A Concord Consortium White Paper

1:1 COMPUTING IN SUPPORT OF SCIENCE AND MATHEMATICS EDUCATION

Recommendations for Large-Scale Implementations

Robert Tinker, Alvaro Galvis, and Andrew Zucker
The Concord Consortium
bob@concord.org, alvaro@concord.org, azucker@concord.org
16-Feb-07

OVERVIEW

Many governmental entities—countries, states, and regions—are studying the possibility of stimulating educational gains and economic development by supplying every student and teacher with a personal, portable computer. The *One Laptop Per Child* (OLPC) effort led by Nicholas Negroponte has popularized this idea and has generated increased appreciation that some such technology is certain to be available and widely affordable, whether it is the OLPC computer, Intel's ClassmatePC, regular laptops, cell-phones, or some unforeseen innovation. This White Paper deals with three issues that governments need to address in order to realize educational gains in science and mathematics education from one-computer-per-child initiatives: teacher professional development, instructional materials, and research, as each pertains to 1:1 computing.

The digital divide is automatically reduced by providing students and their teachers with 24/7 access to information and communication technologies—ICT. However, simply providing access to networked computers will have little impact on learning. Studies of numerous 1:1 experiments show that the quality of education can be greatly enhanced through policies that build on the potential of 1:1 computing. Student achievement can be raised in key curricular areas—such as language arts, social sciences, the natural sciences, and mathematics—through research-based, focused interventions that provide students with rich and powerful learning environments. Making this potential real requires aligning educational goals with implementation strategies. In this document we will be focused on implementation strategies for science education at the pre-college level.

We use a broad definition of "science education" that includes the natural sciences, mathematics, engineering, and technology (SMET)—the subjects that drive economic development. There are many important ways of using computers and information technologies to transform education and we are confident that by empowering teachers and students with digital tools designed to amplify problem solving, communication, and thinking skills, it is possible to better develop a wide range of competencies needed by young people in the information age. However, SMET education deserves special attention because of the complexity of the content and the impact that SMET competencies have on economic development.

One of the chief justifications for an investment in educational technology is to increase economic competitiveness in SMET fields. It seems reasonable at first blush that because computers are a form of technology, their use in education would automatically increase students' technical skills. But there is a huge gap in this logic—technical skills do not accrue simply from the use of technology any more than engineering skills evolve from using automobiles or aeronautical engineering skills from flying. There are tremendous educational gains in science, technology, and mathematics to be had from the use of computers and information technologies, but they do not happen simply by supplying the necessary technology or even by using technology in education. A coordinated effort is essential to supply learning materials and teacher professional development, together with an integrated research effort to provide feedback and accountability. The costs of this effort can easily exceed the costs of the technology, so it is important both to consider the total costs of an educational technology initiative and to build into the plan strategies that will minimize long-term costs and maximize benefits.

This paper sketches an overall strategy for utilization of ubiquitous computer and communications technologies in SMET subjects in grades K-12 in countries, states, regions or school districts that have decided to implement 1:1 computing. The paper suggests ways to economize through planning and pilot testing, early investments, and by exploiting local and global resources.

Our recommendations are independent of the actual computers used for 1:1 computing, providing they can run Java and have at least intermittent access to the Internet. The operating system should not be an issue, because the SMET-related applications should be written in Java so they can execute under Windows, Mac OS, or Linux. With this strategy, initial pilot implementations of new approaches could even use existing, more expensive laptops and the results confidently extrapolated to other platforms. This strategy of using Java applications preserves hardware flexibility and puts policymakers in a strong negotiating position when placing large orders.

A complete 1:1 computing implementation plan also includes a strong administrative side: hardware delivery, support, upgrades, repair, servers, security, student authentication, usage policies, etc. This is not part of this white paper; our goal is to explore how to optimize the impact of 1:1 computer initiatives in SMET education once they are in place.

Issues concerning large scale 1:1 computing efforts

There are a series of educational policy issues that 1:1 computing raises, which require defining objectives, identifying available resources, developing appropriate educational materials, and preparing teachers. When there are not enough resources for a universal solution at the country level, priorities need to be established for selecting the regions, sectors, and school levels. Should all regions be included? Is there a danger of diluting the effort to the point that it is meaningless? Should all elementary schools, middle schools, high schools, or technical schools be involved? Should teaching of all subject matters be enhanced with support of technology, or should there be a selective use of ICT, favoring domains that are the core of educational competencies at each educational level? Answers to questions such as these are not easy, since they must take into account both the local context as well as the local strategic educational plan. There are many diverse educational needs, and not all of them have the same urgency or impact in the educational sector or in the economy of the country.

Another set of issues emerges from practical constraints or from existing conditions. For example, school buildings may be shared by different learning communities, using shifts to split the time allocated for each community. Should each of the shifts be included in 1:1 computing? Should students share the machinery from one shift to another? Although experience suggests that most teachers support 1:1 computing, teacher unions may feel that 1:1 computing threatens teachers' traditional roles. At what moment should teacher unions be included in the process? Teachers may also feel that 1:1 computing threatens their self-esteem because they will need to lead groups of "digital natives," while they are "digital immigrants." How can one help teachers overcome these fears? Curriculum materials in use may not be designed to help teachers and students benefit from 1:1 computing and networking; how can one create or adapt curriculum materials in tune with the new resources available? Technical support staff at the school building may feel that their kingdom is about to end, since computer rooms may be not needed when 1:1 computing becomes a reality; how can 1:1 computing benefit from their expertise in the implementation of the new solutions?

Strategies must be developed to overcome natural inertia of institutionalized and centralized educational systems—"Education: the sacred cow" as described by Ivan Illich (1968). Many educational innovations have failed to add value to the educational arena, not because of lack of potential, but because of poor adoption, implementation, institutionalization, and support strategies. How can policy makers define strategies that increase the likelihood of success with ubiquitous computing and networking? Given that there are so few pilot experiences to nurture decision making, is it sound to launch large-scale implementation strategies from the very beginning? What pilot experiences—implementations with accompanying evaluation and research—should be implemented? Who else should be involved in these efforts, in order to increase the probability of success?

Once these general policy issues have been addressed and a 1:1 intervention is planned, then there are specific questions of teacher development, materials, and research, which are addressed in the balance of this paper. These considerations apply to all disciplines, but are particularly important in SMET fields because of its challenging content and the importance of inquiry-based learning as a strategy for acquiring this content.

Teacher Professional Development

Teacher professional development can be the largest cost in implementing effective 1:1 computing, so its goals and strategies must be carefully planned in advance. TPD costs can be reduced by concentrating on teaching and avoiding overemphasizing technology. By using well-designed student materials with built-in teacher supports and taking full advantage of local resources, TPD costs can be reduced and resources focused primarily on new content and instructional strategies.

The goal of 1:1 computing necessarily requires the development of strategies that work for all teachers. Therefore, the instructional and TPD strategies used must apply to every teacher, not only the "early adopters," or those with "above average" technical skills. It is often erroneously assumed that the introduction of educational technologies requires teachers to become experts in information technologies—in the use of various software tools, a broad range of applications, and one or more programming languages. While it may be desirable for every teacher to have such skills, it is neither a realistic nor necessary goal.

Similarly, it is often assumed that teachers will create their own technology-enriched student learning materials by authoring lessons or at least knitting lessons together from a wide range of resources. Again, it would be wonderful if every teacher could do this, and it is certainly expected of university faculty, but this is an unrealistic and unnecessary goal for the majority of pre-college teachers.

By investing in high-quality technology-based instructional materials that include teacher guides and other forms of teacher assistance, it is safe to omit training in technology and lesson development from TPD plans for 1:1 computer implementations. This greatly reduces the cost of TPD but only if materials are supplied that are easy to implement. When this is the case, the only TPD required is related to maximizing the educational impact of the materials. The strength of information technologies is that they support better ways of teaching and new ways of learning content. Therefore, the TPD must focus on the pedagogy and content that is unique to the materials. With good materials, this means student-oriented learning that is focused on concepts and relationships.

Parameters concerning effective TPD have changed. It is now accepted that the measure of success cannot be limited to participation and satisfaction in TPD opportunities, that effective TPD should produce learning gains for both teachers and their students. In our search for effective TPD strategies for SMET education we have found that different types of blending are needed: both content knowledge and pedagogy should be addressed, and there should be opportunities to integrate work with training and learning. Professional development should not be planned as a single intervention where teachers are simply exposed to opportunities to enhance their teaching. Instead, TPD needs to be a continuous cycle of exploration, reflection, discussion, application, and knowledge building, through which teachers grow professionally and their students gain deeper knowledge of the corresponding SMET standards.

Technologies permit teachers to go beyond simply learning about new approaches. By participating in communities of practice, teachers thoughtfully share and reflect on their own teaching experiences. We have learned that video-based communities of practice provide a powerful way of allowing teachers to internalize improved teaching strategies. We have also learned that by having genuine conversations with their students and with their colleagues about processes and findings in inquiry-based learning, teachers become co-learners and help their students become creators of their own knowledge.

The following are proven strategies for maximizing the impact on student performance of limited TPD resources:

- Build "blended" communities (face-to-face and online) of SMET teaching practice in which teachers reflect on their own videotaped teaching episodes. Teacher-developed classroom videos can be extremely effective in helping teachers be more effective. The transition from conventional SMET teaching to inquiry-based teaching can be fostered by means of reflection on student thinking as captured in SMET classroom interaction, and by discussion of strategies to overcome teacher's limitations. ICT becomes a means to document digital evidences and reflections, as well as a natural way to introduce multimedia digital environments to SMET teachers. Faculty members from local teacher colleges and faculties of education may play a significant role in online coaching and on-site communities of teaching practice. They are a geographically distributed community of potential facilitators that can become leaders of educational innovation in large-scale implementation of 1:1 computing. We have successfully pilot tested this strategy both in the Congenia project in Colombia and in the Captic project in Perú, where blended communities of practice supported by faculty members helped change the teachers.
- Develop capacity for "on-the-side" facilitation. The discussions among SMET teachers about topics important for their professional practice are one of the most valuable forms of professional development. Facilitating these conversations and guiding teachers to reflect on specific content, or on teaching episodes, is a learned skill, which requires knowledge of on-the-side facilitation and expertise in grounding discussions in evidence from the video. This can be done effectively and inexpensively online, preparing SMET master teachers to become facilitators of text- and video-based discussions. We have succeeded doing this with our Metacourses (e-courses about teaching with ICT).
- Develop a collection of short ICT-based courses that focus on teaching SMET using ICT. These courses should be carefully crafted to stimulate teachers to implement SMET teaching standards and give teachers practical ideas and effective materials that they can use in their teaching. These courses can be online or face-to-face, but the most efficient are usually a

blend of both. Teachers can remember what it is like to be a student while learning by using active (e.g., simulations, games, digital manipulatives) and interactive materials (e.g., collaborative projects), and then applying them to their teaching. Reflection on video case studies of other teachers using the technology in real classes helps teachers focus on student thinking. Video commentary by experts is also important for underscoring key content and pedagogy issues. By scheduling the courses so that groups of teachers have the same experiences at about the same time, then asynchronous online discussions among these teachers can be an important part of the learning experience. We have tested the efficacy of this approach in our Seeing Math Telecommunications project, where teacher gains in pedagogy and content were established.

- Develop self-study materials that exploit inexpensive DVD technology for video delivery and some interactivity. These can be particularly effective if they help teachers prepare for specific SMET classes and course content that is difficult to teach or to learn. The DVDs can help teachers be more effective in discussions and technology use without requiring Internet connections or even a computer. One of our business partners has successfully implemented this strategy in SMET education at the state level.
- Harness the energy and technology affinity of students. Students can be trained to be effective teacher aides: to help find resources, install software, troubleshoot, and act as teaching assistants. Blogs and online communities allow students to communicate and learn from each other. Powerful web-based resources and online conferencing are the primary vehicles for preparing students to help their schools and communities to become members of computing clubs. These ideas, promoted by the Generation Yes project (genyes.com), have been successfully implemented in many school settings.

With strategies such as these, it is possible to design and implement cost-effective TPD that promotes quality ICT-based learning. Students that belong to computing clubs in participating schools could play a significant role in setting up and supporting teachers and other students in the use of 1:1 computers and Internet. Short ICT-based courses and online facilitation courses could help to prepare a distributed community of SMET master teachers from many regions. SMET master teachers, from faculties of education and teacher colleges in each region, could play two complementary roles: (1) help selecting and localizing SMET materials, attending to cultural, curricular and contextual differences, and (2) give support to SMET communities of practice that reflect on their own teaching and on the appropriate uses of SMET materials in 1:1 settings.

MATERIALS FOR SMET EDUCATION

There is little point in going to the effort required of a 1:1 computer initiative while failing to exploit the educational gains that are possible from new approaches and new methods. While putting texts or hypertexts on computers or providing access to digital libraries has some, limited value, computers and the Internet offer students unconventional and more important learning opportunities when they are used to support inquiry and collaboration.

ICT-based materials can greatly improve SMET education. High-quality materials can provide vivid, interactive learning environments, incorporate ongoing assessment, support new forms of collaboration, and be adapted to individual student needs and interests. Computational models, tools, and databases allow students to explore new ideas in ways that are more powerful and accessible than traditional approaches. In addition, ICT materials can be widely distributed electronically at virtually no cost.

Inquiry, experimentation, concept integration, and transference of knowledge to different settings are the core of SMET education. Technology can facilitate greater reliance on every step of this kind of learning by giving students and teachers control of the learning experience through active and interactive technology-based learning environments. There is no need to completely replace existing curriculum materials; a better approach is to enhance current practice by letting students and teachers have direct experiences with highly interactive digital environments. The best strategies allow students to experiment with real and virtual environments to ask "what if" questions and to build concepts based on the organic feedback provided by the system.

We recommend the inclusion of three types of electronic materials to support effective SMET education:

- Models and tools. These are software applications that allow students to work with data, to model relationships between variables, to play with variables, and to get rapid, meaningful feedback. One particularly important kind of tool is "probeware" that can collect, display, and analyze real-time data. These generally require additional electronic interfaces and probes, although the microphones and cameras built into computers can also be used.
- Activities. While the models and tools provide the functionality needed in SMET education, they need to be combined with online curriculum materials that provide motivation, background, guidance, and assessment. This is the pedagogical layer that converts the models and tools into useful educational materials. The best materials embed models and tools into the activities and configure the each package so that the learner can begin using the materials without prior instruction.
- Teacher supports. Teachers need to be able to monitor student progress through activities in order to make appropriate interventions. Software can allow teachers to track student progress, alter the materials and the sequence of activities, and suggest other kinds of interventions. Because technology allows new content to be taught in new ways, teachers also need access to information about content and pedagogy.

An example from our work illustrates these three types of materials and the importance of distinguishing between them. We have developed a sophisticated, open source computational model of the interactions of atoms and molecules called the *Molecular Workbench* engine. The engine can simulate a wide range of atomic-scale physical phenomena that are important in biology, chemistry, physics, and related technical fields. Figure 1 shows the model configured for exploration of crystals and phase change. Figure 2 shows how this model might appear as part of an activity that a student could explore. The surrounding material focuses student thinking and interaction with the model to learn specific content.

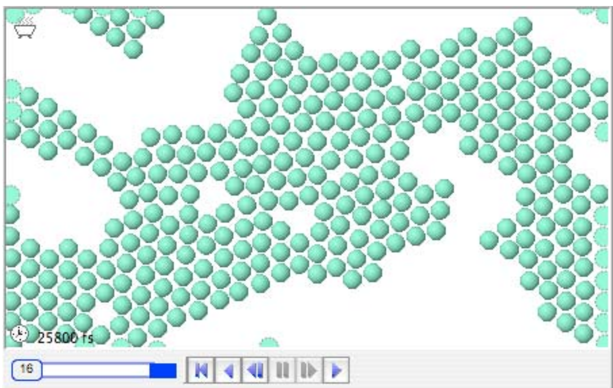

Figure 1. A Molecular Workbench model of a crystal. The actual model is dynamic, showing the motion of each atom under the influence of all the forces present. Many atomic phenomena can be simulated with this model.

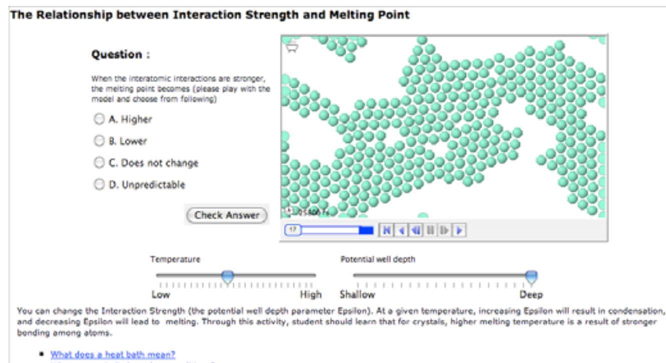

Figure 2. One page of an activity that uses the model in Fig. 1. In addition to the model, there are special controls, a question, explanation, and links to additional information.

Figure 3 is an example of supporting materials for teachers. This is a record from a database used by teachers to locate one of the hundreds of activities that are based on the *Molecular Workbench*. This record provides information teachers need to make good use of the activity: its content and objectives, where it might be used with several common textbooks, and how student mastery of its content could be assessed.

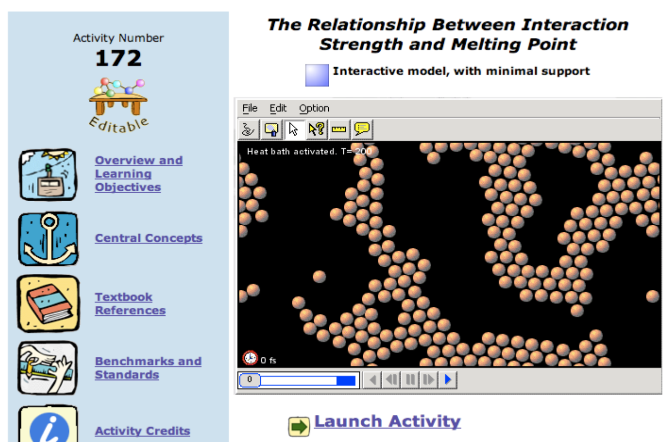

Figure 3, One form of teacher support—a record in a database of activities that has a picture from the activity, describes its content, provides links to standards, addresses the background science, and has a link to the activity.

The distinction between these three types of electronic materials is important to policymakers because the materials can have different origins. Tools and models like the *Molecular Workbench* engine are expensive to develop but universal. Providing they are open source like the *Molecular Workbench*, only one tested application is needed worldwide. The models and tools can reflect the universality of the science that they incorporate. There is no advantage in creating multiple versions of tools and models such as the *Molecular Workbench* engine. What is needed is an international collaboration in the creation and sharing of a few dozen open source applications that could cover most of the topics in science. The development work requires sophisticated developers who can be found at universities and software development specialists.

The activities and teacher supports, however, need to be adapted to the language, curriculum, and culture of specific regions. This can be done by authoring the activities regionally, or by adapting materials developed elsewhere. The activities are the 21st century equivalent of textbooks and the level of funding that is put into texts needs to be allocated to activity development. It is important to have an activity-authoring environment that simplifies the creation of activities so that non-technical educators can create activities. Again, using the *Molecular Workbench* example, around 300 activities have been efficiently developed for that one model engine, because authoring is simple; very attractive and highly interactive activities can be created in an authoring environment that is much like a word processor.

Online teacher supports are extremely valuable to provide a range of resources that busy teachers need when they implement ICT materials, particularly if each student makes use of the materials at his/her own computer. Because the best uses of technology go beyond what is possible with texts and traditional instruction, there will inevitably be new content and new instructional strategies that teachers must learn. An investment in providing these materials online will reduce the need for expensive teacher workshops and courses.

Sometimes ICT materials are mistakenly seen as a way to reduce or eliminate the role of the teacher. When interactive ICT materials are used, the teachers' roles may shift, but they are no less important. To work effectively in classes using ICT, it is essential that teachers have accurate and timely reports about student progress and thinking. All ICT materials should include a means of evaluating students and reporting on their progress.

RESEARCH

Research should be an integral part of any 1:1 program, informing policymakers about the implementation of their plans, documenting impacts of the program, and helping key groups of participants focus on results. By providing formative feedback on implementation and impacts of the 1:1 program, research provides decision makers with an ongoing stream of useful information.

Developing a research agenda and a plan first requires policy-makers to set goals and establish the basic parameters of their 1:1 program. People will naturally want to know whether students have learned more with the laptops. To answer that research question, or many others, it is a good idea to identify a comparison group ahead of time. For example, if the 1:1 program were implemented in a number of pilot schools, then from the outset of the program it would also be a smart idea to identify "control" schools. Experimental schools can be randomly selected from a pool of volunteer schools, or a group of "control" schools can be matched to experimental schools using a small number of variables (e.g., students' socioeconomic status; urban, suburban, or rural locations; etc.).

Implementing a 1:1 program in a set of pilot schools first has other advantages, too; for example, policymakers, teachers, parents, and others will able to observe 1:1 computing in action before committing a large amount of resources to equip most or all schools. Also, policymakers might pilot test different variations of 1:1 computing and compare them, for instance, by providing every student with a personal computer in some schools while in other schools classroom sets of computers might be used, shared among the different groups of students using the classroom during the day. The latter alternative is less expensive; however, it is also less likely to be successful, because personalizing the devices and having ready access to them throughout the day (and perhaps evenings, as well) will make them more powerful learning devices for students.

If an important goal of the 1:1 program is that students learn more (that is, more than other students in a comparison group), it is important to develop a plan that maximizes the odds of success. Besides choosing appropriate grade levels and subjects on which to focus attention; selecting or developing effective instructional materials that make effective use of personal computers; and training teachers, students, and school administrators, it will also be important to use appropriate high-quality tests to measure student outcomes—in other words, tests that are valid and reliable and that fit well with the goals of the 1:1 program. If, for example, the 1:1 program emphasizes conceptual understanding of science (say, by using dynamic computer models, as well as probes attached to the computers), then using a test that emphasizes vocabulary more than concepts would not be a good idea; the test results might very well show "no significant difference" because of the laptops. The development of a research plan must take such issues into account at the earliest possible opportunity.

Typical research questions

There are a great many research questions that can be asked about 1:1 computing programs—too many for one study to try answering them all. Some typical questions asked about 1:1 programs include:

Overarching questions

1. Is teaching and learning improved as a result of the laptop implementation?
2. Are there student achievement gains from the laptop initiative?
3. What are the challenges and successes of program implementation; how can implementation be improved?

4. Is the laptop program a cost-effective way of improving teaching and learning?

Students

1. Does student performance in science, mathematics, and writing change?
2. Does homework time-on-task increase?
3. Is there a change in student attendance or grade promotion/retention rates?

Teachers

1. Does classroom instruction change as a result of the laptop implementation?
2. Which teaching/learning structures are changed? How are they changed?

Program Implementation

1. What is the nature and quality of the training opportunities provided for teachers, students, and parents?
2. What problems or challenges do teachers encounter as they make use of the technology and change their instructional environment?
3. When students use the laptops outside the school environment, what are the challenges or problems they encounter?
4. What can be learned from the schools and classrooms where the implementation was most and least successful?
5. What are the total direct and indirect costs and cost savings associated with the initiative?
6. What was the quality of the technology in terms of availability, network capacity, technical support, repair, and software?
7. What are parents' attitudes toward the program? If the computers are allowed to go home with students, do parents use them? If so, in what ways?

In addition to studying student outcomes, formative research should focus on teachers' professional development and the development and use of computer-related instructional materials. It should document the facilitators of and barriers to success experienced in 1:1 schools. A research framework, such as one developed with funding from the National Science Foundation, is used to organize research questions, data collection, analysis, and research reports (see http://ubiqcomputing.org/eval_mat_framework.html).

High-quality research can be costly. At the Concord Consortium, we have developed ways to reduce costs and thereby make research more viable, including automatic logging of usage data, quick observations using school staff, assessments embedded as part of instruction, and the use of university faculty and staff as partners in the research. Connections with other researchers experienced in studying 1:1 computing is important to the research program because it allows the research team to learn from experiences of other groups and programs.

The prospect of conducting research on 1:1 computing in many different countries and states is an exciting one and is very likely to result in new insights into effective ways to deploy computers in settings that often are different from those in Organization for Economic Cooperation and Development (OECD) countries. In the United States, the number of 1:1 programs is growing because policymakers see that computers make options available to students and teachers that cannot be provided in other ways. The low-cost devices now becoming available throughout the world are bringing the possibility of 1:1 computing to a much larger group of nations than ever.

Integration of efforts and diversification of solutions

Implementing 1:1 computing in large scale is a unique opportunity for collaboration between countries, research and development groups, state and local educational agencies, economy sectors at the interior of each country (in particular, communications and education), intergovernmental agencies, NGOs and technology providers. There are many local variables that need to be considered in planning for a successful implementation; only local stakeholders can establish what strategic and operational factors can make 1:1 computing flourish or perish. But there are also many global opportunities that could be linked, in particular, those related to universal knowledge such as SMET. The real challenge is to find out how to succeed in each of the interested countries, how to make the links between opportunities and needs, by building on the strengths from different potential partners. It is strategically necessary to work together, to create a collaboration agenda in which different kinds of expertise can be articulated.

Under such a collaborative agenda SMET education at the pre-college level is a domain where the Concord Consortium can add value to countries that share our concern about stimulating educational gains and economic development and that trust in our expertise dealing with teacher professional development, curriculum materials, and research in SMET education.

Our approach is to make synergy between these three components of 1:1 computing in SMET education. Making the goals of research clear from the beginning helps everyone pull in the same direction. Research informs materials development and customization. Extensive teacher resources placed in materials can reduce the costs of TPD. Customization can be a powerful TPD strategy. TPD ensures that ICT-based materials are used well. These overlaps, however, need to be built.

We do not think that our ideas about SMET education resources should be transplanted; they need to be adapted and our resources localized. This cannot be done in isolation. It is critical to bring in local universities for research and developing/enhancing open source tools and platforms, as well as to engage professional education groups for localizing and testing curriculum materials; it is important to collaborate with networks of educational portals for distributing SMET curriculum materials and for collecting data about their use; it is needed to work with local teacher colleges and faculties of education in the creation of local and distributed communities of practice; it is good to partner with different technology providers for the effective implementation of SMET solutions in a variety of computing platforms. Our recommendation is to build on local expertise and knowledge in SMET education to make viable a strategy that helps countries foster science learning with the support of 1:1 computing.

BIBLIOGRAPHY AND WEBSITES

Anytime Anywhere Learning. http://www.aalf.org

One-to-One Information Resources. http://www.k12one2one.org/

Rockman, S. (2003). Learning from Laptops. *Threshold*, 1(1), 24-28. (Available from http://www.ciconline.org.)

Russell, M., Bebell, D., & Higgins, J. (2003). *Laptop learning: A comparison of teaching and learning in upper elementary classrooms equipped with shared carts of laptops and permanent 1:1 laptops.* Chestnut Hill, MA: Technology and Assessment Study Collaborative, Boston College. (Available at http://www.bc.edu/research/intasc/PDF/Andover1to1.pdf.)

Ubiquitous Computing Evaluation Consortium. http://ubiqcomputing.org.

Warschauer, M. (2006). *Laptops and literacy: Learning in the wireless classroom.* New York: Teachers College Press.

Zucker, A. A. (2004). Developing a research agenda for ubiquitous computing in schools. *Journal of Educational Computing Research*, 30(4), 371-386. (Available online at http://ubiqcomputing.org/Research_Agenda_Jan_04.pdf.)

Zucker, A. A. (2005). *Starting school laptop programs: Lessons learned (Policy Brief). Available online at* http://ubiqcomputing.org/Lessons_Learned_Brief.pdf

Concord, MA, February 16, 2007