they can tackle exciting projects and share the results!

The computer is a visual and auditory medium as well as a verbal medium, so it can enable a wide variety of representations. For example, some of the earliest patterns of ratios in mathematics were found by Pythagoras when he connected math and music. He connected musical notes to the lengths of the lyre strings and found these lengths to be simple whole number ratios. With the new technology we can let students build ratios, hear them as notes, and even share their math music with others. They not only can connect music and math; they learn to build the patterns of mathematics.

Reasoning and problem solving have too often been just the words we mouth and pretend that we are teaching when we try to get students to solve textbook problems or follow proofs in geometry. We have never had a means to teach these crucial math processes and 21st century skills. But imagine that we could give students interesting assignments that required them to program the computer. I am not talking about learning a full scale programming language, but rather about making the computer screen do something you want it to do. What if students could put an object on the screen and then animate it? Say you asked a student to make a circle move across the screen, slow it down, and then stop before it hits the edge. This kind of motion occurs in many computer programs, and although it may seem trivial at first glance, the mathematics behind it is also behind technologies from antilock brakes to space shuttle docking engines. Suppose the student could move the circle with simple mathematical tools that linked its motion to equations whose values the student could vary, or program? This is real world problem solving. When a student programs the circle's motion correctly, it will do just what she wanted it to do! As everyone who has ever programmed will tell you, the feedback is exhilarating. This is education in the best sense of the word.[23]

The People

Teachers and a new technology of learning

The side benefit from a new continuous progress *practice* technology is the freeing of teachers to customize learning for each student. Since they no longer have to manually grade homework, enter grades in gradebooks, or spend class time going over problem sets that were not really done, teachers will have the time to prepare and to help students as individuals, to develop interesting real world applications and exciting excursions, and to ensure that all students in the class can grow to their maximum potential. Teachers will also be able to know where every student in the class is from day one without relying on testing. By removing the homework burden which keeps teachers on ground level looking at one student at a time; the new technology of learning will enable them to take a higher view of the class, to see groups of students who may be having significant problems or individuals who might be linked together. This new technology of learning, by making practice productive, will turn the job of teaching into a much more satisfying, less hectic, and more rewarding profession where managing learning replaces repetitive clerical tasks.

This technology will, of course, have to provide the data in an easy-to-manage form so that teachers know which students to target for help and what kind of help they need. It would enable teachers to make assignments to individuals, groups, or the whole class from a full range of content across grade levels, so that they can tailor the assignments to the real learning level of the student. It could allow for fully individualized instruction, provide a wide variety of content, and even enable a teacher to create and share content with others. It would do all of these things and yet be easy enough to use so that teachers would need little if any special training for it. Unlike the early technology products, these new learning technologies will need much smaller manuals and much less handholding.

But this does not mean that staff development would be unnecessary. For these new programs to be truly successful, teachers must learn to fully value student practice and to use their classroom time for more individual student help and less for full-class presentation. As teachers we will have to wean ourselves from whole class recitations that go over examples and instead let students work through them on their own. We will have to recognize that student failure most often starts on the first day of class and not let it happen on that day, or the next, or any all.[24] We will have to look at each of our students as individuals and ask ourselves "What does this student need?" We will have to stop the constant and wasteful grade-to-grade repetition of content and focus on mastery and the persistence that mastery brings. We will have to stop pretending that we cannot fix the problems students developed in the past. And we will have to make our classrooms places of learning, not merely of instructing, with the emphasis on the student's intellectual activity rather than the teacher's. This new technology can make the dream of a student-centered classroom a reality for the vast majority of teachers, but only if teachers are given sufficient support, time, and training to experiment with the new technology and master its potentials.

Administrators and a new technology of learning

Administrators will have much to gain from this new technology of learning and will see some significant changes in their jobs. For the first time, they will have immediate feedback on student learning. They will know which students are practicing enough and mastering the content. They will know which teachers value practice. They will be able to see student progress day-to-day and week-to-week. This feedback, like any good feedback, can give administrators the ability to focus teachers and to coordinate service providers within and across grade levels and even schools at a level not possible today. Of course, with this new power comes a new level of responsibility. Administrators will now have the data to continuously monitor student progress. This feedback will enable administrators to ensure that no student fails, that everyone can and will succeed. This feedback will make all administrators responsible for the success of every one of their students.

For both teachers and administrators the emphasis will not so much be on learning to use particular tools or programs, but rather on learning to do their jobs in new ways. This has always been a requirement of all new technologies and this one is certainly no different. With a new technology comes the need for new skills, new processes, and new requirements. Administrators will need to ensure that the technology is working properly. In the textbook era administrators had to ensure that the books and supplies for students and teachers were delivered by the start of school in September. Now, they will have to worry that the computers and the wireless systems are all working, that they have the bandwidth needed, and that student privacy is protected. They will have to learn how to keep a new kind of record and prevent unwarranted intrusions in their students' lives. And they will have to learn about a new level of communication with parents, teachers, and students, some of which they are already becoming familiar with. They will need to recognize that parents are partners in their child's education and provide the information that will enable them to support teachers. They will need to recognize and empower students to be partners in their own learning because today most are not. Some of this may seem scary and overwhelming at first, but school administrators have always had to cope with these kinds of issues, and they have learned how to handle them.

Parents as partners

Today it is very difficult for parents to be effective partners in the education of their children. Perhaps one of the reasons that so many parents are opting to homeschool their children is that they seek such a partnership. Today's educational technology gives parents very limited feedback on their child's learning. The direct feedback comes in the form of quarterly grade reports or teacher conferences. Indirectly parents quiz their children on what happened in school that day, or try to help them do their homework. But parents as partners requires more than rare feedback. Parents need to be able to see their child's work on a daily basis. They need to get weekly reports on their child's progress. And teachers need the time to talk with parents by email. These can easily be provided with the new technology of learning.

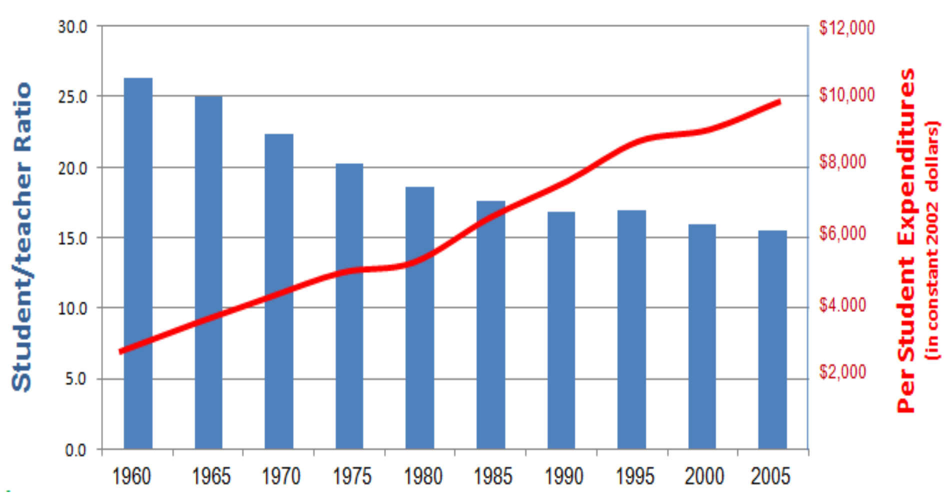
Parents as partners allow them to play a significant role in their child's education. They can better encourage their children to practice. They can help build their child's fluency. And they can encourage and grow their child's flexibility. Perhaps equally important, parents can play an important role in making sure that their children are not abusing this new technology. They will need help with that role and the partnership between parents and teachers and parents and school administrators can be very valuable.

The Economics

The cost and the savings

We can revolutionize education by making sure that every student has as a primary tool an internet-connected computer. Netbooks retail for about $400 and notebooks for less than $500 today. This cost represents less than 5% of the average one-year cost to educate a student in America's schools today.[25] And these computers should last for 3 to 4 years. This means that per-year, per-student cost will be between 1% and 2% of total educational spending at today's prices. And even these low costs should halve over the next few years.

The content for these computers will require some significant investment, but will generally be much less than many have forecasted because it is very likely that heavy-duty, multimedia game-like educational software will be rare and generally unnecessary. Since this new technology of learning will take a significant piece of the instructional burden that teachers now carry, any additional cost above the level of current curricula, which average about 2% per year out of each student's cost (about $200) will be well worth it. There is little reason for the software to cost significantly more than that since the cost of goods (printing and paper) will be gone and the cost of distribution will be much, much lower. Elementary textbooks today are generally written and edited on a five-year adoption cycle. Thus their development costs are amortized over that period. Educational software on the other hand, since it will be live and continuously upgradable, may require additional yearly expenses. But these too should be relatively modest and much less than previously estimated. When all of the costs of curriculum today, including workbooks, tests, videos, computer programs, special intervention programs, etc., are figured in, we will find that the new technology of learning will be substantially less expensive as new technologies generally and eventually become.



The cost savings to education with this new technology of learning can be substantial. In 1960, with 44 million students in K-12 education, we had 1.6M teachers. Today, with 55M students, we have 3.7M teachers. This increase has significantly lowered class size and increased the number of special education teachers. It has also dramatically increased the cost per student on an inflation-adjusted average from under $3,000 per year to $10,000 per year.[26] If we are to more than double the number of students who get a college degree, our costs will expand significantly. It will be critical for us to reduce per-student cost while substantially increasing quality.

Like all new technologies, the new technologies of learning will enable productivity gains. Teachers will gain substantial productivity. They will be able to easily customize the curriculum for each student, track student work without many papers, and break the isolation that our current technology of education fosters. They will be able to mainstream Special Education students much more easily into their classrooms and help them get more support from their peers. These productivity advances will enable us to return to the 25-to-1 student-teacher ratios we had in 1960 without added burden on most teachers. It will enable us to pay teachers more and to find teachers of higher quality.

The results

It is not unreasonable to estimate that, by making practice more productive and substantially reducing grade-to-grade repetition, we could see a doubling of learning productivity. The average student could cover twice as much content in one year as that student currently covers. That would mean that the average 10 year-old could learn the same total amount as the average 15 year-old has learned today.

Now let us be very clear here; we are not talking about accelerated learning, about 10-year-olds learning high school geometry or fourth graders studying Shakespeare. Remember we have a lot more material that we want our students to learn than we can currently manage. We want them to learn to be flexible in their thinking processes, those 21st century skills that we deem so important, and remember we want them to become more fluent in applying what they learn. This is not to say that the curriculum should stay the same. No indeed, the new technology suggests some major curricular changes that need to be explored and developed. It is to say that both breadth and depth will expand to fill this new opportunity. We must be careful not to waste it, but at the same time we are not trying to rush our children through content that they may not yet have the mental maturity for. It can mean that our brightest students will not work at the crazy pace that they do today, but will also find time to be kids. It can mean that we can again favor more arts education, more physical education, and more community-oriented education that has been squeezed out of the school day over the past half century. And it can mean that our children who start out with English as a second language can have the time and the bandwidth to catch up in their new language, and that students who want to learn a second or a third language will have the time to do so.

Overall, this is more than enough learning growth rate to enable average students to gain 25 or more IQ points. This total change will not be immediate, but the longer students use the new technology the greater the gains, and from the time they start seriously using it as the key tool in their learning they will immediately jump their learning to a faster pace. They will have immediately increased their IQ. The total amount they will accomplish, the distance they will travel at this faster speed, depends upon the number of years they work with it. But the benefit will certainly be clear from the beginning.

If we started our average student with this program from Kindergarten, then we expect that on average, students will advance three or four years past the point they would otherwise reach. For instance, if today the student was ready to take Algebra I, then with the new technologies he or she would be ready to take calculus. Seems impossible? It is not. In the 1890s 3% of Americans graduated from high school with Algebra II as their highest math course. Today 3% of our students take AP Calculus.[27] Could average students be ready to take a calculus course? Could students who today have an IQ of 80 be ready to take a rigorous high school algebra course? Today, our children will spend nearly an FTE (full-time equivalent) working year learning math: approximately an hour a day for 150 days per year for 12 years, which comes to 1800 hours, the amount of time the average worker spends yearly on a job. And yet most barely manage the algebra of linear equations. It seems entirely logical that a technology that substantially improves their learning productivity would enable almost every student to master much more math in that huge amount of time.

We have imagined the value of this new technology of learning for future students. What can it mean for students today? For example, can it profoundly improve a student's chances of getting a college degree? Once again the answer is a resounding yes. Our company,[28] working with forward-thinking colleges, has already proven that students using new technologies can succeed in the "developmental math" courses at a rate approaching 50% higher than today's norm. What if we gave these new technology programs to our high school students before they had a chance to fail the college entrance exam? What if we could get them college-ready, saving them the cost of failure in both dollars and in confidence? What if we combined these new learning technologies with online communication technologies that exist today to enable either retired math teachers or college math students to work with the more than one million high school students who would fail that entrance exam and who need to "jump start"[29] their learning.

A computer in every student's hands could not only enable all students to learn more efficiently and effectively, it could give us a way to use the great talent residing in our retirees and in our college students to assist K-12 students without the logistical nightmares of schedules and physically bringing those individuals into the schools themselves. We have just scratched the surface here. We know that new technologies not only mean change that we can forecast, but produce change we cannot possibly imagine. We do not have to solve each and every problem before we begin.

The Plan

So how do we change education?

Do we just pour billions of dollars into a new technology of learning and buy a notebook or netbook for every student in America? Do we start with the teachers, get them trained, and then get every student a computer? Do we incentivize students in science, technology, engineering, and math (STEM) to become teachers and stay in teaching with differential pay and forgiveness of student loans? Do we just pay teachers more? Do we wait for new young teachers who are computer literate to take over, and then get them working with this new technology of education? Do we have to kill public education as we know it and move to charter schools and homeschooling? Or do we embark on a massive effort in teacher training/staff development to change teachers, their attitudes about schooling, their comfort with technology, and their knowledge in their discipline? If this were a multiple choice test, the correct answer would be "none of the above."

Education is considered by people who work within it and people who look at it from the outside as the most stubborn of institutions. The common belief is that change occurs in this enterprise with glacial speed, that this is the only institution where a practitioner from 1900 would be perfectly comfortable. The reality is that all great institutions change little when their primary technology remains stable.[30] They change rapidly, they are transformed, or they disappear when a new technology comes to dominate their activities. While the same will happen to education, we would be wise to think through the change process, to make it as rapid as possible, and at the same time to keep its level of disruption as low as possible. So I suggest the following ground rules as we design our solutions:

1. **Let's use the school schedule to our advantage.** Schools are cyclic with a clearly defined yearly structure with a beginning, middle, and an end. Teachers and students follow the sequence of their textbooks or their course syllabi. Tasks and procedures become regimented and standardized as teachers define and students learn the "liturgy of the classroom."[31] This long yearly cycle is part of the reason that change occurs so slowly in education. Disrupting this pattern is very difficult, and as teachers tire, students lock in to their patterns; as demands from state tests, college tests, curriculum, parents, and just the plain schedule growth, change as the school year progresses becomes more and more difficult.

2. **Let's focus first on the chokepoints of education and work up and down from there.** The chokepoints are the critical decision points, the places where students, teachers, and parents make choices that limit children's futures, the places where students are blocked, where their progress slows or stops.

3. **Let's recognize that our new technology of learning will be transformational and must take teachers and students from where they are today to where they need to be tomorrow.** We need to plan and work for curriculum innovation along with the new enabling technology. New technologies do not exist in a vacuum; they are part of a system. It makes no sense for us to just

make practice more efficient if we do not ask, "Is this the stuff we want our children to be practicing?"

4. **Let's understand that for education to be more effective, it must become much more efficient for both students and teachers.** Yes, this does mean that we will have a smaller, more highly trained and highly paid workforce because it will have technology as an ally and not as a competitor. The only way we can pay our teachers more is to have fewer of them. The only way we can get more teachers of higher quality is to have fewer of them. The only way to improve the quality of education is to have larger and more efficient class sizes.

5. **Let's accept the reality that schooling will take place in a variety of settings with a variety of people who have heretofore not been able to fully participate in the process**. This may mean a wide range of choices in school schedules as well as in who works with our students. It will mean that this new technology of learning will transcend the limitations of the old technology that made schools castles surrounded by moats. We need schools to be porous, to use the human and the physical resources of our community and the world we live in to better educate our children.

6. **Let's think about this as the acceleration of a process and not as a product.** Education will be transformed in the 21st century. I am sure that there is no one who believes that schooling in 2100 will look the way it does today. But many are waiting for a completely new product, for a Manhattan Project to build a new kind of school or new kind of computer program that is really artificially intelligent and can replace teachers. They do not know that the technology is here now, both the hardware and the software. They do not know that we are ready for this transformation today. We have the opportunity to accelerate an inevitable process of moving to a new technology of learning. The tools are available to us.

7. **Let's set our *ends* together as one country but allow the *means* to be freely customized to fit the needs of each child, each school, each city and town, and each state and region.** The lesson of the past decade in education, the NCLB decade, makes the need for this perfectly clear. The Balkanization of education has been a failure; it has meant that we have no clear goals as a nation, no consistent message, and that our standards are ridiculously complex and impractical. We are one country with one educational system that for most of our subjects has common goals and standards. It makes no sense to teach one kind of math in one state and another next door.

The blueprint for transforming American education

With these ground rules we can establish a blueprint for America to bring its schools and its children the full benefits of the 21st century.

1. **We do not have time**. The conventional wisdom of the enterprise sale[32] of anything, including technology, to schools is that it takes a year and a half. We do not have that much time today.

Using the schedule to our advantage means that we start this September 2009 with a plan to have a new technology program for a substantial subset of the students in every school by September 2010. So we have to plan which grades and students will get their computers – and yes, each student must have his or her own. We don't share computers at work, and students should not share them at school. In the fall, teachers should be looking at new technology-based curricula, not hybrid textbooks with some technology painted on it, but real, complete technology-based programs in the key disciplines. These programs should be previewed over the winter months as schools are working through their logistical issues: availability of wireless internet, care of the computers, increased bandwidth, etc. During the spring the schools should work with the community and the parents to increase broadband access at home or in afterschool venues, begin their staff development program, and plan for summer workshops with the teachers involved to acquaint them with the new curricula, etc. Everything should be ready for the September 2010 start of school. Yes, one year to prepare to implement the program for the chokepoint grades.

2. **So which grade levels do you choose?** We should first focus on the chokepoint grades, those grades where student's educational dreams get squeezed out. They are the 11th and 12th grades, when students need to be made college-ready. They are the 7th and 8th grades, where students are first segregated into levels that are very difficult to overcome and when they need to become high school-ready. And the 3rd and 4th grades, when students first find failure in math and when those who can't read adequately start to fall seriously behind. The other grades, 1st & 2nd, 5th & 6th, 9th & 10th should follow suit in year two. Yes, we are going to make this transformation in just three years.

3. **Student-centered learning.** As we move toward a new technology of learning we have to move from a teacher-centered world to a student-centered one. It is the students who must do the learning. The current conventional wisdom among even our best educators is that each day "every teacher should craft an exquisite lesson that will engage every student in learning."[33] This is 20th century educational philosophy. In the 21st century, education starts with students and not teachers. It is students who are practicing productively. It is students who are working together to solve interesting problems. It is students who are given a customized and personalized program for maximum growth and more and more student control. Our classrooms and our curricula are going to be changing, and we will all be challenged to keep up.

4. **Fewer, better, more highly paid teachers.** We can return to a 24-to-1 student teacher ratio by 2020 without layoffs. The current loss of 9% of our teachers, nearly 350,000, each year means that over the dozen years between now and 2020 we need to hire only 240,000 new teachers a year to fill vacancies and reach the 2.5M mark. Our teacher workforce will still stay vibrant with plenty of opportunities and will be able to grow in effectiveness, in job satisfaction, in stature, and in pay.

5. **Connecting schools to their communities.** There is every reason to continue to think of schooling as a communal activity, but no reason to think of it as limited to the school building. There are many in the community who can help educate our young, not only college students but also the elderly, the workers in large and small companies, and even the parents during their workday. There is no reason to limit schooling to buildings open only during certain times of the day, the week, or the year. We need not have to think about radically changing the idea of a summer vacation for every child or every family, but then learning does not have to take a vacation, and administrators need not worry about snow days or sick days when students can stay connected in the varied ways that will now be available.

6. **The goal of education**. I believe that we should set as our goal that by 2020[34] every child in America will be able to achieve his or her educational ambitions and the educational degree to which he or she aspires. This will mean that 88% or more will be able to get a college degree. These are easily measured achievements. We know how to do this. We do not need to create tests or artificial lists of required topics to learn. We need only measure output. We can measure intermediate results by entrance tests indicating that we are not narrowing the funnel and leaving children behind. The only exit "test" that counts is the last one, the college graduation rate.

7. **Customized learning**. Education, as Clayton Christensen says, has to be customized.[35] One size fits all will no longer do. Today we have the ridiculous quilt of state standards for math and English which has absolutely no inherent value. Our children are mobile, they go to college in states that they do not live in, they get jobs in places they did not grow up in, and they need to have a standard of learning that they can depend on. But America and Americans are diverse and we need an educational system that can match that diversity, that can be customized by student, by community, and by state. It is not the content that we teach, but the time, the scale, the relationships, and the opportunities, that should and do differ. We can have a pluralistic educational system with content and technology of learning common throughout, but a schedule, a process, and a methodology that can vary widely.

7th and 8th grades

No segment of schooling has had more experimentation, more uncertainty about its mission, and less success than our middle grades. We have tried K-8 systems, 7-8 systems, 5-8 systems, and 6-9 systems. We have tried open classrooms, schools within schools, satellite schools, charter schools, longer schools days, departmentalization, and whole-school projects. We have tried a host of new curricula, a plethora of new teaching methodologies, and even a focus on accentuating the different intelligences that students may have. None have become canonical; none have resolved the problems, because none have effectively integrated the contradictory requirements of these years: the choice between equity for all and the rights of individual students to achieve. This is, of course, the great challenge in our society, and it is played out daily in our middle grades. This is the deepest chokepoint in American education; we all know this because we have given it the most attention.

How do we enable those who are ready and able to move forward as quickly as they can, and at the same time give all students an equal chance to succeed, to achieve their goals? This was the dilemma that caused us to create junior high schools in the first place. It is the dilemma that has driven us to try to constantly reinvent these schools. Students come out of their grade 5 or 6 heterogeneous classrooms, where the grouping that does occur is overshadowed by the essential cohesion and egalitarianism of the primary school classroom, and enter departmentalized homogeneous classrooms where grouping becomes tracking and tracking defines the life-path.

This is about to get much worse. Our elite school systems are moving quickly to push their first year algebra course to 7th grade. They are accelerating their math program because the AP calculus test has replaced the SAT as the discriminator for college entrance and therefore must be taken in the junior year. So count back, AP calculus as a junior, pre-calculus as a sophomore, algebra II as a freshman, and geometry as an 8th grader means that students have to pass what used to be the honors freshman algebra course in 7th grade! The elite students have to take algebra in grade 7 and to prevent their total segregation the regular math students will also need to take algebra in 7th grade. This enables "average students" to join the "fast track" if they are very successful and gives fast track students a landing place to drop down to.

What choice do we have? A typical sixth grade teacher with a heterogeneous class faces students with a range of five or six grades in math ability and by 7th and 8th grades the disparity is even greater. Some of his students will not have command of multiplication while others are doing algebra at home. Some are reading at a third grade level and some at a college level. Some are still mastering concrete operations while others are maturing into formal operations and abstract thinking. By 7th and 8th grades, as these students with newly raging hormones zip between Jekyll and Hyde personalities, the differences become further exaggerated. This is why every teacher who has taught these grades will tell you that these are the hardest. So we try hybrids, homogeneous grouping in math and English and heterogeneous grouping in science and social studies. We try smaller classes and special catch-up classes. We keep trying and do not even know why we keep failing.

The failure is not in the makeup of the school or in the rigidity of the tracking, the failure is in the technology of learning. The textbook technology of today forces us into rigid group-learning dependent classrooms. It forces most teachers to narrow the scope of their instruction in such classrooms, treating the whole class as a single learning unit. It forces administrators to make impossible choices between a caring, flexible, and egalitarian system and a European-Japanese-style exam system that routes students to particular learning paths and into rigid social segments. These choices lead school systems that currently have K-8 elementary schools to think about some kind of middle school arrangement for in such systems with just a few classes at the junior high level, there is little opportunity for such "necessary" segregation of students.

How does this change if we give every child in the 7th and 8th grade their own computer as their primary learning technology? It is easy to imagine that with software readily available today, a student who needs fluency practice in his or her multiplication facts could practice online. It is easy to imagine that students with holes in their math background could fill them. It is easy to imagine a computer-based, individualized, and adaptive practice system that all students could benefit from, becoming much more procedurally fluent and ready for algebra. It is easy to imagine that students who are ready could be studying algebra through an online course taught by a competent algebra teacher. And it is easy to imagine how students could work together online and in person on exciting and interesting authentic problems with the power of the Web to build flexible thinking skills and explore mathematical patterns that govern their lives.

Such a new technology of learning in the hands of our children could have profound effects in every subject area. For example, this ability to take courses online would mean that students could choose from a wide variety of courses. Students at this age are interested in a wide variety of topics and they should have a wide variety of experiences. Why can't their science courses and their history courses reflect this? Why should they wait for high school and in many cases for college before they can do interdisciplinary studies? We have usually limited students to bland and generally uninspiring general courses in these two subjects, but with a wide variety of online courses at various levels, we could give all students the opportunity to pursue their interests and their dreams. Such courses could be taught by middle school teachers and reach out across schools and even school districts. And such courses could be taught from many other venues: colleges, museums, nonprofit groups, government and even for-profit companies. Our middle school students could have access to a rich treasure of courses in all subjects, courses that could be great fun and highly challenging, providing direction to their learning and their lives. These students are a natural audience for such courses.

Finally, could a computer in every student's hands help them to master English as well, where text is the critical component? Computer programs in use today have already proven their ability to improve reading fluency just as they have improved math fluency. They can provide books and other written materials at just the right level for practicing reading. They can be used to grow vocabulary rapidly so that students who are behind can catch up to their peers. They can even be used to diagnose reading difficulties and provide exercises for them. Using the computer as a tool to help students learn to read does not mean that all reading occurs only on the screen; we have long brought trade books and other reading materials into our classrooms and we will certainly continue to do that. It does mean that reading exercises and reading assessments can and should be done online. Books on the Web can give every teacher the ability to find content at just the right level and interest for every student.

Word processors improve student writing, editing, communicating, and publishing. They make writing easier to produce, edit, read, and of course share. We all know about word processors, but there are also programs that help students organize their thoughts, write outlines, and generate ideas. We can also easily imagine other web-based writing tools that could enable students to take notes and organize them in a variety of ways. And we can further imagine new software that lets students critique each other's work in shared ways. Most adults today write on the computer screen and would never go back to pen and paper. There is a reason for this: productivity. It is the same reason that our children should be learning to write on computer screens certainly by the time they reach 7th grade.

11th and 12th grades

Today, as we place great emphasis on making college affordable, on opening the college door to all of our children, the barriers to a college education are not just about money. They are just as much a problem of “preparedness,” or what many call the “achievement gap.” The great egalitarian institutions of higher education, the community colleges, enroll approximately half of all college students. However, most of these students are ill prepared and walk through a revolving door.

The revolving door is better known as “Developmental Studies.” Students call them the “killer courses” because they kill their dreams. The colleges call them “developmental courses” to camouflage their remedial nature and the waste they represent. The majority** of incoming community college students must take at least one developmental math course. With an average failure rate of 50% in each developmental math course, the chances of a student successfully exiting this program and beginning her college education is under 20%! Community colleges devote more than half of their math classes[36] to these non-credit courses. The developmental math courses are the biggest cause of college dropouts, the killer of college dreams, the barrier to a better life.[37] And they don’t count for credit toward a college degree. How can we fix this problem?

There is a great asymmetry in high schools today. We prepare our upper-level students for college through extensive AP programs that get them ready to take AP exams, which mark their readiness to take higher-level college courses. Yet, we do not do the same for the rest of our students, even though there are placement exams[38] that they will take to mark their readiness for college. We expend great effort getting the lower achieving students ready for their 10th grade NCLB tests in math. Then we generally forget about them in that subject. Many high schools still require only two years of math. By the time these students take the college entrance placement tests toward the end of their senior year, they have forgotten or lost fluency in the math they learned and then fail that test.[39] To make matters worse, the typical high school program with Algebra I in 9th grade and Geometry in 10th grade never teaches these students Algebra II, which is on the placement test. Is it any wonder that these students then fail their college entrance math exam? Is it any wonder that they are not college-ready?

We should treat these high school students the same way we treat the upper-level high school students. We should give them college-ready math courses as juniors and seniors to prepare them for the college entrance exam and for success in their college math requirements. Some high schools are trying to do this by adding to their math requirements in high school. Unfortunately high school courses and college courses differ in focus and in content. Students who have borderline understanding in math and learn mainly by rote do not transfer or generalize their learning. They see the placement test as a completely different kind of math. To be useful, the new college-ready courses, like AP courses, have to be aligned to college expectations. Hopefully, these expectations should change with time for they represent an inordinately procedural vision of mathematics. But it is the entrance test that rules and not the exit test.

** I believe this is a very conservative estimate and that more than 2/3rds of community college entrants will take one or more of these courses.

We also cannot be doing just more of the same, for the experience of these students in their long failure to learn math cannot be remedied with just more of the same. We would only be making the same mistake that the colleges are making today. What leads us to believe that simply repeating the same material again in the same way will finally enable these students to learn it this time? And even if we could come up with new types of textbook courses that tried to make math more accessible and more interesting, we do not have the math teachers to make this happen. The severe nationwide shortage of qualified math teachers in K-12 would only worsen if we actually increased the number of required math courses in our high schools and taught them in the traditional way.

There is an alternative when we approach the problem through the new technology of learning, for there are online courses available that can be taught by skilled, retired professionals. Such programs based on the methods described earlier already exist. Students could be supported by their own online learning managers who customize their program, who assign practice, and who monitor progress to prepare these students to be college-ready in math and to pass the college entrance math tests. Such a program would also work to prepare students to be college-ready in English as well. Such programs would focus on reading and writing skills because even though most high schools require English through the 11th or 12th grades, many of these courses are literature-based. High schools could give students these online college-readiness courses and even give students the college placement exams. Students would start college with success and not with failure.

The new technology of learning could have significant benefits for AP-level students as well. There are more than 30 different AP courses and exams. Even the best high schools can manage fewer than a dozen such courses. Here again the problem of finding qualified teachers for math and science presents a huge barrier, especially in urban and rural districts. Online AP courses have been tried with limited success, but as online learning matures, new versions of these courses built on the precepts described earlier could radically change the AP landscape and offer a much more equitable opportunity to all of our children. A computer for every student in the 11th and 12th grade chokepoints can help many more of them to become truly college-ready.

3rd and 4th grades

The use of technology to build fluency for the multiplication facts is so obvious we need not dwell on it. But it is worth us taking a moment to think about the reasons for this need. In the days before the recent acceleration of the curriculum, the "math facts," as they are known, were the main subject of 3rd grade arithmetic. Teachers drilled and drilled students on the multiplication facts in 3rd grade and then students learned the multiplication and division algorithms in 4th grade. Today, as part of our general acceleration of the curriculum, we have pushed these algorithms for two digit multiplication and one digit division down to 3rd grade. They have squeezed out the facts!

Now in this age of the ubiquitous calculator some may argue that full fluency in these facts, like full fluency in the algorithms, is unnecessary. Spending a full year and a half of every student's math learning time trying to master the three-digit multiplication algorithm or the two-digit division algorithm may indeed be a waste of time. But the facts are a very different story. Fluency in the facts is critical. Without it a student cannot do mental arithmetic. Without it a student cannot solve a simple equation or find a ratio. Without it a student cannot do a simple integral or understand how to factor a quadratic equation, or even graph a function.

There are a number of new programs available to help students achieve fluency in the addition and multiplication facts. We need to make these programs available to all our 3rd and 4th graders for five minutes of practice a day. The only way to do this is to be assured that they each have their own computer. We should never again have to be frustrated that our students have not mastered the multiplication facts. Accomplishing this is easy: the programs exist, the need exists, and teachers know how to handle these kinds of programs. We just have to make sure that every 3rd and 4th grader has his or her own computer.

Fourth grade is also the place where our students start working with fractions. For so many, this is the critical point of inflection where their understanding of math ends and they start seeing math as difficult and themselves as failures. We need new ways to help students learn these subjects; we need the visualization that the computer enables. So how do we help teachers learn how to use technology to present such concepts in new ways?

A very strong argument can be made that to teach math at one level you have to know math at the next level. To teach algebra you need to know and understand calculus. To teach arithmetic you have to know and understand algebra. This is because the next level of math makes clear why the methods and conventions of the lower level math exist, how they work, and what they do. For example, our multiplication algorithm is based on the product of polynomials. We can make a very strong argument that all of our elementary school teachers need to have a very good grounding and understanding of algebra to teach arithmetic well.[40]

So what if we gave all of our 3rd and 4th grade teachers an online algebra course focused on visualization and always related it to the arithmetic they teach? What if the elements of this course that applied to arithmetic with its visualizations and practice were also available to their students? As their teachers were learning algebra the students would be using similar visualizations and concepts in arithmetic. As their teacher applied a number line to the real numbers, her students could be applying it to fractions. As a teacher learned to factor a polynomial, her students would learn to factor whole numbers. The fundamental ideas are the same and teachers can then use their learning in algebra to help their students learn arithmetic.

The FAQs

Can we afford it? Many will say that this is a laudable goal, but they will ask this all-important question. We hear far too often that the solution to our educational crisis is more money, better teachers to whom we pay higher salaries, smaller classes, better textbooks, and smaller schools. The cost of education has tripled in constant dollars since 1960. It is today more than 7% of our GDP, almost half the cost of healthcare. We must be able to improve education without substantially increasing its cost. We must find a way to make an initial investment and then reap the benefits of lower operating costs in years to come. This we can do with the new technology of learning.

What will be the initial cost of this new technology? The bulk of the computers for the chokepoint students will not have to be purchased before the summer of 2010. By that time netbooks, which are computers with limited memory, small hard drives, and no CD or DVD players, will be fully ready for education. They will be completely internet focused for all student work will be done on or linked to the internet. By that time these computers should cost no more than $250 each and in these large numbers they could be even cheaper. Schools could purchase them on the basis of need. Schools will need support to improve their wireless capability and the bandwidth of their pipe, as well as their administrative IT. And teachers will need computers and training if they do not already have that. We are talking in the neighborhood of a $10B investment over three years.

How will this lower operating costs? Today, our student-teacher ratio hovers just above 15:1[41] with a constant call for smaller classes and increased demand for special education. Our national average per student cost is $10,000/student. If we can increase our teacher productivity using this new technology and improve our student-teacher ratio to 24:1 we would reduce our national average per-student cost to a little over $7,000. There will, of course, be new costs associated with this new technology and we will finally be able to pay teachers more, but despite these added expenses, we should be able to lower K-12 operating costs by at least, $1000 per student per year for a savings of $60B per year.

How will we measure success? The answer is easy; we already have a wide variety of measures that we use from high-stakes tests to graduation rates. We will be able to correlate these measures with individual student and teacher activities. Once again, this is not a pie-in-the-sky dream; it is happening today. With the daily feedback from student online practice and online activities, teachers, parents, and administrators will be able to monitor and continuously correlate their actions to student success. This new technology allows rapid feedback cycles, not the six-month cycles that plague the NCLB testing. At each chokepoint, the most important question must be: What percent of our students are ready for the next phase in their education? What percent of our students are ready for 5th grade? What percent are ready for high school, and what percent are college-ready? Our target is clear: we need be sure that we can remove the chokepoints from the pipeline to enable 88% of all of our children to get a college degree.

How do we train or retrain our teachers to use this new technology? Some of the new learning technologies that are now available are much less demanding for teachers. We have learned how to make them easier to use and smarter. The computers themselves have become much easier to use and much more reliable. American industry constantly faces the question of how to train a workforce to use a new technology. First of all we move in small steps. We constantly focus on lowering the threshold to the user. And we focus our staff development attention not on the technology but on enabling the student-centered classroom, in the same way that industry now focuses its attention not on technology but on production.

What is the science? The efficacy research on the use of computers in classrooms has been equivocal. This is because it has been used mainly as very short term supplemental experiences, 10 minutes a day, a unit here or there, or as an addition to an existing textbook curriculum. Under these circumstances we should not expect spectacular results and we get few. When a fully mature new technology of learning is used consistently the results are extraordinary. We have found those results with thousands of community college students who have used the EnableMath program as their complete curriculum.[††] Our research further indicates that the correlation between the number of assignments a student does to mastery and course grade is between 0.5 and 0.7[‡‡]. While the testing of this new technology of learning is critical and must be part of the continuing search for improving its quality, we should not forget that there is today no significant science behind our textbooks, just years of tradition.

What about STEM? STEM (science, technology, engineering, mathematics) is the acronym for a part of education that we have too long ignored. We have ignored it for good reason; it is very hard to teach STEM subjects well with the current technology of instruction. Many have tried over the past 50 years but failed because the full range of STEM requires highly trained teachers with a substantial knowledge of these disciplines along with the ability to teach a mix of basic skills and problem solving. We are all agreed that STEM education is necessary for our national security, and this is one more reason for us to accelerate the transition to the new technology of learning. For how can we teach the technology and engineering of today's world without using computers to do it? How can we scale the teaching of better science and better math along with the integration of engineering and technology without using the new technology of learning? A computer for every student will finally give us the ability to add a full and valuable STEM orientation to our national curriculum.

Should every student have an IEP? An IEP (Individualized Educational Plan) is the heart of Special Education. Many educators have long felt that every student should have one. The problem has always been the reality of today's classroom where individualization is extremely difficult. It takes a highly talented and energetic teacher to provide each individual with their own customized education. Here again a new technology can provide so much support that all teachers will be able to implement it. Whether we use the term individualization or customization, increased support for student learning along with a much broader range of available curriculum will enable an IEP for every student.

What about the dangers inherent in this new technology? New technologies always produce new fears. Some teachers and parents worry about controlling student use of computers that are connected to the internet. They worry that students will be constantly emailing or IMing their friends, gaming, or otherwise getting into trouble because they have this connection to the outside world. Controlling students in classrooms has always been an issue, whether with pens and inkwells, paper and spitballs, books and comic books, cell phones and iPods. Yes, kids can get into trouble with just about anything. As teachers we will have to learn a new set of processes, but we will also have a new set of tools. The very technology that can

[††] At De Anza College in Cupertino, CA, students who take developmental math class using EnableMath have pass rates over 70% in classrooms with 40 students per instructor compared with 55% pass rates in classes using textbooks.

[‡‡] These correlation coefficients are very high. Square them and you get the variance. So the number of assignments a student does to mastery represents up to 50% of all the variance associated with a student's grade in these developmental math classes.

get kids into trouble also lets us continuously monitor their activities. Balancing this, putting the emphasis on student self-control, student-centeredness, and the student's appropriate use of technology will be part of the learning and teaching experience. Teachers, administrators, and parents have always had to stay one step ahead of students on every new technology. We learned to deal with these issues before, and we will do so again.

The cost of perfection: One of Christensen's most interesting insights is that each new technology and new innovation will have flaws that the practitioners of the old technology will criticize. New technologies by their nature are more ragged, less finished, less perfected. They are new and have not gone through the cycles of use, of testing, of feedback, and of revision that the older technology did. Today publishers spend as much as $100M to develop a new elementary textbook series. They spend as much as $2M to develop a single new college textbook. New "disruptive" educational software companies developing new programs will never be able to spend these kinds of dollars, and even if that investment were possible, we cannot afford to wait the 3-5 years that such immense new projects require. Textbooks have been around in their current form for at least 150 years; educational software is just starting to reach adolescence. This is not to say that we should hold the new technology of learning programs to lower standards. But we must not judge them by the quality of 'finish' or of completeness we have come to require of textbooks. And the new technologies of learning will improve dramatically because they are still in invention mode, still learning, and still perfecting. The question we must ask ourselves is, "Will textbooks get substantially better?" For the cost of waiting for perfect is a failure to act.

Are hybrids the answer? One of the oddest concepts that I know about is called the "electronic textbook." This plan would take printed textbooks, turn them into PDFs, and put them online. That way they will be much cheaper to produce and not kill trees. The reasoning is that we will give students computers and they will then read their textbooks on them. Some educators, some lawmakers, and most textbook publishers think that this will be the next wave of educational innovation. They think that the content of the textbook, slightly changed, with images that are sometimes interactive and sometimes moving, with hyperlinks and problems which get graded online, will be the future of education. They see the new medium as an extension of the old: automobiles as horseless carriages, movies as stage plays in motion, television as radio with pictures and the internet as an extension of the phone system.

But then all new technologies were first thought of as extensions of the old paradigms. Their real power, however, their revolution, was in the new paradigm they created. When automobiles became a new form of transportation, when television became a new form of entertainment, and when the personal computer and the Web became a new form of communication they fundamentally changed the way we live. We witness today a new form of learning made possible by this new technology of learning. It is visual, it is interactive, it is student-centered, and it has little to do with the old text-book methodology whether on paper or online.[42] This paper has argued that learning is not reading long textbooks. Learning is doing, and we must reinvent our curriculum for this new technology.

The Conclusion

Clayton Christensen, Michael Horn, and Curtis Johnson in *Disrupting Class* tell us their research into technology transitions suggests that by 2014 about half of all of the new curriculum dollars will be spent on the new technology of learning. For there can be no question but that the new technology of education will replace the old technology, as all new technologies eventually do. While even this date may seem very rapid by the standards of change in our educational system, it represents a massive failure to properly educate a whole generation. This failure is particularly frustrating because all of the elements of this transformation are available to us today. Our nation has become "digital" – today's net-generation[43] is poised and indeed hungers for this transformation. This is why President Obama's promise to transform education in America, and the opportunity offered by an investment of ARRA dollars,[44] are so important. This ARRA investment can accelerate substantial improvement in student achievement. An ARRA investment in a new technology of learning can enable us to reach our goal of 88% of our children graduating college in 2020 by making students more productive now.

One of the purposes of the ARRA legislation is to make an investment in America that will enable it to lower its costs of healthcare and education. We must reduce the cost of education in America if we are to increase dramatically the number of students who complete a college degree for we must absorb the additional cost of their further education. Nor should we forget that in order to have a truly equitable educational system we must also provide a high quality pre-school education for every child who needs one. So we will need our educational dollars to do that as well. As our population ages, we need to clearly understand the reality that the education of our young must take a smaller portion of our GDP. To meet these competing demands our K-16 educational system must become much more efficient. This new technology of learning can enable teachers to become substantially more productive and we can use that productivity to increase class size and lower our per student costs.

Year	Students	Teachers	Student Teacher Ratio	Average Salary & Benefits	Teacher Cost/1000	Total Cost/1000	Per Student Cost
2008	56,000,000	3,700,000	15.14	$68,600[§§]	$253,820,000	$560,000,000	$10,000
2016	60,000,000	2,500,000	24.00	$68,600	$171,500,000	$428,500,000	$7,142[***]

As a baseline, this chart assumes constant 2008 dollars and no growth in teacher salaries or other school expenses. In reality we will have to pay for the hardware and software, pay for staff development and other training, and most importantly pay our teachers at a professional rate. These additional costs will still leave us with significant savings in our long-term per-student cost.

[§§] This number represents the average salary for teachers from NCES tables in 2008 plus 40% for benefits.

[***] This cost per student does not include any additional costs of technology, curriculum, or staff development. It is meant to be simply a raw number for comparison purposes.

America has tried again and again to remodel and rebuild its educational system. Sputnik in 1957 produced a rush of new curricula. *A Nation at Risk* in 1983 fought educational mediocrity. And No Child Left Behind in 2001 drove educational change through assessment. We have tried so often that many have lost faith that real change can occur in our schools. They have lost faith in America.

But America was created in revolution. America has again and again transformed itself. America has learned to use new technologies to strive for its most cherished belief, "that all men are created equal." America can use the new technology of learning to bring our children closer to our founders' dream by providing the education to which they aspire. America can revolutionize education.

Author

I am the president of Enablearning. A graduate of the University of Chicago with a BA in physics and an MAT in science education, I started as a high school physics teacher, taught junior high school math, coordinated the math curriculum, and started Learningways in 1980 to develop educational software. Learningways became one of the biggest independent developers of educational software. I was the Chief Science Officer at the Learning Technology Group of Simon & Schuster and founded Enablearning in 1999. Enablearning develops and markets EnableMath (www.enablemath.com), online math programs for grades 3 through college algebra based on the new technology of learning. I authored *New Physical Ideas are Here Needed: Revolutionizing Education* (2007).

The ideas expressed in *The Common Wealth Plan* have a rich and varied heritage. I am indebted to many, but can thank only a few for the help they have given to birthing these ideas, encouraging this effort, and greatly improving this manuscript: my business partner, Dr. Larry Reeves; my wife, Dr. Betty Bardige; my son Arran Bardige; and my colleagues Dr. George Blakeslee, Peter Mili, Steve Bayle, Joel Bresler, Frank Ferguson, and Lisa Camner who gave it a professional edit. I also wish to express my deep thanks to Dr. Linda Roberts for her direction and encouragement and to Dr. Isa Zimmerman for her help.

Art

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Endnotes

[1] American Recovery and Reinvestment Act

[2] Stanford Bridge Study *Betraying the College Dream*, Andrea Venezia, Michael Kirst, Anthony Antonio, Final Policy Report from Stanford University's Bridge Project, 2005, p 2,

[3] NCES 1961-62 data

[4] 2004-2005 NCES Statistics $9,266.

[5] Nearly 10% of teachers leave education each year. This means we have to replace over 25,000 math teachers in grades 7-12 alone each year. Yet we graduate less than 4,000 with a BA in math education and only 14,000 with a BA in mathematics each year.

[6] E-Rate – Funding for internet access in schools and libraries from the Universal Service Fund.

[7] Sylvia Allegretto, Jared Bernstein, and Lawrence Mishel, *The State of Working America 2004-2005*

[8] NCES Statistics http://nces.ed.gov/programs/digest/d04/tables/dt04_247.asp

[9] The normal distribution is the familiar bell curve. It is also called a Gaussian distribution. In IQ there are as many people below the mean of 100 as there are above it.

[10] Though of course it is a tragic 50% for our African-American and Latino children.

[11] The premier college calculus book in 1960, Thomas had one column text, a 6-by-9 inch form factor and about 600 pages of text. It cost about $5. Today the premier calculus book, Stewart, has over 1200 pages in two columns with smaller margins and an 8 by 10 inch form factor. It costs about $175.

[12] My professor Bruce Joyce used to say that a teacher who reads the textbook to the class should be paid what the textbook costs. But today a teacher has to do his own job and the textbook's job at the same time. So why do we need the textbook?

[13] Trademark Microsoft Corporation.

[14] http://www.wired.com/wired/archive/13.05/flynn.html

[15] I am here mainly focused on middle and high school students. Elementary school students generally do their practice in class and teachers generally grade it immediately. I have been hearing that as the work gets more complex and moves out of the school day into the home, teachers grade less and less of it. One of the reasons for this is that workbooks which in the past provided an easy grading means for teachers are now rare. And with so many other demands teachers simply find grading more complex exercises with worse student penmanship more and more difficult to sustain.

16 The National Council of Teachers of Mathematics was the first to set Standards and has been a forward thinking organization.

[17] This new productive practice technology exists today; we (Enablearning, Inc.) have developed it for grades 3 – Algebra II. And teachers and students are using it to improve motivation, efficiency, and mastery learning.

18 EnableMath is a complete online program based on the new technology of learning. It currently has content running from third grade through high school algebra and is available at www.enablemath.com

[19] This is the average number of problems students do per assignment to achieve mastery in the college EnableMath program.

[20] 21st century skills are generally thought of under the following headings: creativity and innovation, critical thinking and problem solving, communication and collaboration. I think of these skills as those of a flexible thinker, a person who can approach and solve novel problems. See Partnership for 21st Century Skills at www.21stcenturyskills.org.

[21] The National Council of Teachers of Mathematics, online at www.nctm.org.

[22] Programs like Wolfram|Alpha and Gapminder are just a two of the exciting new possibilities and potential ways that students will be able to find and build connections.

[23] My son Brenan taught algebra to high school students in Jackson, Mississippi, with Bob Moses in the Algebra Project. He believes that one of the most successful lessons they taught, based on student interest and response, was on programming the TI 83 calculator.

[24] For failure is like any addiction, it must be conquered one day at a time.

[25] The average cost of educating a student today in K-12 is $10,000/year in round numbers.

[26] School Enrollment, National Center for Educational Statistics Table 63 from 2005 – forecast 2007 enrollments 55,102,000 students.

[27] Professor, mentor, and my friend Jim Kaput gave me these important numbers. Jim, a brilliant math educator, believed in democratizing math, in teaching algebra before acne, and he proved that even inner city 6th graders could learn the essence of calculus if it was presented on a computer screen.

[28] Enablearning has been developing the EnableMath program and technology for the past 10 years. Online at www.enablemath.com.

[29] The Jumpstart program www.jstart.org sends college students into preschools to accelerate the language levels and to build quality attention for young children in need. Accelerating a student's learning at a key stage will put that student on a faster trajectory and lead to lifelong improvement.

[30] *New Physical Ideas are Here Needed*, 2007, Art Bardige. This book contains a more detailed account of many of the ideas found in this paper. It is available on Amazon or if you write me I will be happy to send you a copy.

[31] Phil Jackson, my professor of education at the University of Chicago, later president of AERA, used to talk of the liturgy of the classroom. I always thought that a very powerful insight.

32 An enterprise sale is to the institution at large rather than to the individuals. Enterprise sales to schools would be to school systems rather than individual teachers or students.

[33] I heard this from a very fine school superintendent. I believe that it represents the thinking of most superintendents in the U.S. today.

[34] "President Obama recently set the goal of again making the United States the nation with the highest proportion of college graduates by 2020, which means a lot more students who start college, will have to graduate." *New York Times* 5/28/09. While this is a great goal, we may want to think about the measure I suggest instead because it is an internal measure of our success.

[35] Clayton Christensen, Michael Horn, Curtis Johnson, *Disrupting Class,* 2008, McGraw Hill. I think that this is a terrific work and should light the way for all of us.

[36] AMATYC 2008.

[37] A similar but not nearly as devastating problem exists in Developmental English. But fewer students have to take these courses and many more pass them. Math is the big problem.

38 Accuplacer by the College Board is one such exam.

[39] Interestingly, the most popular version of the college entrance placement test also comes from the College Board. The test is called Accuplacer (online at www.accuplacer.com). ACT has a similar test called Compass.

[40] Massachusetts in 2009 has instituted a new testing program for teachers seeking certification that now separates math from other subjects.

41 Student/teacher ratios are just an indication of general class sizes. Many of these additional teachers work in special education on a 1 to 1 or 5 to 1 basis. I am arguing that we can use this new technology of learning to both reduce the need for special education and at the same time increase general class sizes while providing more and not less individualization and customization.

[42] My friends in the textbook industry generally believe that their companies will survive and prosper because they own the content. They continue to carry the delusions that Christensen describes for all companies that are undergoing revolutionary change in their technologies. We do not read extensively on computer screens and even if we do, their text heavy methodology born of their old technology of instruction will not be appropriate for this new technology of learning.

43 Don Tapscott, Growing up Digital (1997), Grown Up Digital (2008)

[44] www.recovery.gov