Presentation to the California State Senate, Informational Hearing on Technology Integration in Education*

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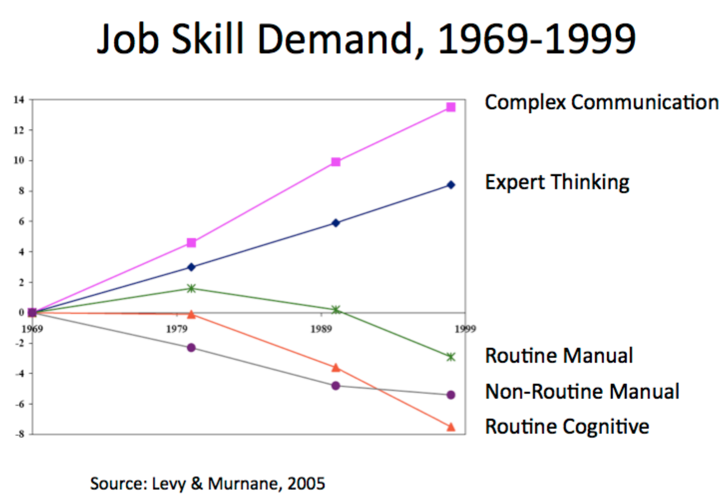
The greatness of our state and nation has been achieved through innovation. Nowhere is that more evident than here in Silicon Valley, where groundbreaking companies have helped transform almost every aspect of life, enhancing productivity, creating jobs, and reshaping our nation's information infrastructure for the 21st century. Yet, in spite of these pockets of excellence, our nation is starting to fall behind other countries in measures of education and innovation and thus gradually losing the battle for global competitiveness.

If we are serious about turning this around, we must consider the findings of Harvard and MIT economists Murnane and Levy, who analyzed changes in the US job market over a recent 30-year period. They grouped all job skills into five categories. Of those five, there has been a dramatic increase in demand in jobs requiring *expert thinking* and *complex communication*. In contrast, there has been an equally dramatic decrease in demand for jobs based on *routine or non-routine manual labor* or *routine cognitive tasks*. Indeed, routine cognitive skills are those in least demand in today's knowledge economy, yet those are the precise set of skills that our schools most focus on today.



* For further details and references on the topics addressed in this presentation, please see Warschauer, M. (2011). *Learning in the cloud: How (and why) to transform schools with digital media.* New York: Teachers College Press.

How then can we better teach expert thinking and complex communication in our schools? Research suggests there are four critical elements, each of which is highly dependent on improved use of emerging technologies. First, our students need the ability to access and understand the widest amount of educational *content*. With the quantity and quality of scientific information doubling almost every 10 years, it is no longer sufficient for students to memorize information from a few seldom-updated textbooks. Rather, they need the ability to explore, combine, and analyze information from a variety of up-to-date texts and documents across domains.

Second, students need to write, and write well. *Composition* is absolutely invaluable in the knowledge economy. Studies indicate that even engineers typically spend 30-70% of their time writing, an amount that increases with the responsibility of the position. Informational writing is also key for developing students' critical thinking skills and advanced content knowledge. As students write, and revise, and write again, they are forced to think through their ideas and make their thoughts visible for critique and feedback, leading to deeper understanding of academic subjects and the connections among them. Indeed, a large study by Reeves found that frequent information writing was a key instructional practice in what he called 90/90/90 schools, that is, schools with high percentages of low-income and minority students who are also in the highest ranks in academic achievement.

Third, students need opportunities for *construction*. They need to work with ideas to build their own models, plans, projects, and designs. There is no better way to build innovative leaders for the future than by giving people chances to create and innovate in childhood. That too is evidenced in Silicon Valley, where we find so many IT leaders who got started by designing, building, and remaking things as youths. Not all our young people have the tools or social support to tinker with technology at home, but we can and must give all the opportunities to engage in creative design in our schools.

Finally, students need to engage with a *community* of peers and mentors. The development of expert thinking and complex communication do not take place in a vacuum, but rather by developing and sharing ideas with others inside and outside the school environment. This is precisely how many of our most privileged and highly motivated youths learn today—by joining communities online where they interact with experts around the world. Once again, we need to bring these same kinds of networking opportunities into the classroom.

Now, the best schools have long sought to provide these elements—content, composition, construction, and community—even without technology. Yet the world has changed. How in today's world can students access and reflect on a broad array of content without the Internet? Who, outside of school, would even attempt to write any serious quality document without use of a computer or digital device? What process of design or modeling takes place today without digital media? And how can students best connect with a community of peers and mentors, near and far, without online communication?

Looked at this way, the benefits of digital media in schools become evident. Yet computers on their own do not make you smart any more than a stove on its own makes you healthy. Rather, in both cases, the benefits depend on the ingredients. And there are four essential ingredients to improving education with technology: infrastructure, curriculum, pedagogy, and assessment.

Infrastructure

As for infrastructure, we have to find a way to provide an Internet-connected digital device—whether a laptop, netbook, tablet, or Web-device—to all learners, at least once they reach upper elementary grades and are capable of autonomous learning with diverse academic content (this is referred to as a "1-to-1" environment). Again, it is useful to think outside of school contexts. There are few adults in the US who are expected to engage in serious knowledge acquisition and production—whether in higher education or the workforce—who do not have access to an individual digital device (and in many cases multiple devices). Students sharing digital devices, with one computer per 4 to 5 students as is often the case in California schools, makes about as much sense today as sharing one pencil among five learners did yesterday. The only real question is whether we can afford 1-to-1 access, a question I'll return to later.

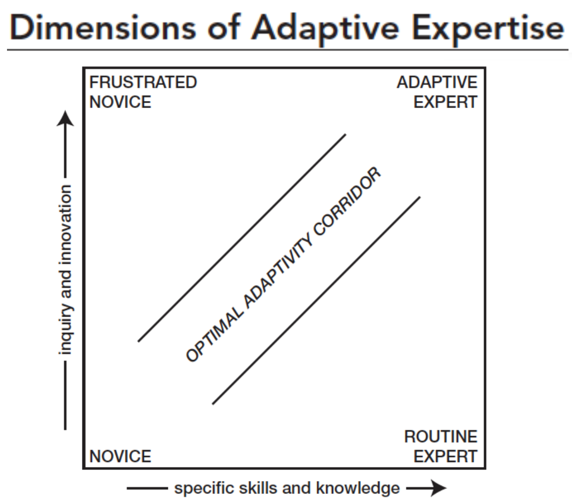
Digital textbooks and curricula represent another important element of infrastructure. Digital materials are not only less expensive than printed ones, but are more flexible, updatable, and interactive. For example, an organization called CK-12 produces free digital textbooks that meet California standards and can be downloaded, remixed, or edited—and include links to extra material, animations, and videos. A wide range of other open educational resources are available online, including inquiry-based science learning environments. Digital textbooks and curricula also make possible important forms of support for English learners and struggling readers, such as the Live Ink program, which automatically converts material from traditional block text format to a syntactically-organized cascaded format that better matches how the eyes and brain process information.

Other important elements of infrastructure include new cloud-based tools such as Google Apps for Education, which can be freely accessed from any Web-connected device and used to facilitate individual or collaborative writing, data analysis, and interaction. There is also a wide range of affordable software and apps to meet the needs of diverse learners. For example, on the iPad, we have general apps such as iAnnotate, which is being used from medical schools to middle schools to promote more active student engagement with texts, to targeted apps such as Proloquo2Go, which assists communication for children with special needs, thus replacing the need for specialized devices costing thousands of dollars and often seen as stigmatizing.

While this new infrastructure is a necessary element of educational reform, it is insufficient without three other ingredients: new forms of curriculum, pedagogy, and assessment.

Curriculum

As for curriculum, we need to move beyond basic skills to an organization of academic content that allows for the development of *adaptive expertise*. An emphasis on inquiry and innovation without building a foundation of specific skills and knowledge is useless, as it only leads to frustration among learners. However, a focus on specific skills and knowledge without inquiry and innovation is limited as well, as it focuses exclusively on the kinds of "routine cognitive" abilities that are losing importance in the job market. Adaptive expertise combines the mastery of specific skills and knowledge with the ability to rethink and repurpose them in innovative ways.



Source: Bransford, J., Mosborg, S., Copland, M. A., Honig, M. A., Nelson, H. G., Gawel, D. et al. (2009)

One example of an innovative curriculum that works toward adaptive expertise is in the area of robotics. Robotics youth teams participating in local and national competitions have become quite popular in recent years, but they are typically organized through extra-curricular after-school clubs. Dos Pueblos High School in Santa Barbara has taken this much further by integrating robotics projects within its highly innovative Engineering Academy. This, in turn, has required a serious re-working of the curriculum to achieve, on the one hand, better integration among different disciplines, and, on the other hand, better integration of knowledge and innovative application. For example, students in the academy, instead of taking separate one-year courses in physics, engineering, and art, with each course too rushed to cover more than the basics, now take an integrated three-year interdisciplinary course in physics, engineering, and art, which allows better integration of theory and practice throughout as students earn partial credit in each subject each year. Within this three-year course, students learn all the requisite theory but also have time take on small projects, such as designing and making simple toys for children in need, and then a larger capstone project, such as collaborative design and construction of a large kinetic sculpture for a community organization. Then, as seniors, they participate in a one-year robotics competition, in which they take both theoretical and applied courses that guide them in their design of robots that meet specified challenges.

Pedagogy

As seen from the above example, issues of a new curriculum are closely integrated with pedagogy as teachers assume new roles to help their students develop innovative expertise. At King Middle School in Maine, all instruction is carried out through three annual 8-to-12 week interdisciplinary projects, which are jointly planned by teams of math, science, social studies, and language arts teachers. The projects, called learning expeditions, involve collaborative inquiry on thematic issues, leading to sophisticated products including both student writing and new media development. Examples include a CD on endangered animals that eighth grade students produced and that was shared throughout the state, and a digital and printed book sharing the stories of civil rights leaders in Maine. Interestingly, standardized test scores at King are far above the norm for the state, even though the school has the highest percentage of English learners, about 25%, of any school in Maine.

Note that neither King nor Dos Pueblos make "computers" an object of learning. Rather, computers and other digital media become essential tools in knowledge production, just as they are for adults in universities and professional life. These schools are not teaching "hammer," they are teaching "carpentry."

Note as well that teachers in these contexts also play new roles. It is often said that teachers in the digital classroom must be prepared to be "guides on the sides," but to leave it at that would be simplistic. Rather, teachers must play a variety of roles, as orchestrators, designers, editors, lecturers, mentors, coaches, and evaluators. Thus while some people see computers as replacing the need for good teachers, in fact, the effective integration of digital media in learning requires very well prepared teachers.

Assessment

Finally, we get to what is arguably the most important ingredient of all: assessment. Educational assessment is a multi-billion dollar industry in the U.S., but one that, unfortunately doesn't promote the kind of innovative learning our students and country need to compete in the 21st century. By analogy, let us consider another kind of assessment, that for driving. We actually have two driving tests: one that measures knowledge of the rules, through a multiple choice test, and one that evaluates people's actual ability to drive a car, through a road test. You have to pass both tests to be considered a qualified driver.

In our schools, for the most part we only have the first of these, the multiple-choice test, but we lack the second, the performance assessment. There are a number of excellent suggestions for what these road tests for learning could look like, but all require actual application of knowledge through in-depth thinking and communication. For example, to assess the ability to analyze data, second-grade students might be asked to interpret the data on heights of their classmates and prepare a chart for the first-graders that helps them understand how students change from one year to the next. To demonstrate more advanced analytic skills, twelfth-grade students could be asked to interpret the data on the spread of the H1N1 infection on each continent over 12 months and prepare a Website or newspaper article for a public audience that explains the spread rates in relationship to seasonal variation, international travel patterns, and government policies.

Now, let's see how assessment fits in with technology use in schools. Again, returning to the driving test example, if the only test required for a driver's license was the written test, there would be no reason to incorporate actual vehicles, or even driving simulators, in drivers' education. The only thing you would need is a book of rules for people to study. Cars and simulators are useless to prepare people to memorize driving rules, but absolutely necessary if you want to teach people to actually drive.

In schools, the same logic holds. If we are only preparing learners for multiple-choice tests, as is so often the case in schools, the value of integrating technology is unclear. But if we are actually preparing people to perform academically, to construct experiments and analyze data, to carry out authentic research and write compelling papers, then access to the tools used for that, such as hardware, software, and online networks, is critical.

Finally, in addition to making assessment more performative, we also need to make it more *formative*. Perhaps the single best way to help all learners achieve is to provide consistent feedback on their performance and opportunities to improve—in other words, frequent formative assessment rather than just one-shot summative assessment. Good schools have tried to provide this kind of formative assessment anyway, but there is absolutely no substitute for digital technology in facilitating frequent evaluation of student work and feedback on how to improve it. Just to give one example, the new digital algebra textbooks produced for the iPad by Houghton Mifflin don’t just have quiz answers in the back of the book, as is typically the case in textbooks, but also provide fast automatic scoring of student quizzes, together with links to in-depth explanation of how problems can be solved. What's more, assessment results are communicated instantly to teachers, so they can see where improvement is needed both by individuals and classes.

Two Examples

Now, not all schools get these four ingredients right. Let's look at two examples.

In 2009, Birmingham School District distributed 15,000 low-cost "XO" laptops to students as part of the international "One Laptop per Child" (OLPC) program. The Birmingham program was initiated by the former mayor of the city, who believed, as did the OLPC founders, that if we simply give students laptops and get out of their way, they would do amazing things. Thus there was virtually no funding provided for Internet access, curriculum development, teacher training, or even computer maintenance.

Though students received the computers enthusiastically, the results were disappointing. The tiny XO laptops with their unique interface and operating system were very difficult to use by teachers. With almost no professional development or any district-developed digital curricula or assessments, teachers had little incentive to integrate the laptops in instruction and few did. Even those who wanted to use the laptops struggled mightily since, without Internet access, servers, or connections to projectors or printers, it was very cumbersome for teachers to even access student work done on the laptops. In addition, the low-cost XO computers proved to be less of a bargain than expected; they started breaking down quickly and nobody knew how to fix them or had the money to do so. Within 18 months, the majority of the laptops no longer functioned. Soon thereafter, the district abandoned the program, which had come to be viewed as a costly lesson.

In contrast, Saugus Union School District, in Los Angeles County, started its 1-to-1 program with a more focused intervention in fourth grade classes. As in Birmingham, students were provided low-cost netbooks, but in this case carefully chosen ones that were easier to maintain. An open source software platform was developed that made support and update of all applications painless and provided an easy-to-use interface for teachers and students. The student netbooks were incorporated in support of a curricular initiative carefully designed to improve student writing. Teachers were trained in the curriculum, and an appropriate support infrastructure was developed, including wireless access in all classrooms, a district-wide writing environment including blogs and wikis, and specialized software that provides writing tools and rubrics and facilitates assessment and feedback. As a result, the netbooks are used extensively on a daily basis, the program has been highly popular with teachers, students, and parents, and tests scores in writing and English language arts have gone up, with the greatest gains among Hispanics, English learners, and students from low-income families.

Can We Afford It?

The example of Saugus is also helpful for returning to the question I asked before: Are 1-to-1 programs affordable? Saugus is using netbook computers with an open source operating system that costs, together with maintenance, about $300 over a four-year period, or about $75 per student per year. According to district officials, the remainder of its expenses—for network services, software, technical support, and professional development—come to another $55 per student per year. The total cost is thus about $130 per student per year.

Not all 1-to-1 programs are that inexpensive. Those using tablets or regular laptops will cost somewhat more. The statewide laptop program in Maine, for example, which uses MacBook computers, costs $242 per student per year for an all-inclusive system that provides laptops, warranty, software, wireless infrastructure, an online learning system, and staff development. The estimated cost for a program with iPads or tablets would be somewhere in-between.

In contrast, some districts are moving to "Bring Your Own Device" programs that are less expensive. In these programs, families are encouraged to send their children to school with their own netbook, laptop, or tablet, with the school providing computers only to those students who don't bring one. Any needed educational software programs or applications are accessed online. These programs costs substantially less for hardware, software, and technical support, and, depending on the degree of family participation, may total under $50 per student per year for district expenses.

There can also be substantial *savings* from 1-to-1 programs, especially if organized statewide. A group called Project RED has estimated the total savings per year of a national transition to 1-to-1 programs to be $459 per student. About half of these saving would be seen directly through the purchase of lower-cost digital textbooks and materials, lower photocopying costs, lower costs of online assessments, a reduction in paperwork, and simplified student data mapping. The other half would be longer-term savings achieved, for example, by reducing the need for disciplinary actions or remedial education. Other possible savings, such as through better use of classroom space due to a need for fewer computer laboratories, are not included in the Project RED report.

The Project RED estimate was based on national costs and savings, and may or may not translate precisely to a California context. The bottom line though is that, whenever we consider the costs of a school laptop program, we also need to consider the savings entailed. If all of these savings were accurately captured at the state level, and appropriate steps were taken to facilitate access to digital curricula and assessments, I expect that a statewide 1-to-1 initiative could be organized that would be very inexpensive or perhaps cost-neutral. The question is whether we have the will to seriously examine this question at the state level so as to best leverage our resources for improving and modernizing K-12 education.

Conclusion

With the science and technology necessary for basic manufacturing now spread throughout the world, the United States can no longer compete on the basis of making and selling basic commodities. Rather, our competitive edge comes from how well we produce products, services, and technologies that are new, special, and non-standard. The value of such products does not reside primarily in the material or labor that goes into them, but rather in their innovative design. That is the story of the success of Apple, Inc., for example, and all the other innovative companies that have helped make California the eighth biggest economy in the world.

Yet, using Apple as an example, no matter how brilliant its founder, Steve Jobs, was, I have a feeling that, if he had grown up anywhere else but Silicon Valley, he may not have become such a great technology entrepreneur. By all indications, his early experiences working with technology—such as when a neighbor who was a Hewlett-Packard engineer brought Jobs to the company for lectures, activities, and hands-on projects—were critical to his intellectual and career development.

Not every young person is fortunate enough to have those kinds of mentorship experiences *outside* of school. But we can ensure that all students have the experiences of innovative learning with technology *in* schools. Such is the path required to help keep our state, and nation, great.

School districts throughout California are improving instruction with technology, but the challenge is too big and too important to be addressed at the local level. I would suggest that a statewide commission examine these issues holistically to develop cost-effective technology-rich programs that incorporate new forms of infrastructure, curriculum, pedagogy, and assessment. Working together in this way, we can give all our children a chance to become the knowledge entrepreneurs of the future.

Thank you very much.