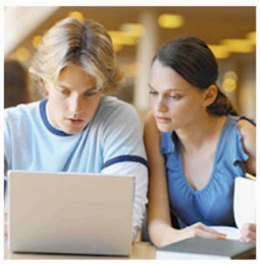
Wi Fi High



The test of time: Ubiquitous computing visions and realities in 7 pioneering schools

This report was prepared by the staff of "Researching science in the Wireless High School," a TERC project funded by the National ScienceFoundation through grant NSF/TPC 04-55795. We are grateful to the administrators and teachers of our participating schools for their collaboration on this project, and their willingness to help us study their experience, for the benefit of their colleagues in other schools.

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Introduction

Schools all over the country are developing technology plans to implement "ubiquitous computing" in some form. By "ubiquitous computing," people usually mean a combination of two key ingredients: wireless networking which provides high-speed Internet access, and a 1-to-1 computer-to-student ratio, achieved in most cases by the acquisition of laptops. The educational press has reported on many experiments such as the Maine Laptop Initiative, and similar programs at the local and state level. The new XO, "$100" computer provides an added dimension of affordability and innovation, along with the attractive vision of universal access to computer power and the many gifts of the World-Wide Web.

The history of educational technology provides many cautionary tales of promises unfulfilled, so researchers and policy makers have been eager for reports from the field, recommending "best practices" for schools implementing this new technology vision (e.g. Keefe et al. 2003, Fouts 2000). Most studies provide promising initial results on a number of fronts :

- Web-based science reports, data sets, instrumentation, and activities become more prevalent in the wireless classroom. (Zucker and Hug 2008, Tinker et al. 2007).
- The tasks that students undertake may become more data-oriented, more collaborative, or project-centered, or more writing-intensive (Zucker and Hug 2008, Davies 2004, Anderson and Dexter 2003a,b).
- The ease of access for student investigation can provide both deeper student engagement in school, and a sense of student empowerment (CCT 2000).
- "Intranet" capabilities can provide valuable new capabilities for peer-to-peer communication and collaboration (Davies 2004, Hill et al 2000, Anderson and Dexter 2003a).
- Assessment patterns may change in the classroom to include formative methods (Black and Williams 1998) as teachers provide more feedback on student work, encouraging revision, peer-comment, and reflection (Davies 2004, Hill et al. 2000, Walker et al. 2000).

But despite these and other encouraging reports, concerns have appeared, as educators question whether the innovation provides benefits that justify the cost and effort of implementation (Cuban, 2007, NY-Times, 2007). Clearly, this innovation like any other needs to be evaluated realistically; it is potentially so expensive and pervasive that getting it wrong can mean far-reaching negative consequences.

In this white paper, we provide an important perspective on this innovation, by reporting research on high schools which have moved past the installation phase of their vision of "ubiquitous computing." These schools have all gone through the process of envisioning and designing their implementation and acquiring and installing hardware and software; they have been in the "integration" phase of their innovation for some years. For this reason, they provide lessons about how different approaches to ubiquitous computing play out over time. We suggest that the experience of these schools will be of considerable use to schools and districts as they plan for their own implementation of "ubiquitous computing."

Based on the literature on ubiquitous computing to date, we have identified 5 characteristics which are seen to be strategically important for the implementation of this technological innovation.

1. Vision and planning: a technology plan that is aligned with educational goals
2. Technological adequacy: adequate, maintained hardware, software, and Internet access available both in the school and at home for teachers, students, and parents
3. Innovation pathways: a system for managing, monitoring, and revising the innovation
4. Teacher learning: professional development and training for teachers, administrators, and technical staff
5. Support and security: adequate technical and curricular support, and appropriate security

While most of our schools have some or all of these in place, the way they are implemented has had important effects on the process of infusion and teacher uptake. In what follows, we will draw on our study schools' experience, and teachers' perspectives, with respect to these 5 characteristics, and in this way address these two questions:

How did each school envision "ubiquitous computing"?

What factors seem to contribute to, or prevent, the successful implementation of these visions over time?

Background to the study

This white paper grows out of a research project called "Researching science in the wireless high-school: implementation, integration, effects on science teaching, and ramifications for professional development."[1] This project, now in its final phase, has been conducting case studies in 7 high schools around New England, 3 private and 4 public. The studies have examined aspects of school culture, technology vision, administrative support and professional development for teachers, and classroom practice. We have conducted intensive observation of the practice of 44 science teachers, with approximately equal numbers of biology, chemistry, and physics teachers, and a smaller number of earth science teachers. We have interviewed administrators, technology coordinators, and teachers, and been permitted to examine planning documents such as technology plans or standards in the various schools. (This white paper draws on the experiences of these schools, and does not address science specifically; the perspective of science teachers is addressed in other publications from the study, e.g. Drayton et al. 2009). The participating schools are quite different from each other, which has enabled us to examine a range of possible visions, implementations, challenges, and strategies relating to ubiquitous computing. [See **Box 1** for thumbnails of participating schools] [2].

Box 1: High schools participating in "Researching science in the wireless high school."

1. **Large Urban High** serves 2,115 students in grades 9 through 12. The student body is approximately 73% White, 14% Hispanic, 8% Black or African American, and 6% Asian. Of the student body, 28% did not have English as their first language, and 10% had limited English proficiency. Twenty three percent of students are classified as low income. Carts of laptops were purchased, but lack of funds for maintenance or replacement has resulted in a dwindling computer/student ratio. Internet access is through Ethernet connections for desktops, and also through hubs mounted on the mobile computer carts.
2. **Rural Public High** serves 419 students in grades 9 through 12, drawn from seven rural towns. A new facility was opened in 2003; the current technology set up was planned as part of the new school's design. There is wireless Internet access, throughout the building. There are "towers" of 14 laptops for each class, and a lease-to-own laptop program. Thus there is virtually a 1-to-1 computer/student ratio.
3. **Urban Seacoast High** serves 1,034 students in grades 9-12. The student body is approximately 89% White, 4% Black or African American, 4% Hispanic, and 2% Asian, and 1% some other race. 24% of students are classified as low income. There is wireless Internet access throughout the building. Funds for computer maintenance and upgrades are scarce, so the computer/student ratio has declined steadily.
4. **Urban Tech High** is a pilot school in a racially and economically diverse neighborhood of a major New England city. The school graduated its first senior class in 2006. It serves approximately 300 students in grades 9 through 12. The student body is 53% Black or African American, 29% Hispanic, 9% White, and 8% Asian, and there are twice as many boys as girls. 64% of students are identified as low income. There is wireless Internet access throughout the school; all students have laptops.
5. **Private Academy** is a private school in central New England, serving 360 students in grades 9-12; 80% of the students board at the school. Internet access by means of hundreds of Ethernet ports is ubiquitous; all students have laptops.
6. **Mass independent** is a denominational day school founded in 1997, serving 290 students in grades 9-12. The school recently moved into a new building 10 miles from a large urban center. Wireless Internet access is ubiquitous. Students can access the Internet from any wireless capable computer via 20 wall-mounted wireless access points.
7. **RI Independent** is a denominational day school founded in 1784, and serving grades 1-12; there are about 390 students in the high school. The student body is approximately 87% White, 5% Hispanic, 4% Asian or Pacific Islander, 3% Black or African American, and 1% Native American. There is wireless Internet access throughout the science building, and is being extended across the campus gradually. Laptop carts do not yet provide a 1-to-1 computer/student ratio, though this ratio is being approached.

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[1] Research conducted under a National Science Foundation grant, NSF/TPC 04-55795.
[2] School names and locations are disguised to protect anonymity.

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One innovation 7 ways

If you went with us to visit each of these schools in turn, you would be struck by the diversity of technology environments in the science departments: each of these schools approached the ideal of "ubiquitous computing" in a different way. In what follows, we describe and analyze the variety we found, with respect to each of the 5 success factors we outlined above:

1. Vision and planning
2. Technological adequacy
3. Innovation pathways
4. Teacher learning
5. Support and security

1. Vision and planning

There is abundant good advice about the need to underpin a major technology innovation with solid planning. Some of the schools in our study do not have technology plans in place; others have extensive and elaborate plans. Yet, several years into the experiments, there are schools which have achieved substantial success in their ubiquitous computing programs which do not have such plans, and others which have very full plans which show little effect in the classroom. As we have looked more closely at this apparent paradox, we have come to see an important distinction between good planning and the educational vision needed to implement a complex vision like ubiquitous computing.

• *Are the goals of the technology innovation articulated explicitly, and are these goals shared or at least widely understood? Are they embedded within a school reform plan or school change vision, so that technology contributes in a well-articulated way to the school's overall mission?*

The implementation of ubiquitous computing is an expensive, often disruptive, and complicated process. Because the technology, to be effectively infused, requires a permanent commitment to maintenance and upgrading, it is important from the point of view of teacher and community support that the expenditure of money, time, and effort is justified by articulating clearly how it is to contribute to the educational mission of the school. In Urban Tech High, both principal and faculty made it quite clear that, in their eyes, technology was in the service of student empowerment. This was fostered by the school's commitment to seeing and supporting each student and by its emphasis on workforce readiness as well as academic achievement. The technology supported this goal in both "soft" and "hard" ways. "Soft" support includes the motivation and engagement that technology can provide for students, and the opportunities to explore new uses and deeper technical proficiency. "Hard" support includes the integration of a carefully chosen set of tools into daily classroom practice, but also programs to certify students to do technical support of various kinds, and to find opportunities — both within the school and outside — to put these skills to professional use.

In Private Academy, the technology was seen as an essential thread in a comprehensive reform of the school. This reform was built around the concept of student mastery of subject matter, as well as a view of the students as participants in a learning community (both in class and outside of class, in this boarding school). The technology served the development of a responsive, revisable curriculum, which was needed in order to address another key aspect of this school, which is differentiated instruction. With a significant proportion of learning-disabled students, the curriculum was developed to provide 3 parallel curricula to three strata in the class simultaneously. At the time that this reform took place, there were no technology infrastructures available commercially to give the necessary administrative and logistical support, so the school developed a system that provided the teachers with an integrated system for creating curriculum, lesson planning, managing student data, and also maintaining electronic portfolios for their own annual evaluations. Moreover, since the school was well aware of the system's uniqueness, they developed an annual, 6-week summer institute to educate new faculty on the features and use of the system, and to help them incorporate it into their curriculum planning for the following year. Thus, classroom and administrative technology evolved in coordinated and organic relation with the new curriculum and professional development systems.

In Rural Public High, the planning was thoughtful and well-informed up to a certain point, but the relation of the planning to practice was not articulated either in design or implementation. The director of technology, in consultation with the administration, had developed a fully elaborated technology plan. The principal aims are encapsulated in this summary from the plan:

Rural Public High

Five Key areas of technology focus

1. Student Learning as it relates to the MCAS standards, including technology skills
2. Teacher Prep and Delivery of Instruction
3. Administrative Data Management and Communications
4. Access to Technology
5. Technology

Support Students grades 5-12: internet research, word processing, project development, mini-movies, reading and math assignments on line, graphing, drawing, computer assisted drafting, Office training, specialized programs for technology/science projects.

Teaching and Professional Staff, regular education: Internet research for students and lesson planning; develop webquests, grading and attendance, email to parents, word processing lesson plans, report cards and progress reports.

Yet the teachers themselves were not at all clear how their individual efforts to integrate technology into their curriculum were supported by the school. Towards the end of our study, the school hired a technology integration specialist to support this work, and she could say (now 5 years into the implementation of the ubiquitous computing experiment):

> I don't think there is a vision of what it could look like in five years. And one of my struggles has been to get people to name what they think, what the curriculum benchmarks are. In the high school this year they really didn't really want to do it.

The integration specialist attributed the teachers' disconnection from the schools' technology objectives to a desire to maintain teacherly autonomy:

> In general, the teachers haven't been required to change on paper what they are doing in terms of all the sea change in education with the huge amount of accountability. They think that if they write down what they expect kids to know and be able to do, then they will have to do that...They worry that if the teachable moment comes up and the wrong thing happens on the wrong day, then they will get in trouble. They've been told more than once, that's not what it's about. It's about establishing guides. But they just don't want their hands tied and they don't want anybody to be able to pin them down.

Placing this interpretation alongside the teachers' reports of insensitive administration, micromanagement, and a feeling of "surveillance," one can say that, at the least, there is not a shared vision for the future. The teachers did experience, and acknowledge, regular technical support as they learned the grading/reporting system, and expressed hope for school supported teacher websites (although as of fall 2009, only one of the science teachers had a website linked to the school site, and it had had little recent activity). The evidence suggests that the process of envisioning, planning, and implementation in this district has not yet included the teachers. As a result, teachers have been extremely slow to take advantage of the excellent resources available to them, and the adoption has relied entirely on individual teachers' initiative. Teachers feel they have been given no clear direction, and there are elements in the school culture which are discouraging to more energetic engagement (we return to this point below).

• *Are the educational goals general ("skills for the 21st century") or are they specified with respect to content, student skills to be learned, the role of inquiry, etc.? Does the vision articulate how the technology will be used in the curriculum, help or mandate the teachers in making pedagogical choices, provide them with content-specific support?*

The school technology plans from most of our study schools identify goals that are fairly general with respect to curricular content or classroom practice. They can be quite detailed with respect to technology acquisition plans, such as how many computers with what kind of software and peripherals, and yet quite general when it comes to purposes for the technology. For example, one school's plans specify the student benefits expected as follows: " internet research, word processing, project development, mini-movies, reading and math assignments on line, graphing, drawing, computer assisted drafting, Office training, specialized programs for technology/science projects." Another focuses on "1. Increasing student achievement. 2. Improved administrative efficiency. 3. Connections to the world beyond the school."

In the two schools whose ubiquitous computing has reached most thoroughly into the classroom, Urban Tech High and Private Academy, the technology planning is considerably more specific. At Urban Tech High, the implementation of technology was focused on providing students with skills that would both benefit them as learners, and give them skill with tools that are in daily use in the workplace — word processing, spreadsheets, databases, and presentation tools. Each department in the school has primary responsibility for instruction in one of these tools (e.g. for science it is a database program, for math it is spreadsheets), but by the second semester of the ninth grade, all students should have the basics of all four kinds of tools. The departments, therefore, are required to develop curriculum to employ their core technology in their instruction — and then incorporate other tools, taught in other courses, as the year moves on. On the one hand, the focus on the 4 core tools can lead to a sense of monotony —both teachers and students remarked on this. On the other hand, the consistent use of a few powerful tools makes mastery more likely. A challenge that remains, however, is precisely how to design curriculum and student tasks which consistently make effective educational use of these core tools. Nevertheless, the school has achieved the goal of making digital tools a basic, daily element of the school day across the curriculum, for both teachers and students.

In Private Academy, there is not the same coherence with respect to systematic instruction in a limited set of tools; teachers are given plenty of freedom to experiment. As described above, however, coherence has been achieved through the development of a school curriculum in each subject. For example, course materials for each science class have been created by master teachers over the years, and posted on the school's internal website, lesson-by-lesson. These lessons can be used as the basis of teacher presentations and of student work (homework or in-class). They have been modified over the years, so that new material, including Web links and video clips, have been incorporated. While teachers are free to make modifications, the school curriculum ensures that the classes will incorporate technology throughout, on a regular basis.

• *Is the plan comprehensive? Does the plan include a consideration, and balancing, of the technology needs of the constituencies within the school? Does the vision for the school's technology plan identify educational goals for the technology plan, as well as administrative or accountability goals?*

What motivated the adoption of the new technology? In our study schools, the technology plans were typically cast in terms of educational goals, as one might expect, but they also identified important goals relating to administrative effectiveness, accountability, and communications (teacher-to-teacher, teacher-to-student, teacher-administrator, teacher-parent). Early in the study, we asked technology coordinators to describe for us the relative emphasis of the technology program at their schools, and corroborated this in focus groups with teachers. (see **Fig. 1**). The differences of emphasis among schools are instructive. Among the three schools with the fullest installation of ubiquitous technology, the one with the highest relative emphasis on student data has the lowest actual teacher use.

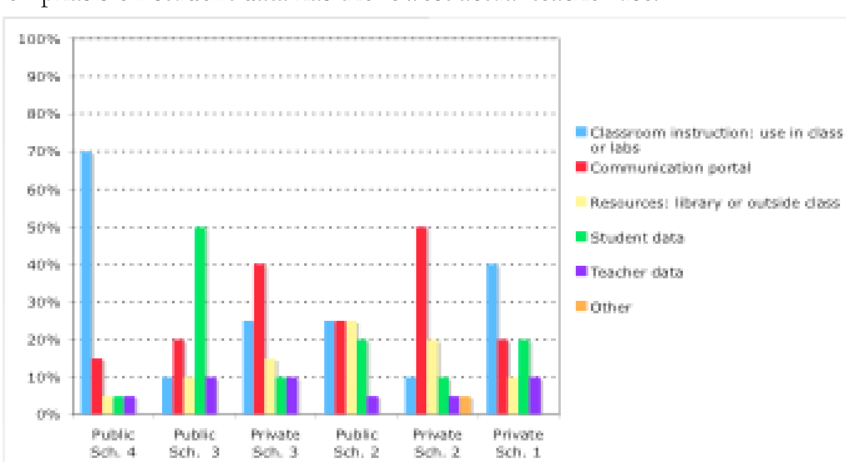

Figure 1: Relative emphases of technology use in study schools, as reported by technology coordinators. Note: No data reported from Large Urban High (Public School 1).

In fact, in several of the schools, the administrative efficiencies which computers offered for the management of student achievement and other data were a very high priority for the administrators whom we interviewed. This is important, since it is the administration which is responsible for allocating and deploying resources. In the schools where administrative uses had high priority, this shaped what kinds of computers were purchased, and who received school computers, but also the focus of professional development for teachers. In two of the public schools, when the number of usable laptops dwindled, owing to breakage or obsolescence of equipment, the remaining machines were liable to be redistributed first to teachers, but also to administrative staff. In these cases, the "installed base" of computers was treated as a single pool of resources, rather than being treated as two or more dedicated domains (e.g. for classroom and for administration, or teacher, student, and administration). Thus, allocation of resources in bad times required a triage in which the three constituencies were in direct competition.

In addition to concrete matters such as resource allocation, it is possible for the school to so emphasize what we may call administrative values that teachers are actually discouraged from beginning the experimentation that is necessary for effective uptake of the tools. When we first visited Rural Public High, for example, we were surprised by the climate we found. The school leadership had been very enthusiastic and welcoming of our invitation to participate, but when we began to speak to the teachers, we found that some of the science teachers were unwilling to participate in the study, and others were very reluctant. As we probed the reasons, we discovered that the administration's emphasis on the values of accountability and security had resulted in practices of oversight or surveillance which were aversive or even intimidating. As a result, some of the teachers avoided all but the most necessary use of computers, felt prevented from attempting to make use of new resources not officially sanctioned by the technology coordinator, and were fearful of any observation which might be (even inadvertently) reported to the administration. This was one factor (though only one) inhibiting successful infusion of digital resources into the science classroom.

In schools where the different needs of these constituencies (teachers, administration, students) were balanced, so as to maintain a strong educational focus, the technology climate in the school was supportive of teacher uptake in the classroom. This is because the balance of effort and attention translated into investment in the technology and tech support, professional development, and troubleshooting to support classroom experimentation. Classroom resources were protected and maintained (to the extent possible given budget constraints), and teachers were encouraged to seek out and experiment with new tools. Furthermore, since the teachers themselves were making use of a range of technologies in their "out of class" lives, with a more welcoming tone for experimentation, their personal learning could easily provide new resources and practices in their classroom. In such a climate, the better the technology available, the more were the avenues for classroom uptake. This in turn promoted the idea that classroom computers were to be seen as basic classroom equipment, and thus created incentives to maintain if not improve the technology climate.

2. Technology adequacy in our schools, 5 years on

The acquisition, deployment, and maintenance of a laptop base are difficult for schools to achieve. The challenges here are emblematic of the complexity of the apparently simple "ubiquitous computing" innovation. This is because it involves both initial, targeted investments in equipment and training, and continuing costs[3] which will not diminish in the future, and which require administrators to draw on several kinds of technical expertise when choices and decisions arise.

Network access in the school. Our seven schools presented three differing strategies for Internet access: ubiquitous wireless networks; mobile carts providing temporary wireless access in whichever room they were located at the time; and ubiquitous Ethernet access.

[3] Costs of laptop programs vary tremendously, because there are so many ways to implement them, including the quality of the network installation, whether the school or the students and teachers purchase the laptops, installed software suites, size and expertise of technical staff, the design of the professional development program and whether it is outsourced— and other factors. A minimum cost has been suggested by Zucker and Light (2009) at $65,000 for one classroom, for 5 years — using "ultra-low-cost computers." Of this, a key recurrent cost is training, accounting for 24.5% of the total. This configuration, which reflects the current state of research, and "wisdom of practice" with respect to such technology innovations, is likely to be more generous than most schools' allocations.

Four of the seven schools in the study have ubiquitous wireless networks accessible for the science classroom. Large Urban High has wireless access in the classroom by means of mobile carts, which are plugged into Ethernet ports when brought into the classroom. These carts, which serve as docks for a set of laptops, provide Internet access only to laptops identified with the cart. This strategy was employed by several schools we considered for this study, and their experience resonates with that of many other schools across the country that have used laptop carts with mixed success (Peck et al. 2008, Grant et al. 2004).

Private Academy has taken a very different approach to ubiquitous computing: the campus is not wireless at all, but rather has ubiquitous Internet access by means of about 3000 Ethernet ports around the campus, including several in each classroom; students are provided with their own Ethernet cables, which they carry from classroom to classroom along with their laptops. (This school has created some wireless zones at selected locations on campus, including in dorms and in the dining hall.) [See **Box 2:** "Wireless access — pro and con")

Box 2: Wireless access — pro and con

Universal Internet access by means of wireless networks may be the wave of the future in schools, as well as in homes, coffee shops, airports, and urban centers. Yet one of our schools, Private Academy, has resisted this wave. Their students have Internet access everywhere on their campus, by means of brightly colored Ethernet cables used to connect to the hundreds of Internet drops in classrooms and other spaces. The school's vision of ubiquitous computing was developed before the easy availability of wireless routers, but their reasons for not moving to the newer technology point out serious issues that need to be taken into account in wireless settings.

Wireless access means that, unless you have the laptop closed, you can't tell if a student is on the Web or not. Student surveys in our schools reveal that even in class, a substantial portion of students use chat sites and surf the Web for personal reasons unrelated to the class. This can be distracting to the individual student, but can also be disruptive to the class. When bandwidth is an issue, students' use of Web access for media applications can interfere with instructional uses of the Web. Easy Web access often tempts students to copy and paste information — to plagiarize — more easily than their parents ever could retype paragraphs from an encyclopedia. School Web filters are often one step behind the students' ingenuity — in one school, students found that their school's filter did not keep them from logging into a Dutch chat service, and the interface was intuitive enough that they could use it without reading Dutch. In most schools, we heard stories — or saw incidents — in which students were disciplined for accessing forbidden sites.

While student distraction and inappropriate behavior are inherent features of the educational process in every century, the wireless classroom adds new dimensions to the problem, and provides students with new resources for extracurricular divagation. Furthermore, in several schools, teachers told us that the protective filters intended to prevent student misuse of the Web also inadvertently prevented the teachers from going to legitimate science Websites. The balance between the benefits and drawbacks of Web access requires frequent adjustments. Most schools find that the benefits unquestionably outweigh the costs — but our schools' experience shows that the costs are real. At Private Academy, the faculty is not eager to move to classroom wireless network access, because of the complications it adds to classroom management and pedagogy.

Laptops and peripherals. For most schools in the study, "student computers" means laptops, first and foremost, but peripherals of various kinds are essential elements of the ubiquitous computing environment. While in three of the public schools desktop computers remain part of the basic equipment of the school, providing lab stations, stations for the teachers, or equipment in computer or media labs, laptops are the computers being acquired for student use.*

Laptop ownwership. In four schools, the laptops used in the science classroom are those provided by the school, rather than computers owned by the students. There are two benefits of this approach. First, the school can easily standardize the equipment being used, by requiring the use of school-purchased equip-

* In three schools, the laptops are Windows machines; in three they are Apples; in one, they are ACER tablets, which run MS Windows, as well as custom software.

ment. Second, by using school-purchased equipment, parents are not required to buy computers for their children: the district or school bears the capital costs. A drawback of this is that if the district's financial situation becomes more difficult, a cut in technology allocations may mean that laptops are not maintained or replaced, and the computer:student ratio shrinks, requiring adjustments for both students and teachers. A second drawback is that the laptops on mobile carts "belong" to no one student, requiring that the students spend more time and care transferring their work to storage media (school servers, school intranet, or personal equipment) or, as we saw in several cases, emailing their files to themselves for homework or other purposes. While laptop carts seem to offer many advantages to a school system moving towards ubiquitous computing, the experiences in our schools suggests that there are hidden problems that can actually inhibit the innovation. (See **Box 3**: "Laptop Carts, pro and con")

Box 3: Laptop carts, pro and con

The method of access, first to computers, and second to the Web, brings with it both opportunities and challenges (often unforeseen), and therefore presents management issues for the teacher. Some schools in our study have chosen to acquire mobile carts holding laptops, with wireless access points. The carts were seen to provide two advantages. First, they help in the effort to regulate student access to the Web. This matters for security reasons (controlling inappropriate use, for example), for reasons of classroom management (so that Web access is not a distraction), and, in one school, to limit the number of computers competing for bandwidth at any one time. A second, important rationale for a cart-based implementation is that it seems to offer an incremental way to buy the equipment, and then distribute the computers as needed, class-by-class, thus providing a strategy for dealing with the problem of purchase costs (Grant et al. 2004).

The carts themselves are equipment that require care and maintenance. In our study schools, they presented a range of problems which seem not to have been envisioned upon purchase. For example, a problem that was mentioned in several visits was students' not understanding the physical vulnerability of the "docks" for recharging. Sometimes a cart "goes down," sometimes preventing recharging, sometimes preventing access to the Web. In a school where computer use is increasing, competition for the use of carts can actually discourage some teachers from attempting to plan lessons using the laptops. Secure storage for the carts may mean parking the equipment at inconvenient distances, or behind security barriers that limit teachers' access.

Urban Tech High has a system that avoids some of the difficulties inherent in the cart system. First, the students own the laptops, and are responsible for their maintenance. For this reason, the carts are for storage and recharging, but their buildingwide wireless system gives Web and intranet/server access everywhere. Teachers do need to monitor their students' attention, therefore; directing them to close their computers becomes part of the flow of the class. Heavy Web usage can burden the network, so that the system is slowed down. Issues with careful placement of laptops in their recharging docks (and also with short-lived batteries) persist.

Two schools implemented systems in which each student has his or her own computer, for at least the duration of the school year. In Private Academy, all students purchase laptops as part of their regular school expenses; these laptops travel with the students to dorms and homes, as well as classrooms. They are kept at the school over the summer in order to upgrade the standard software suite. Urban Tech High leases-to-buy laptops for all entering students. The students return their machines to carts for inventory and recharging at mid-day and at the end of the school day. While the students own the laptops, they do not take them home until graduation, when they leave with the student; this cuts down on theft and accidental damage, though it requires the students to make other arrangements for computer access for homework done off the school grounds.

Rural Public High has developed a hybrid system. Fourteen laptops are stored in "towers" in each classroom. Despite the relatively small class sizes, this does not quite provide enough computers for a 1-to-1 ratio; but the school system has instituted a lease-to- buy program, with a sliding scale of fees, and about 50% of the students are taking advantage of it. Subject to security and software guidelines, students can configure their machines to be compatible with the school's system, and then bring their laptops in for classroom use. With this "public/private" arrangement, a 1:1 ratio has been achieved.

How to compare these different approaches to a “ubiquitous computing environment”? On the basis of our observation of the experience of these different schools, we would suggest that an approach thatdoes not look well past the computer-to-student ratio and Internet access will not lead to satisfactory results. While the whole of this white paper elaborates this point, here we wish to make the narrower point that the way in which a 1-to-1 computer-to-student ratio is achieved will affect how students and teachers come to make use of the school’s technology investments. (See **Box 4**: “Beyond the 1:1 ratio.”)

Box 4: Beyond the 1:1 ratio

All of our schools developed plans for acquiring enough computers to reach the 1:1 ratio. One of the prime differences among the plans is *how* this ratio is achieved, and a decisive factor is some version of student ownership of the computers. By “ownership,” we mean a computer used consistently by a student all year. This can be achieved by various arrangements such as lease-to-buy,or student purchase. In such a system, each student has a computer which serves as a consistent coordinating center for her work, and an archive or portfolio that grows over the course of her school career. In schools where the 1:1 ratio is ensured by school-owned laptops (on carts or in “towers” as in Rural Public High), students use public equipment, and have no control over the state in which the computer was left by its previous user; and students’ work has to be transferred, by email, memory stick, or intranet, to some other location. Given that organization of materials is a continuing challenge for students, this transfer process introduces another layer of complication.

More important, when students have consistent use of a single machine all year, their ownership and responsibility make them the front line monitors of the computer’s maintenance needs. They are responsible for keeping the computer charged and for seeking technical support for software or hardware problems. Not only does this significantly aid in the challenge of maintenance for dozens or hundreds of computers, but it provides a basis for building student capacity for trouble-shooting issues themselves. Urban Tech High has extended this responsibility to the training of all their students, to at least an introductory level, as certified technicians. As a result, while breakages and software issues occur, teachers and students become accustomed to students having the computers available throughout the day, which contributes to the seamless infusion of the technology throughout the curriculum.

Interactive whiteboards. Most schools are installing interactive white boards; five of our schools have them in all science classes. Two schools are gradually installing interactive white boards as funds permit. While this tool is not a logical requirement for a school with ubiquitous Internet and 1-to-1 computing, in practice it seems to play a pivotal role in the teacher’s deployment of the Web in the classroom. It allows the teacher to seamlessly incorporate multimedia resources (images, simulations, animations, etc.) projected from the computer, from the Web or from a software program that the teacher is running. Moreover, the teacher can use the whiteboard to focus the class when the students are working on computers, and so their attention is focused there — with the interactive white board, the teacher can convene the whole class’s attention, perhaps while using the same program the students are using. Finally, the interactive whiteboards allow the teacher to save notes and classroom interactions to a file, which can then be distributed later.

Intranet. All of the study schools have at least the simplest kind of “intranet” — shared hard drives where teachers and students can share and save files. In two schools, while this is the commonest way to exchange files within the school, it is limited because external access is blocked -- even for students who might want to get files for homework. In this case, students and teachers use email to move files between school and home. For three other schools, the First Class system enables file sharing, external access for students and sometimes parents, and also discussion areas, which can be used for homework help, student collaboration, and other kinds of student-student and student-teacher interaction.

Teacher Websites. With one exception, all schools support teacher websites. The contents of these are left to the teachers in most cases, though in at least three schools (two private, one public) there is technical support to help teachers populate their websites and make effective use of them. In one (private) school, part of the technology strategy is to integrate school operations (administration, teacher, and student) by means of the Web, and while finances have limited equipment purchases and upgrades, the Web strategy has been actively pursued, with the result that all science teachers have had support for designing the contents and capability of their Websites.

Reflections on the schools' technology implementation. As our brief sketch has shown, each of the seven schools we studied had a unique way of envisioning the 1-to-1 environment. Some implementations were more effective than others, as evidenced by the sustainability of the ubiquitous computing environment. Three of these schools have reached and maintained the goal of ubiquitous Web access and 1-to-1 computer/student ratios. They also have other, peripheral tools which can support the deployment of digital resources in the classroom, such as interactive whiteboards and teacher websites or multi-function intranets. In two schools, the high availability of reliable hardware and network access is accompanied by high technology use in the classroom — daily. In the third, despite the high quality of the technology, the use of Web resources and other available tools is quite low.

The other 4 schools have developed in ways that are instructive about pitfalls and challenges to the realization of a technology culture that might be consonant with the "cyberlearning vision" of NSF and other innovators. In two the situation is quite discouraging. A large initial investment in technology, intended to be the first phase of a school-wide ubiquitous computing effort, has stopped, and in fact gone into reverse, as school budgets have been cut, and priorities rearranged.

In two of the private schools, an initial investment in technology was made possible by special donations to the schools as part of a larger capital investment. Yet by the time the schools joined our study, the computers were beginning to obsolesce, and the wireless systems were showing limitations— sometimes because of unpredictable network "dead spots" and other kinds of poor design, sometimes because the bandwidth was not sufficient to make efficient use of the video- and audio-heavy Web pages that were being used. In both schools, "vision" and planning, teacher professional development, and some other aspects of school culture proved to be hindrances to addressing the issues that arose. We will return to the fates of these schools in our discussion below.

The acquisition plans in some of our study schools were shown over time to be flawed in a couple of ways. First, in several cases, acquisition of computers took the form of a major capital outlay, with no follow-on funding — typically in conjunction with some other capital investment, for example new building or renovation.

For private schools, the upgrading of the installed base of computers is a concrete target for fundraising, and donors who are concerned with educational technology may well come forward eagerly. It is much harder to raise funds for continued technology support, which has no obvious "finish line", and after the initial flush of investment takes on the aspect of a basic operating expense. The result is that teachers and other personnel may be presented with a new, enriched technology environment, which they must begin to learn to use, reshaping curriculum and pedagogy slowly and with considerable effort — and which starts out in the best condition it will ever be in. With no reliable, dedicated funds to maintain the complex system that is now in place, the system will deteriorate in various ways. Teachers who are not eager adopters will begin to encounter disincentives to using the technology. Methods with which they are familiar and which have brought good results will trump unreliable if promising innovations. If a culture of technology use does not become established, based on increasing success in practice, technology will be even harder to raise funds for, as it will not seem to be an imperative.

To counteract this downward spiral, boards of trustees need to be educated about the implications of upgrading technology, and the acquisition strategy may need to include a technology task force or some other mechanism by which technical alertness is combined with strategic insight about long-term institutional change. In one of our schools, the technology coordinator developed a technology strategy to be implemented during a phase of school construction. She tried to convey to the trustees the rule of thumb that an investment in equipment would entail a continued annual expense for maintenance and tech support amounting to about 10% of the original investment. The trustees, who had with vision and enthusiasm raised a million dollars for a sophisticated technology infrastructure, retreated from the prospect of an annual addition of $100,000 to their budget. As a result, the equipment purchased in the era of generosity deteriorated, and teacher professional development did not move beyond the rudiments of initial technical instruction on the tools available.

Private Academy has not followed this pattern, however, and this for several reasons. First, the design of the school's technology environment was embedded in a larger vision for the re-creation of an old New England academy in the early 1990s. Second, a very long-term strategy was seen to be essential to the innovations envisioned, and the technology infrastructure, seen as a support for the kind of school that would develop, was considered in great depth, both as it should relate to administration , the classroom, and student life, but also in terms of the human infrastructure necessary to maintain the system. Finally, the strategy chose carefully what technology the school would invest in, and what costs should be borne by the students' families (with help from the school). We return to some of these points below. [See **Box 5**: "Private Academy: wired ubiquitous computing, full infusion"]

Box 5: Private Academy: wired ubiquitous computing, full infusion

The campus, dramatically situated in the northern New England landscape, is a mix of frame houses, brick buildings, and fields scattered across several hectares of land. Two thirds of the students board, but one third come in by day from the surrounding towns, hearkening back to a time when Private Academy was the secondary school in the region, one of the town Academies established in the XIX century to provide advanced education. Up to 20% of the students have special learning needs, but the school is diverse in other ways as well, with a significant proportion of international students. The curriculum has been developed, as part of a whole-school reform begun 25 years ago, to reflect this diversity, and indeed to make use of it to spur better education for all the students.

As part of this commitment to differentiated instruction, the curriculum, assessment, pedagogy, and administration are designed to integrate the available technology. The school is not wireless, but the Internet is ubiquitously available, as there are 3,000 Ethernet drops on campus. Every classroom has many, so that there is an Ethernet connection within arm's length almost everywhere. In a typical classroom there are about 6 pillars (square in cross-section) in the room, each with Ethernet ports and electrical outlets (one of each on each side). The students all have Ethernet cables, but they don't connect unless asked to by the teacher. The school prefers this, as the teachers can make an in-class decision about when to connect to the Internet, and when not. All students purchase iBooks through the school. Printers are located in most classrooms. Classrooms have projectors, connected to the teacher's laptop. At the beginning of the study, many classes had a detachable visual-capture product which takes images from a white board and saves them in digital form. By the end of the study, all classes had an interactive white board.

A very similar process obtains in public schools. In Massachusetts, state funds have been made available to school districts for school building and renovation, and these funds are typically decisive in the district's ability to upgrade their physical plants. More than one principal told us that the only way they can upgrade technology in a significant, system-wide fashion, is to roll technology funding into building projects — thus it is typically building-by-building, at a pace that does not make it easy to bring the whole system up to a common standard.

As a result, we see again a pulse of investment, which is unconnected to maintenance and replacement costs, much less professional development. Of the four public schools in our study, all four benefited from an initial capital influx of this kind. In two of these schools, continuing support was lost when declining tax revenues squeezed both the town and the state's education budgets. As one principal told us, "My choice is between cutting technology or cutting staff, and you know which I will need to do." Four years after the initial investment in laptops, operating systems and RAM were inadequate; batteries were worn out and not replaceable, and more and more machines were damaged by accident.

While computers did not completely disappear from the science classroom, the computer-to-student ratio dwindled year by year. In two schools, however, this fate has been avoided, both through innovative governance structures, and through a growing emphasis on individual computer ownership. Urban Tech High is a pilot school; while this does not provide more generous funding for the school than for other schools, it does give the principal much freedom in financial matters, allowing her for example to economize on labor costs by negotiating lower salary levels for staff, freeing some funds for hiring technical staff, and for other technology-related costs. [See **Box 6**: "Urban Tech High: Wireless, 1:1 computing, nearly full infusion"]

Rural Public High, which did establish its technology infrastructure as part of a school building program, has been able to incorporate technology support and maintenance into its annual operating budget (supplemented on some points by grant funding), despite the relatively low SES of most of the communities in the unified district. In addition, the school has a lease-to-buy program which enables students' families to purchase laptops through the school, thus ensuring that compatible computers are available both by school purchase and by family purchase. [See **Box 7**: "Rural Public High: Cautious deployment of rich technology resources."]

Box 6: Urban Tech High: Wireless, 1:1 computing, nearly full infusion

Urban Tech High is an urban pilot school with a technology theme. Founded as an experiment within the city school system, its vision was developed and is maintained by a core group of dedicated faculty, led by an imaginative, eloquent, energetic principal. The aim of the school is to see and empower every student, and to enable each student to achieve academic excellence, and to feel confident that he or she is ready to move ahead in life — in the workplace and in further post-secondary schooling. The high school has had notable success — its first class, 80% of whose entering students had failing 8th grade test scores, graduated with more then 90% of students going on to post-secondary education.

At Urban Tech, wireless Internet access is ubiquitous. Students can access the Internet from any wireless computer via an adequate number of wall-mounted wireless access points. The wireless network is used for most tasks – students only use the wired network for high-bandwidth tasks like video production.

Every student is given a laptop computer after completing technology training within the first couple of months of their freshman year. Computers are inventoried several times per day. To keep students safe in the neighborhood, the school does not allow them to take computers home at night. Instead, parents have the option of purchasing an affordable computer through the school after completing a technology training program. The majority of students have web access at home. Every class has a SMART Board, and the teacher's computer is used for projection. All teachers are given laptops as well.

Students keep their laptop computers upon graduation, so the laptops have been replaced on a four-year rotation. While in service, the computers are maintained within the school. A laptop coordinator, network coordinator, and student-based technology consulting company all contribute to the care and maintenance of the hardware infrastructure. This is an important point! The computers are sometimes subjected to strenuous conditions, as well as to accidents and the technology support system keeps student downtime to a minimum.

The technology use in Urban Tech's science classes appears to exploit to a significant degree the affordances of the Web-enabled classroom. Web resources, and web-enabled tools, are in regular use across the curriculum, in teacher presentation, as resources for student learning, and as tools for students' presentation of their work. However, the faculty is still consciously inquiring how to make the technology serve subject mastery as well as student engagement and differentiated instruction. While there is definitely room for growth and development, there is a solid foundation for a sustained and intelligent use of technology in the service of the school's mission.

Box 7: Rural Public High: Cautious deployment of rich technology resources

Rural Public High school is actually one part of a school complex, including one of the district's elementary schools, and the unified middle school, which is linked at several points with the high school. The building was designed, among other things, to accommodate technology.

The facility has wireless access throughout. Each classroom has a "tower" of 14 laptops, and the district has a program promoting student or family purchase-through-lease of laptops, which can be used in the school, though the small class size means that the class-stationed computers are often enough for one-to-one student use. The school has a technical staff of 3, including the district technology coordinator, plus (during the final year and a half of the study) a technology integration specialist. The district has a 3-year obsolescence plan for its school-owned laptops. All classrooms have interactive whiteboards with projectors, and teachers have laptops.

What does technology use look like in the science classes in this school? The tone may be described as very cautiously optimistic: teachers rely first and foremost on standard apparatus — microscopes, digital scales, calculators, electrophoresis gels, meter sticks, etc. Computers and the Web are appreciated but not consistent elements in the classroom, for student use. Presentation tools (e.g. PowerPoint or SmartNotebook) are being used more and more regularly. Communications tools — intranet, teacher websites, student/teacher or teacher/parent email exchanges — are occasionally used. So far, while the science teachers are intrigued, they are also conservative in their embrace of the tools made available, as the digital technology system still feels more the province of administration than of teaching and learning. Experimentation with, and integration of, the technology is driven by the individual teacher's initiative. While the school is dedicating a staff person to provide support and guidance to the integration process, uptake is slow. The school's technology culture is still under development.

3. Innovation pathways, and monitoring the innovation

Planning and strategy for technology, technology integration into the curriculum, and technical support are more likely to be coherent and effective if there is a functioning process in place for evaluating and revising the school's or district's technology plans. Most schools in our study have some such structure, though one public school lacks a technology coordinator, and one private school has a skilled technology coordinator but no current other organizational structure to help her plan and implement the school's long-term vision for educational technology. In the other schools, there is a committee or council, with representation from most constituencies in the school community (teachers, administrators, parents). Meanwhile, individual teachers or technology staff in each school are experimenting with technology — their exploration ranges from seeking new Web sites to learning new technologies, e.g. low-cost radio-enabled cameras, digital polling equipment ("clickers"), new probes or visualizations. This individual exploration can be an important source of improvement in the school's technology culture and capacity.

Yet when we asked teachers about how they can explore new technological tools, and expand their use in the school, we most often heard about informal methods, which had little or no link to formal processes of evaluation, adoption, or acquisition. Thus, teacher initiative drives technology innovation, but most of the schools have no coherent way to take advantage of it.

Technology innovation based on individual teacher experimentation has several strengths:

- Teachers tend to explore classroom applications of new tools with specific curricular goals in mind, providing direct tests of utility or potential.
- Classroom "pilots" provide practical information about how the new tool can be used in the school context.
- Exploring tools usually goes hand in hand with reflection and learning about the content or skills which it's hoped the students will learn, and so exploration of technology stimulates teacher learning about the related content.
- Teacher curiosity helps identify limitations and potential improvements in the schools' technology suite.

In the schools in which this is the primary mode of innovation, however, we have seen that there are some real drawbacks:

- New technologies are adopted piecemeal, and their propagation through practice depends entirely on teachers' time and resources (including financial) for learning and experimentation.
- Piecemeal adoption with costs primarily borne by the teacher tends to favor teacher centered use of the new tool, owing to the cost of supplying a whole classroom.
- Incompatibilities with the school's software environment may result in innovations causing trouble with regard to maintenance and reliability.
- The school's security systems may discourage innovation and experimentation, especially if the new technology has a Web component.
- The school does not benefit strategically from teachers' initiative: the school's technology climate is less innovative and inquiry-driven, which can have negative impact on uptake of installed and sanctioned tools.

In three schools (two private, one public) there are defined pathways by which promising tools can become more widely tested within the school, and eventually become part of the standard equipment. In the other schools, such conversations are not supported by a specific protocol or process, aside from informal exchange, and the periodic review/revision of the district/school technology plan.

In Urban Tech High, the focus on workplace-relevant technologies is maintained by the continued connection between the faculty and the workplace. The majority of the science teachers, for example, had worked in industry before moving into teaching, and they monitor developments in the private and research sectors which might be of use in the school. Once a year, the curriculum leaders (principal, director of academics and technology, technology coordinator, and core teachers) attend a regional technology conference, and in that context they identify candidate technologies which might be worth further investigation. One or more teachers may get training with the tool, and they experiment with it in the classroom. If it seems promising, in connection with the school's overall mission, then it may be adopted into the suite of tools being used across the curriculum, and a plan is formed for when and how the students will be introduced to its use.

In Private Academy, the faculty works in parallel with the technology council (on which there are also faculty representatives). Over the course of our study, we watched the process in action with the adoption of "clickers" for in-class student feedback. One "early adopter" obtained a small set of these, and tried them in his class. He loaned the clickers to other members of the science department, and after a year's experimentation, he made a report to the whole faculty council. The science department invested in a larger number of these clickers, and continued to experiment with integrating them into their practice. By the third year of the study, with the approval of the technology council, students were asked to purchase personal clickers, whose use was propagating throughout the school. While some teachers make much use of them, and others little or none, the technology is now integrated into the school's technology infrastructure, and availability of the tools is not a barrier to teachers' use of them.

4. Teacher learning

It is widely accepted that professional development is an essential ingredient for the success of an innovation in curriculum or pedagogy, and new technology is both of these, in addition to the technical requirements of learning how to make the tool work. From the earliest reports on laptop programs, researchers and policy makers have stressed that technical training is not enough. Yet we have found that in most of our study schools, all of whose administrators understand the role of professional development, professional development rarely if ever moves beyond technical rudiments. Sixty-six percent of teachers said that they had received professional development that relates to technology integration in the past two years, but the teachers also told us that they wanted more.

When we asked the teachers about the professional development they most desired, and lacked, the answers overwhelmingly focused on access to useful lessons or materials (or, interestingly, a tour of what is "out there" on the Web), help in integrating technology into the curriculum (or doing so more efficiently), materials that support hands-on learning or student investigations, and deeper technical knowledge (e.g. about instrumentation, building Web pages) in connection with specific tasks (supporting student investigations, student presentations and evaluation, the explanation of complex ideas and phenomena).

Furthermore, the majority of teachers expressed a strong desire to communicate with colleagues around the curricular and pedagogical challenges they were encountering with the technology, and strategies for addressing them. Teachers value tips and advice they get from teachers (and others) from anywhere, and more and more are seeking such input from various Web resources. Nevertheless, nothing can substitute for focused collaboration in my context — my school culture, with my technology, in relation to the aims that my colleagues and I are seeking to achieve. Professional development, especially collaborative inquiry with colleagues, needs also to be rooted in the disciplinary challenges unique to the subject matter — mathematics, science, language arts. The most effective professional development approach for technology integration will involve a designed mixture of more formal workshops and courses, with structured peer-exchanges of various kinds, and opportunities for this kind community-based learning are lacking. Yet they seem to play an important role, not only in teachers' use of technology, but their buy-in to the innovation and their willingness to give it the extra time and effort that such an innovation requires.

5. Support and security: finding the right balance

The schools vary in the amount of on-site technology support they have. Private Academy 1 has a technical staff of six, plus student interns, which maintain and revise the school's customized intranet and data management system, as well as the school's hardware assets, and student computers during term-time. At the other end of the spectrum, Urban Seacoast High, with over 1,200 students, has one tech support person available, who is often on call for other schools in the district as well. All the schools in our study recognize the importance of maintenance and technical support, which only increases with the importance of (and dependence on) computers and the Web for teaching, learning, and administration. Budget constraints are most often the factor limiting the amount of technical staff.

Security is a dominant concern for any institution with Internet connections, but in schools the concerns include protection of student records (both the integrity of the data itself, and the confidentiality of the records), protection of teacher (personnel) records, and protection of students from inappropriate Web activity. In addition, the network needs protection against viruses, downloaded software that is incompatible with school computer systems, and spam. Finally, there is the need to ensure that teachers and students make appropriate use of the system.

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All schools in our study have a firewall and Web filtering software. In addition, two schools have programs that allow teachers to see all student monitors echoed on their own screen. One of these also has an analogous program that allows it to monitor teacher computers, and scan the hard-drives for contents, for example unauthorized downloads. Other schools rely on teacher vigilance and student cooperation to limit students' roving off-topic when on the Web.

The balance between security and freedom is a complicated one, and it is inherent to any networked system. Teachers report difficulties in downloading Web applications, and even some science sites, because of security systems which must be manually disarmed — which can be time-consuming if the technical staff is overburdened. In a wireless system, students will roam off task, though this can be constrained both by filters. Teachers can also limit the "wandering" by placing key resources for classroom use on their websites, and directing the students to work from there. Yet the problem of too much freedom of access to the Web is reported in study after study, especially with reference to the classroom management issues that arise from Web access.

Conclusions and recommendations

Our case study high schools provide a range of valuable lessons about issues to consider in the implementation of a wireless, 1:1 environment. The hope, as with any educational technology, is that this "ubiquitous computing" environment will offer tools and resources which will stimulate and engage learners, and increase the capacity of teachers to support their students' learning, and their own, as well as facilitate the work of lesson planning, managing student data, and communicating with students, parents, and administrators.

The factors for success discussed above have affected the extent to which the promise of ubiquitous computing has been realized — and maintained — in our study schools.

<u>Make the vision rich, practical, and flexible.</u>

• Choices made in the development of a coherent, specific, and comprehensive vision for educational technology, serving as the framework for planning and implementation, have important implications for teacher uptake and technology infusion. The vision can be decisive in setting priorities for resource allocation, of course. More than that, however, it provides guidance to teachers as they make strategic decisions about what new tools, techniques, or resources to explore and adopt. It also helps provide criteria with which to evaluate the value added by the new technology. It also provides a coherent basis for professional development both formal and informal.

<u>Implement innovation pathways.</u>

• The establishment of coherent innovation pathways that effectively harness teacher exploration and innovation to the strategic goals of the innovation will foster teacher uptake. The identification, testing, and evaluation of new technologies can be structured in such a way as to take advantage of the faculty members who are technologically curious and adventurous. Within the framework of a well-developed vision, and a well-designed process for teacher-to-teacher collaboration around technology integration, new tools and resources can be identified and tried out, and then incorporated on the basis of evidence developed within the school about how the new addition will serve the vision and needs of the faculty, under local conditions.

<u>Incorporate "focal" tools.</u>

• Certain tools seem to facilitate the integration/coordination/combination of the various technologies of the science classroom, along with the various modes of interaction that are important: individual, small group, whole-class, informational, investigation, qualitative and quantitative understandings, argumentation, narrative, and discourse. Interactive white boards, for example, have been deployed effectively to scaffold group conversation about data sets and other kinds of analysis, drawing both on data from the Web, or presented by the teacher, but also (and most importantly) data from student activities. Teacher websites enable teachers to collect and organize Web resources that they have determined to be useful in their courses, to integrate them with other resources such as course notes, supplementary activities, and student discussions, and to constrain and focus students' Web use more effectively and intentionally.

These lessons and recommendations seem, on the basis of the experience of the schools in our study, to greatly increase the likelihood that the implementation of a ubiquitous computing environment will effectively serve the school's educational mission. They are especially important because they reflect the teacher's needs and challenges, as well as other purposes that the technology may serve, and research has shown that teachers are the key to any successful school reform. Teacher uptake, which combines initial use and an inclination to experiment and move past the difficult initial stages of an innovation, is a crucial element of successful technology infusion. If teacher uptake is supported by reliable technology, technical assistance, and an explicit, comprehensive, and specific vision, embedded in an overall reform context, then technical challenges can be dealt with constructively, and the implementation can grow and develop to reflect changes in the life of the school, in all its aspects — administration, teaching, and learning.

Make teacher collaboration regular and effective.

• Professional development that makes effective use of teacher community, especially with special attention to the challenges of science teaching, can build for success as well. These elements can lay a durable foundation for an implementation that grows and lasts. Professional development to be most effective should be calibrated to the challenge (and opportunities) that the ubiquitous classroom presents for teachers.

This environment brings two major kinds of enhancements to the classroom. First, there is the increased availability of computers. This by itself can drive forward the integration of key tools for science learning which can make an important difference in students' understanding of the process of scientific understanding. Such basic tools as spreadsheets and probeware, which for 20 years now have been seen as important for the well-equipped science classroom, are still used only sporadically, and often not with fluency, in high school science. These, plus presentation tools such as PowerPoint, and software such as Inspiration, are more likely to be used as a matter of course when the computers are generally accessible.

Second, the ubiquitous computing classroom makes the Web available, and through that many, many kinds of resources — among them visualizations, animations, simulations, text, data sets, and access to scientific and educational communities.

Yet science teachers already have many other kinds of apparatus to deploy, from Bunsen burners to air tables to spectrometers to electrophoresis equipment. A major challenge for the science teacher, then, is to evaluate tools newly available in the ubiquitous computing environment, and determine the most effective ways to complement, duplicate, or eliminate the apparatus and other resources they have found useful in their practice.

To enable teachers to make strategic decisions about technology in their classrooms, aligned with the learning goals of their curriculum, and the school's vision for educational technology, courses and technical workshops will not suffice. The science teachers need to have regular, targeted dialogue about what they are trying, why they are doing so, and what the results and issues are. The design of this kind of regular collegial work will be greatly facilitated by the presence of a coherent, comprehensive, and specific vision for the technology. Conversation across the subjects (language arts, sciences, mathematics, social studies/history) will be valuable at some points as well.

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