Ubiquitous Mobile Technologies and the Transformation of Schooling

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Over the past decade, trends in education have increasingly begun paralleling trends in industry. In both cases, the advent of mobile broadband technologies is enabling individualized, personalized experiences within collaborative communities. Indeed, according to the Federal Communications Commission (2009), over 95.6% of all Americans live within the coverage of at least one mobile broadband network, and yet the use of mobile broadband technology for innovation in education is only just in its infancy.

This article explores how the Internet and mobile broadband technologies that are transforming the work of business professionals may be applied to the work of teachers and students in K-20 schooling, with similarly transformative outcomes. First, we discuss the ways in which ubiquitous mobile technologies are changing 21st century business. Then, we describe potential uses of these devices in and out of school and provide examples of current leading edge applications. We conclude by delineating Qualcomm's role in advocating and aiding this evolutionary progression.

Ubiquitous Technology Empowers 21st Century Business – and Potentially Schools

Technology advances leveraging the Internet and always-available, always-connected personal devices have changed the nature of professional work. At Qualcomm, which exemplifies best practices in leading edge workplaces, we once needed to be in offices to have access to the tools of our professions and to our colleagues. Now, via the Internet, that access travels with us to our homes. Many workplace capabilities follow us everywhere via devices that fit in our pockets. Because of this ubiquitous empowerment to create and share professional knowledge, we have unprecedented flexibility in how and when we perform our work.

Thanks to connected web-based and mobile software distribution platforms, the field of software engineering has moved to "Internet Time"; on a daily basis, software professionals can build and release new features to an existing software base, put these in the hands of users, monitor the effectiveness of those new features, then tweak and re-release—all within 24 hours. E-mail, blogs, and other forms of Internet communication now enable corporate communities of practice in which our colleagues share experiences, reflections, and insights in a continuous dialogue not bound by the four walls of an office or the hours of the work day.

This "collective intelligence" infuses our work lives with the kinds of collegial practice that are the hallmark of research disseminated in professional journals and conferences (Dede, 2009). And journals and conferences themselves have moved to

Internet Time: Current articles and texts are published on the Web, making the state of the art immediately accessible to practitioners, and the availability of these resources is instantly broadcast through "outreach" media like Twitter. Overall, the 24/7 asynchronous communication capabilities of our mobile devices and ubiquitous tools allow us to take control of our work day and extend our collaborations in ways that significantly enhance our efficiency and effectiveness.

This shift at Qualcomm and in 21st century workplaces in general exemplifies a sweeping change in our economy. The types of work done by people, as opposed to the kinds of labor done by machines, are continually shifting as computers and telecommunications expand their capabilities to accomplish human tasks. Economists Frank Levy and Richard Murnane (2004) have documented a very important aspect of what constitutes 21st century understandings and performances:

> Declining portions of the labor force are engaged in jobs that consist primarily of routine cognitive work and routine manual labor—the types of tasks that are easiest to program computers to do. Growing proportions of the nation's labor force are engaged in jobs that emphasize expert thinking or complex communication—tasks that computers cannot do. (pp. 53–54)

These economists go on to explain that "expert thinking [involves] effective pattern matching based on detailed knowledge; and metacognition, the set of skills used by the stumped expert to decide when to give up on one strategy and what to try next" (Levy & Murnane, 2004, p. 75). What a skilled auto mechanic does when all diagnostic systems show normal functioning, but the car is still malperforming is expert decision making: inventing new problem solving heuristics when all standard strategies have failed.   "Complex communication requires the exchange of vast amounts of verbal and nonverbal information. The information flow is constantly adjusted as the communication evolves unpredictably" (Levy & Murnane, 2004, p. 94).   A skilled teacher is an expert in complex communication, able to improvise answers and facilitate dialogue in the unpredictable, chaotic flow of classroom discussion. But now these teachers must also inculcate similar skills in students.

In ways that closely parallel the transformations in industry, mobile wireless devices and ubiquitous tools have the potential to transform teaching and learning in K-20 schooling. When this potential is realized, students will benefit from 24/7 access to digital curriculum that is highly personalized with respect to level, pace, and learning style. Teachers will benefit from digital participation in communities of practice with global reach and from dashboards that actively display real-time data regarding their students' progress. As wireless education technologies allow learning to expand beyond the four walls of the classroom and the hours of the school day, teachers will gain flexibility in how they can use precious classroom minutes. In this vision, education researchers too will benefit from a platform that allows the distribution and evaluation of innovations in Internet Time. The next section documents the role that current and emerging technologies can play in this

kind of 21st century learning environment, in which students' and teachers' work increasingly resembles the practices of business professionals.

<u>Empowering Students and Teachers through Mobile Devices and Ubiquitous Tools</u>

Students: In the 21st Century learning environment, students will use the Internet as an important research tool, learning to validate the credibility and accuracy of sources, detect bias, and draw conclusions by analyzing and synthesizing large quantities of varied input. Detailed conceptual frameworks for articulating these skillsets are emerging, with associated rubrics for assessing progress. A good example of this is the Personalization by Pieces framework developed by Cambridge Education (http://www.camb-ed.com/).

Also, students will use collaborative authoring tools to share their work, engage in peer critique, and publicly revise and iterate their work products. The teaching at O'Farrell Community School in San Diego illustrates this approach (www.edutopia.org/creating-culture-student-reflection). "Critique circles" of peers were used to aid students in evolving their designs for stamps the country of Guinea could issue. At the end of the academic year, these design products and processes were presented to the community in individual student portfolios.

Students will publish products via electronic media with the goal of community exposure and the possibility of global reach. These products will set, maintain, and, over time, raise the community standard of quality work.   A current example of this is the Global Kids project, supported by Microsoft and a number of philanthropic foundations. Since 2002, Global Kids (www.globalkids.org) has been a leader in youth developing and disseminating online games to promote global awareness, engaged citizenship, and 21st Century skills. Through the Playing 4 Keeps program (P4K), Global Kids helps urban youth to develop games about important social and world issues.

Teachers: Teachers and peers will coach students on their critiquing skills, creating a learning community that supports the development of true expertise-building. Much of this dialogue will happen using wireless education technologies for 24/7 digital communication. Just as students will benefit from a peer learning community, teachers will continue to form more widespread communities of practice in support of their profession, using evolving collaborative learning and Internet publishing tools. The Teachers Learning in Networked Communities project (tlinc.wordpress.com/), funded by Microsoft as an example of scaling up promising initiatives through technology, is an example of this trend.

Curricula will evolve from static textbooks to immersive, interactive learning environments (Committee for Economic Development, 2009). Nearly all content will be delivered digitally in a hyper-linked, non-linear format that supports exploration, broad overviews, and deep dives. Content will be multi-modal, with video, text, digital images and interactive game-like experiences. As students work

with this digital content, their interactions and performance will be monitored, analyzed and used by researchers, students, teachers and parents to support learning.

Beyond merely bringing models of content and assessment from the paper-and-pencil world to the mobile device, assessment will, over time, come to be an invisible part of learning (Quellmalz & Pellegrino, 2009). As students immerse themselves in engaging learning experiences, their personalized mobile devices will understand their level of mastery based on their engagement with the material. Further, the statistics from all students will be aggregated and analyzed for patterns indicating specific learning challenges. Students' challenges and appropriate interventions will become part of the data available to teachers.

Formative assessments and student progress will continually update in real time, allowing a dashboard picture of student progress. This data will aggregate to show the progress of a class, a school, or a district. At each level, red flags will highlight issues identified sufficiently early to permit successful interventions, such as diagnosing a learning disability or determining if a particular school is on track to report adequate year-over-year progress in connection with applicable statutory requirements (i.e, No Child Left Behind (NCLB), etc.).

The digitization and consequent modularization of curricula will support customization to a given state, district, school, or even student. Educators will have access to both formal, approved curricula from multiple content providers and informal and user-generated content. Learning Management Systems will evolve to allow mix-and-match mash-ups of content according to what is appropriate for a given class or student at a given time. The Open Learning Initiative at Carnegie-Mellon University (http://oli.web.cmu.edu/openlearning/) illustrates how authoring systems to accomplish this goal are now available.

Clear, online, real time data visualization showing student progress and achievement, as well as remaining goals for the week, semester and subject area will inform students, teachers, and parents. Students and parents will share educators' insights regarding curriculum elements as a whole, which elements the student has mastered, and which ones remain in order to achieve subject area mastery. In addition to school-based learning, parents will be able to purchase online, digitally-delivered learning materials, tutoring, and multimedia experiences that support the child's learning and development.

Distance and computer-aided learning will play a large role in formal K-12 education. Certain types of easily testable learning, particularly those associated with facts and procedures, basic math, science, historic events and timelines, have traditionally been targeted for computer-aided skills building. With intelligent tutoring systems technologies, this type of teaching is now possible on wireless mobile devices that are available anyplace, anytime. As Heffernan's research with the ASSISTment project has shown (Feng et al, 2009), teachers can configure

individualized student experiences that result in both substantial gains on summative tests and in deeper knowledge of the underlying subject matter.

A major benefit of such digitally delivered content is personalization to specific learning styles (i.e., visual, auditory, kinesthetic, etc.), level, and pace. Distance learning shares many of those benefits, and the availability of an online teacher and student peer group more strongly supports the kind of interaction and discourse that build higher order critical thinking skills. With the advent of Web 2.0 technologies, many of the dynamics of a classroom can now occur asynchronously after the formal school day is complete.

Student engagement in school will increase, as will educational outcomes, because the wireless devices build on strengths and preferences youth have developed by using these tools outside of classroom settings. A good example of a blended model that combines both face-to-face and distance learning to motivate students is Project K-Nect, a pilot program that began in 2007 to explore whether smartphones with mobile broadband connectivity could increase students' interest and achievement in mathematics (http://www.projectknect.org). The pilot involved 100 "at-risk" 9th grade students in rural North Carolina who were provided a smartphone containing supplemental mathematics content and online collaboration tools with 24/7 wireless connectivity. The first phase of the program demonstrated positive qualitative and quantitative results. In the most successful classroom, class proficiency rates were 30% higher on their State End of Course exam compared to students who were taught the same subject matter by the same teacher but without the use of the smartphone.

Significantly, the K-Nect project also demonstrated that a major contributor to the students' success was the e-classroom support structure made possible with 3G connectivity, which allowed students to connect with their peers, tutors and teachers after school hours and outside the classroom walls. With mobile broadband connectivity, students, who otherwise lacked access to the Internet at home, were visiting helpful web sites, such as algebra.com, and communicating with each other via blogs and instant messaging to assist each other with algebra problems. In a research report completed after Phase I of Project K-Nect, students reported they spent more time working on algebra outside of their class than they did before they received their smartphone.

Less direct student/teacher interaction is required for this kind of learning, which, in turn, enables a fundamental change in school structure. Much digital learning will occur outside of the classroom, leaving precious classroom time with the teacher for the development of higher-order skills, such as critical thinking, problem solving, project-based collaboration, and communication. Initially, classroom time might involve face-to-face elements of inquiry-based scientific experimentation, literary analysis, contextual analysis of historic events, etc., while computer-aided learning might provide extensions of that work in addition to engaging and immersive

learning of content, more akin to online gaming than lectures and webinars (though those will also have their place).

Learning is a human activity quite diverse in its manifestations from person to person (Dede, 2008). Consider three activities in which all humans engage: sleeping, eating, and bonding. One can arrange these on a continuum from simple to complex, with sleeping towards the simple end of the continuum, eating in the middle, and bonding on the complex side of this scale. People sleep in roughly similar ways; if one is designing hotel rooms as settings for sleep, while styles of décor and artifacts vary somewhat, everyone needs more or less the same conditions to foster slumber.

Eating is more diverse in nature. Individuals like to eat different foods and often seek out a range of quite disparate cuisines. People also vary considerably in the conditions under which they prefer to dine, as the broad spectrum of restaurant types attests. Bonding as a human activity is more complex still. People bond to pets, to sports teams, to individuals of the same gender and of the other gender. They bond in different ways, to others similar or opposite in nature, for short or long periods of time, to a single partner or to large groups. Fostering bonding and understanding its nature are incredibly complicated activities.

Educational research strongly suggests that individual learning is as diverse and as complex as bonding, or certainly as eating. Yet theories of learning and philosophies about how to use ICT for instruction tend to treat learning like sleeping, as a simple activity relatively invariant across people, subject areas, and educational objectives. Current, widely used instructional technology applications have less variety in approach than a low-end fast-food restaurant. Now all that is changing with the advent of mobile wireless devices supporting ubiquitous tools that enable every conceivable form of teaching and learning, creating an ecology in which each student can find an appropriate niche.

As Web 2.0 technologies are integrated into a 21st Century curriculum, the lines between all types of pedagogy will blur, and the freedom afforded teachers in optimizing the use of classroom time will continue to increase. Students will increasingly take ownership of learning the content as teachers increasingly become facilitators supporting learners' ability to apply academic knowledge and skills. This type of learning structure lets children gain the skills they need to become members of a world-wide citizenry and competitive in a global, interconnected economy. Although schooling provides far more to children than workforce preparation, much authentic school work will in certain dimensions more closely resemble business professionals' work than NCLB test preparation and college resume building. Indeed, over time we may see the lines between learning and working begin to blur as some student work begins to contribute (as in citizen science programs) to professional objectives and certain types of student outputs become *used* rather than merely graded.

Substantial research is needed to understand the new types of instructional design required to achieve this vision. Fortunately, Web 2.0 tools can empower this research. At the level of sharing, through communal bookmarking (e.g., http://www.diigo.com/), the group could continuously scan the educational context for resources of interest, including non-archival material such as unpublished papers and YouTube videos. Photo/video-sharing tools (e.g., http://voicethread.com) could enable sharing and annotating research data as multimedia artifacts, such as student products and video records of teaching. A ning (e.g., http://www.ning.com) could provide background information to foster informal professional exchanges among members of this community. A wiki (e.g., http://writer.zoho.com) could serve as the basis for a negotiated exposition of theoretical principles; the theoretical wiki at the National Science Foundation (NSF)-funded Pittsburgh Science of Learning Center (http://www.learnlab.org/research/wiki/index.php/Main_Page) illustrates the value of this. Mashups (e.g., http://healthmap.org/en) could offer ways to contextualize individual datasets against a larger context of practice.

Such a research infrastructure could also serve other purposes beyond enhancing the scholarly productivity of its community. For example, federal agencies such as the National Science Foundation are now mandating external evaluations on their funded research projects, to document that the processes of scholarship used are appropriate and effective. The participation of a particular research project in a larger scholarly community as described above could serve as such an evaluation. Also, case studies based on scholarly processes richly documented in such communities could enhance the teaching of research methodology by offering richly grounded examples, including alternative perspectives on complex designs involving both qualitative and quantitative research methods.

Federal investments in "cyberinfrastructure" are fueling all these advances and will continue to do so for decades. During 2004-05, with NSF funding, four workshops attended by experts in education were convened by the Computing Research Association (2005). The foci of these workshops were, respectively:

- Modeling, Simulation, and Gaming Technologies Applied to Education
- Cognitive Implications of Virtual or Web-enabled Environments
- How Emerging Technology and Cyberinfrastructure Might Revolutionize the Role of Assessment in Learning
- The Interplay between Communities of Learning or Practice and Cyberinfrastructure

Collectively, these groups envisioned a cyberinfrastructure that "provides: 1) unprecedented access to educational resources, mentors, experts, and online educational activities and virtual environments; 2) timely, accurate assessment of student learning; and 3) a platform for large-scale research on education and the sciences of learning… Moreover, the new educational cyberinfrastructure will make it possible to collect and analyze data continually from millions of educational

activities nationwide over a period of years, enabling new advances in the sciences of learning and providing systematic ways of measuring progress at all levels."

The report describes a compelling vision of the evolution of Lifelong Learning Chronicles (LLC):

> LLCs can offer rich and compelling information to a wide variety of stakeholders. For example, individual learners would have the data they need to make informed decisions about their own learning—what knowledge they need to study, what learning resources are available that best align with their interests and learning style (instead of the one-size-fits-all textbook), what metacognitive skills could be improved, and what strengths and weaknesses they have that may influence future academic and employment choices. Learners will no longer have to take a single-shot, high-stakes assessment, but instead can benefit from continuous embedded assessments that provide both multiple opportunities to demonstrate their strengths... For all these stakeholders, a major benefit of the continuous learner data collection is the possibility of much more rapid, informative, and accurate feedback and responsiveness than is possible with today's practices of occasional high-stakes and summative tests administered by teachers, instructors, and testing agencies during the school year. Data collection can go beyond traditional measures of domain content acquisition to include records of such factors as the processes learners have used in solving problems, information about whether learners are asking for help appropriately, and the way that learners may collaborate, cooperate and argue with each other. Faster cycles of feedback not only would foster better instructional decision making, but research in learning technology that is better focused on effective design and appropriate uses of that technology as well (pp. 19-20).

Mobile wireless devices are a crucial part of the cyberinfrastructure needed to realize this vision.

In summary, 21st century education must prepare students for a world in which almost all types of routine cognitive tasks are done by computers and in which expert thinking and complex communications are the core intellectual capabilities by which people attain prosperity and economic security individually, as a region, and as a nation. These higher order skills are based on fundamental knowledge about how to do simpler types of work, so the shift needed is not to remove the learning of routine cognitive skills (such as basic arithmetic operations) from the curriculum. Rather, the fundamental change involves deemphasizing fluency in simple procedures as an end-goal of preparation for work and life (e.g., counting bills as a bank teller), and instead using these routine skills as a substrate for mastering complex mental performances valued in the future workplace, such as advising clients about global investment strategies tailored to their individual situations.

Qualcomm's Vision for the Evolution of Educational Infrastructure

The realization of such a vision will require thoughtful collaboration among public and private sectors. It will not be enough to identify the best practices of 2010 and plan for the consilience of known technology innovations such as Web 2.0 collaborative and social technologies, adaptive learning systems, and 3G broadband technologies with known pedagogies such as cognitive apprenticeship, project-based learning, and child-centered learning. It will not be enough to plan for a laptop for every child. It will not be enough to infuse classroom practice with the most thoughtfully articulated 21st century skills. It will not be enough to use data-driven research to cherry-pick the best of the best because no matter how clear our vision, we will fail to imagine the requirements on technology and pedagogy 5, 10, 15, or 20 years in the future.

Our shared responsibility lies in leveraging current and future innovations in education and technology together to support the rapid evolution of educational practice and delivery. Within the wireless industry this includes leveraging mobile broadband networks and devices and working collaboratively among wireless technology firms, wireless application developers, wireless carriers, and all others involved in mobile broadband to enable the rapid scaling, delivery, and evaluation of innovations via mobile learning technologies. We must assume that educators will use technologies in unanticipated ways to blend face-to-face work in the classroom with individual and collective inquiry outside it. We must assume that students will continue to bring new learning preferences and skills to the classroom from their technology-rich experiences of the world. We must assume that access to educational content and learning communities will be distributed among many modalities and devices. We must assume that student connectivity will be distributed among many broadband networks that scale from personal to wide area. Consequently, any infrastructure built in support of education must be flexible and powerful enough to accommodate new ways of teaching and learning with technology as they evolve in unpredictable ways and must be available to students and teachers wherever and whenever children learn.

Fortunately, we are not starting from scratch. As noted at the outset of this article, the FCC has found that over 95.6% of all Americans are covered by at least one mobile broadband network. As a nation, we cannot rest until that 95.6% figure is raised to 100% and until all Americans are covered by multiple mobile broadband networks. Likewise, through the E-rate program, the federal government has invested substantially in wiring America's schools. Now, the federal government needs to unwire the schools through a new mobile broadband-based E-rate program to subsidize the provision of mobile broadband services and applications and devices for teachers and students so that learning can occur no matter where a student or a teacher may happen to be located. Achieving universal mobile broadband coverage and providing funding for mobile broadband devices and services for students and teachers would be hugely positive steps, but would not, by

themselves, be sufficient to realize the full potential of this technology. All stakeholders, public and private, must come together to drive establishment of a cyberinfrastructure platform for education that is built from the ground up to evolve. We must span all particular networks and devices to achieve the most diverse and robust group of options for Internet connectivity. We must allow educational innovations and interventions to be developed, distributed at scale, assessed, tweaked, and re-distributed on Internet Time. We must protect student privacy while allowing data to flow appropriately to schools, parents, and researchers. We must enable schools, parents, and learners of all ages to readily discover, access, choose, and implement innovative curricula, content, and supplemental materials. We must ensure the right of every student to digital equity – the same anywhere, anytime access to content and community that we enjoy as effective business professionals. Most importantly, we must facilitate new technologies and pedagogies, lest we trap every student of the next generation in a system tuned to the best we knew in 2010.

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