Original article

doi: 10.1111/j.1365-2729.2007.00227.x

What added value does a 1:1 student to laptop ratio bring to technology-supported teaching and learning?

M. Dunleavy,* S. Dexter† & W.F. Heinecke†

*Harvard Graduate School of Education, Harvard University, Cambridge, MA, USA
†Curry School of Education, University of Virginia, Charlottesville, VA, USA

Abstract The purpose of this study was to document typical use and configuration of 1:1 computing in two schools focusing on the added value and unique challenges these uses present. A qualitative case study design was used in two middle schools (sixth, seventh and eighth grade) in the south-eastern United States purposefully selected for their 1:1 computing programmes. Data were collected through formal and informal interviews, direct observations and site documents. Results indicated that online research, productivity tools, drill and practice, and eCommunications were the most frequent uses of computers in the 1:1 classroom. Moreover, the 1:1 classroom provided potentially transformative added value to these uses while simultaneously presenting unique management challenges to the teacher. In addition, the presence of 1:1 laptops did not automatically add value and their high financial costs underscore the need to provide teachers with high-quality professional development to ensure effective teaching. In order to create effective learning environments, teachers need opportunities to learn what instruction and assessment practices, curricular resources and classroom management skills work best in a 1:1 student to networked laptop classroom setting. Finally, researchers documented wide variation in fidelity to 1:1 computing, which suggests the need for further research exploring the conditions under which this variation exists.

Keywords 1:1 laptops, classroom technology practices, ubiquitous computing.

Introduction

Beginning in 1985 with the Apple Classrooms of Tomorrow™ (ACOT) (Apple Computer 1995) project, the last 20 years have seen a steady increase in the number, scope and sophistication of 1:1 computer to student ratio initiatives that now stretch from Melbourne to Maine, ranging from programmes with fewer than 100 computers to over 36 000. In 2000, there were approximately 1000 American schools using a 1:1 model, or ubiquitous computing as it is sometimes called, totaling over 150 000 laptops (Johnstone 2003).

Advocates have hailed 1:1 programmes as having the promise to transform education as we know it (Papert 1980, 1993; Stager 1995; Brown 2003), while others see this promise as simply another 'oversold' fad that is at best a drain on the perpetually limited education budget and at worst a distraction that is actually detrimental to the education of our children (Cuban 2001; Oppenheimer 2003).

Researchers and evaluators have been attempting to document what impact this influx of 1:1 technology is

Accepted: 8 January 2007
Correspondence: Matt Dunleavy, Handheld Augmented Reality Project (HARP), Postdoctoral Fellow in Learning Technologies, Harvard University, Graduate School of Education, 333 Longfellow c/o TIE, 13 Appian Way, Cambridge, MA 02138, USA. Email: dunleama@gse.harvard.edu

having on our students, teachers, schools and communities. But the general consensus from reviews of the research to date is that additional detailed information is needed from 1:1 classrooms in order to describe the teacher and student practices and outcomes, and to identify the contributions the 1:1 access level makes to technology-supported teaching and learning (Lemke & Martin 2003; Zucker 2004; Penuel 2005).

This paper contributes to this information need by disseminating typical classroom uses for 1:1 computing by eight teachers of math, science and English across two middle schools within an urban district in the south-eastern United States. We discuss these uses in terms of the added value and unique challenges they present.

Literature review

Much of the 1:1 laptop classroom research to date focuses on the ways teachers use the computers and the general benefits gained as a result. Teachers primarily use productivity and research applications, such as word processors, spreadsheets, presentation software and Internet browsers on the laptops, employing it both for their instruction and for their and their students' research (Fouts & Stuen 1997; Rockman 1997, 1998, 1999; Lowther *et al*. 2003; Ross *et al*. 2003; Russell *et al*. 2003; Hill & Reeves 2004; Russell *et al*. 2004; Silvernail & Lane 2004). As a result of networked laptops, teachers report greater access to 'up-to-date instructional content' in the form of online and computer-based resources, and content that is available to them in a wider variety of modes (Zucker & McGhee 2005, p. 17). Furthermore, they describe such resources as helping them to support students who learn in different ways by allowing them to present information in a variety of presentation styles and overall contributing to their increased instructional flexibility (Zucker & McGhee 2005).

Teachers have also reported how their and their students' access to networked laptops leads to changes in their teaching. They report designing lessons that are more student-centred and constructivist, allowing for less lecturing and more facilitating or guiding students in the learning process (Baker *et al.* 1993; Apple Computer 1995; Sandholtz *et al.* 1997). Some teachers have also described how they increase the length of the instructional periods to better integrate the laptops into cross-curricular lessons (Johnstone 2003). Other teachers have described how they use more inquiry-based and student-centred activities and serve more of a facilitating role than before the laptop implementation (Ricci 1999; Schaumburg 2001; Jeroski 2003; Hill & Reeves 2004; Russell *et al*. 2004). Additional teachers report an increased ability to receive and give rapid feedback on class and student progress allowing for more targeted remediation (Ricci 1999; Kerr *et al*. 2003; Russell *et al*. 2004).

These studies allow us to recognize the general uses and benefits of laptops in the classroom; however, further research is needed to provide detailed descriptions of teaching practices within classrooms with a 1:1 student to networked laptop ratio. What practitioners and policymakers need is knowledge about the teacher practices in classrooms with a 1:1 student to laptop ratio that lead to these benefits and specifically how the 1:1 access contributes to these benefits in such a way that would not otherwise be possible with a higher student to computer ratio. Practitioners and policymakers also need to understand the possible problems and drawbacks that might be caused by such a ubiquitous level of computers in classrooms as it has implications for the sort of teacher training and support that should accompany laptop implementations.

Researchers have described the findings reviewed above in terms of contributions, capabilities, benefits, or advantages to teaching and learning that are provided by networked technologies. In this paper, we use the phrase 'added value' to discuss what networked laptops contribute to teaching and learning; by this we mean the capabilities provided by 1:1 student to networked laptop ratio that otherwise would not be possible. Dexter (2002) elaborates about added value in terms of the enhancements networked technologies provide when accessing data, processing information and communicating understandings (see Table 1). For example, in the 1:1 computing context, this added value might be represented by an enhanced ability to find and retrieve relevant information via the web, an increased level of real-time formative assessment enabling individualized instruction, or the creation of virtual communities that allow students to communicate inside and outside of the classroom.

Another lens that can be used to describe the contributions that a 1:1 level of student access to networked

Table 1. Added value summary for accessing data, processing information and communicating knowledge.

Task	Added value
Accessing data	• Multi-sensory • Greater amounts of data • Searching and 'mining' capabilities • Timeliness of the information • Relevance of the information
Processing information	• Self-paced • Individual attention • Remediation • Practise to the point of fluency • Visualizing information • Develop process or skill capabilities • Organize and categorize information
Communicating knowledge	• Publish information to an audience • Communicate in an authentic format and style • Communicate findings and understanding to others

laptops might provide comes from a summary of cognitive science research over the last 40 years. In the research examining the development of understanding in learners, many studies emphasize the importance of building upon learners' prior knowledge about a topic and of learners' active involvement in their learning. In summarizing the implications of these findings for educators, Bransford *et al.* (2000b) identify four essential design principles of effective learning environments. According to this research, effective learning environments should be learner-centred, knowledge-centred, assessment-centred and community-centred. That is they should, respectively, support making connections between the students' existing knowledge, skills, attitudes, and beliefs and the current learning situation; provide explicit and implicit guidance and clarification on what is taught, why it is taught and what represents mastery of this knowledge or skill; provide learners with insight into their own progress and allow for revising and refining their knowledge representations; and establish classroom norms and connections that support the desired learning values (Bransford *et al.* 2000b).

It is important to acknowledge that the mere presence of a technology-rich environment is not sufficient for enhanced teaching and learning or added value. In fact, the 1:1 computing classroom frequently presents unique challenges and barriers to successful instruction such as an increase in management problems (Turnbull & Gilmour 1991; Newhouse 2001; Hill *et al*. 2002; Kerr *et al*. 2003; Zucker & McGhee 2005), an increase in teacher workload (Kerr *et al*. 2003; Zucker & McGhee 2005) and difficulty linking laptop use to learning outcomes and standards (Newhouse 2001), among others. Researchers have also documented fragile or excessively heavy machines, limited desk space, inadequate battery life, software deficiencies, data loss, scheduling problems, unreliable Internet access and infrastructure inadequacies accompanying 1:1 laptop programmes (Rockman 1997; Bartels 2002; Kerr *et al*. 2003; Lowther *et al*. 2003; Efaw *et al*. 2004; Hill & Reeves 2004; Garas *et al*. 2005).

Together, the elaboration about added value and the four learning environment design principles provide specific language and outcomes that we can use to investigate and describe the contributions to teacher practices and classroom learning environments made by a 1:1 student to networked laptop ratio. In addition, we document the challenges presented to teachers in this environment providing a critical counterpoint against which such contributions can be weighed.

Methods

Methodology

The purpose of this study was to understand how middle school teachers used laptops at a 1:1 student to laptop ratio in the context of curriculum and instruction; hence, a multiple case study design was employed (Miles & Huberman 1994; Stake 1995; Yin 2003). The

research aimed at understanding how teachers made sense of and used the laptops in the process of instruction. Two case study sites were chosen for in-depth examination of this variable. At the two case study sites, we sampled a total of eight teachers from the core subject areas of math, science and English in order to understand generally the phenomenon of laptop uses within varied school contexts and content areas. As the research progressed, the design was formalized so that attention was focused on selected variables in each case derived from the conceptual framework (Stake 1995). We triangulated the data through the use of multiple types of data (observations, interviews, documents), multiple sources (teachers, students, administrators) and multiple researchers.

Sites and participants

The participants in this study were students, teachers and administrators in two middle schools (sixth, seventh and eighth grade) in the south-eastern United States. Researchers identified these schools primarily through purposive sampling. To provide rich, thick in-depth descriptions of each participant, the number of participants was restricted to eight teachers. The participants were chosen through purposeful selection of those teachers meeting the criteria detailed below. The principal selection criteria of the individual participant teachers were: (i) peer and administrative recognition; and (ii) students who consistently perform well on state standardized achievement tests. Each of the case study teachers were nominated by the building principal for their teaching excellence. In addition, all of the case study teachers have met and exceeded the city and school state standardized testing goals set for their classes. Secondary selection criteria included: (i) nature of 1:1 computing initiative (24 h a day for 5–7 days a week); (ii) duration of implementation 2 years or more; and (iii) willingness to participate. Table 2 presents demographic information on the sample school sites analysed for this paper.

Configuration

At the sites, there were different implementation patterns for the laptops that resulted in variations in how often students had access to the laptops. Table 3 summarizes the variations between the two sites in the study.

Data collection

A team of four researchers spent approximately 130 h over the course of a semester on site at the two schools collecting data (See Table 4 for a summary of the data collection procedures.) The data sources are formal and informal interviews, direct observations and site documents. Interviews were conducted with: (i) all eight participating teachers; (ii) a sample of students from each site; (iii) the technology coordinator and resource/media specialist from each site; and (iv) the principal from each site. The interviews and focus

Table 2. Demographic information for school sites.

School name	Level	Grades served	Enrolment	District type	Percentage poverty[1]	Percentage minority[2]
Jackson Middle School	Middle	6–8	551	Urban	21.9	54.7
Lincoln Middle School	Middle	6–8	972	Urban	59.67	87.2

[1]Free and reduced lunch percentage.
[2]African American, Hispanic, Asian, Pacific Islander, American Indian, Filipino.

Table 3. Implementation models.

School name	Implementation model	Access level and ratio achieved
Jackson Middle School	All 7th and 8th Grade students have laptops	24/7 1:1
Lincoln Middle School	Teams of 1:1 laptops classrooms within 6th, 7th and 8th Grade	24/5 1:1

Table 4. Data collection procedures.

Procedure	Number	Total time
Observations	78	117 h
Formal interviews	8	8 h
Informal interviews	10+	2 h
Website postings	50	–
Total	146+	127 h

groups were structured around a set of questions derived from the conceptual framework and research questions. All interviews were audiotaped while the researchers took notes on responses. The researchers systematically observed each teacher an average of approximately 15 h. While the teachers were aware that the researchers would be observing throughout the semester, the teachers were not notified in advance what classes were to be observed. Observations were conducted using an observation protocol congruent with the conceptual framework and research questions. Observation notes, field notes and audio data were compiled for within-case analysis and cross-case analysis.

Data analysis

Within-site data analysis

Using NUD*IST NVIVO, a qualitative analysis program, the researchers analysed the observation field notes and interview transcripts using a structured coding scheme based on the conceptual framework of the study. The first level of coding used five major coding areas: (i) 1:1 role and configuration in school; (ii) students' practices in 1:1 project; (iii) students' outcomes and impact of 1:1 project; (iv) teacher practices in 1:1 project; and (v) teacher outcomes and impact of 1:1 project.

Using the data gleaned with this first-level coding process, the researchers coded typical uses according to the NCREL Range of Use chart (NCREL 2003). This second level of coding used eight major coding areas: (i) drill and practice; (ii) integrated learning systems; (iii) productivity tools; (iv) expression/visualization; (v) online research; (vi) eCommunications video/audio/data online environments; (vii) simulations; and (viii) problem solving with real data sets. The resulting code reports were used to analyse the possible linkages to the effective learning environments and added value theoretical frameworks (Bransford *et al*. 2000b; Dexter 2002).

Cross-site data analysis

The individual case studies were used for the cross-case analysis. The focus of the cross-site analysis was on various factors identified from the conceptual framework (see above); hence, emphasis was placed on the similarities across the cases with regard to the phenomenon and factors of interest (Stake 1995). Variations in the phenomenon of use and causal explanations of those variations were not the focus of this study. Returning to the theoretical and organizational conceptual framework, the authors created a case-ordered cross-site data matrix categorizing the data accordingly. Pattern-matching analysis, in which each case served as a comparative context for the other, was used to determine if there were significant patterns of use that capitalized on the unique capabilities of the 1:1 student to networked laptop ratio across sites as well a significant patterns of challenges across sites. Tactics used for the pattern matching were making comparisons and contrasts among cases as well as counting the frequency of a use or challenge across cases.

Findings

Online research and productivity tools

The most frequent use by teachers and students of the laptops in the eight observed classrooms at the two schools was online research used in conjunction with productivity tools. At each of the two schools, we noted, in our observations and interviews, extensive use of the laptops in these two capacities, as well as a wide range in the instructional approach used, and the resulting complexity of learning task assigned. Overall, the use of the 1:1 laptops appeared to contribute generally to the effectiveness of the learning environments per the design criteria of being more learner-, assessment-, community- and knowledge-centred. However, online research presented unique challenges for the teachers and there were some examples of the networked laptops actually detracting from effective teaching and learning, which was further exacerbated by the 1:1 student to networked laptop ratio.

Across sites, the teachers and students readily and effectively used search engines to access data on a

variety of topics. The students used simple Google searches most frequently, but were also observed using other search engines such as Yahoo, Ask Jeeves and Dogpile with advanced search techniques such as placing the search phrase in quotations or searching for images only. Invariably, productivity tools such as the Microsoft Office suite components Word, Excel, or PowerPoint were used to record and communicate the results of these searches in notes, papers and presentations. Once again, a wide range of students' skills and capabilities in the use of these tools were recorded.

One example comes from an eighth grade language arts class. After explaining the objectives of the lesson, the teacher facilitated an ongoing research project that involved answering biographical questions concerning the author, J.R.R. Tolkien, from information collected on the Internet. As she circulated throughout the room, the teacher modeled the navigational steps of searching on the Internet, answered clarifying questions and reminded the students to bookmark web pages they found especially useful. While the teacher assisted individual students, the majority of the class worked independently using the search engine Google to locate pertinent websites, collect biographical data on Tolkien and then answer the biographical questions using Microsoft Word.

In this example, the networked laptops allowed for the students to access information and to process it in an organized fashion, but what was the added value of the 1:1 student to networked laptop ratio? Further, did this ubiquity provide any drawbacks or hindrances? While the laptops networked to the Internet provided the added value of a large amount of a variety of data at fingertip access through which they could search quickly with keywords, the 1:1 ratio allowed each student to work independently and pursue the facts about Tolkien that were of greatest interest to him or her. Further, as each student's answers reflected the facts he or she located, its contents provided the teacher with a sense of the student's approach and perspective on the topic, his or her understanding of the biographical questions, and, in general, if he or she knew how to carry out high-quality Internet searches.

A second example from a language arts class illustrates the range in teachers' instructional uses of online research and productivity tools that we encountered throughout the two schools. In this observed lesson, the students were assigned to answer reading comprehension questions on a worksheet using an online version of the text *Treasure Island*. The teacher provided the students with the web address (http://www.kellscraft.com/treasureislandcontent.html) that contained the complete text as well as supporting materials such as the author's biographical information. The students were instructed to read the question and then look in the corresponding online section (i.e. chapter) for the answer. After relating these instructions, the teacher provided no additional coaching or instruction and spent the remainder of the class sitting at her desk completing other tasks.

In this example, the networked laptops provided free access to the book, and allowed the students to employ keyword searching to find the answers. As the students had individual access through the 1:1 ratio, they could proceed at their own pace and devise their own search strategies to seek the answers. However, the emphasis in this lesson was on completing the worksheet and providing the one correct answer for each question. Thus, it seems that if the school had this text on hand, the same activity could have been accomplished with a paper copy of the book. While online research and productivity tool use were the most frequently recorded uses of the networked laptops across the two school sites, the examples above illustrate how differently these tools might be employed.

The teachers reported that online research offered instructional challenges for them because of concerns that students might access inappropriate materials (i.e. games, pornography, etc.), or waste time with inefficient or ineffective searches. While all eight teachers across the two sites used online research in their classrooms, the approach each teacher used to address these challenges was different. In some classrooms, the students were given directions and a few suggested websites to begin their research, but were also encouraged to explore on their own using various search engines such as Google, Yahoo and Ask Jeeves. A different teacher at the same site completely circumscribed her students' Internet access by filtering and presenting acceptable websites via a third party website called Nicenet (http://www.nicenet.org/). When one student inquired about using Google to search for something, the teacher responded with, 'You are not searching the Internet, not ever'. While the 1:1 student to networked laptop ratio does not create this challenge, it does intensify it; the teachers have a class full of students who simulta-

neously need to be directed and monitored regarding their use of Internet resources. Further, the presence of the laptops on a regular basis leads teachers to utilize the Internet regularly, as is borne out by our observations that this is the most frequent category of use, and so this too increases the frequency with which teachers need to meet this challenge.

Drill and practice

The second most frequent laptop use among teachers and students across the sites was drill and practice exercises. The 1:1 student to networked laptop ratio provided unique and powerful capabilities to provide self-paced, individualized instruction with embedded feedback loops, scaffolds and other tools embedded in the software that enhanced learning. The authors observed multiple examples of this added value when students were conducting drill and practice exercises. As observed in the online research and productivity tools uses, the drill and practice exercises generally enhanced the effective learning environment design principles. While there were isolated examples of the 1:1 laptops being used for low-level drill and practice, the majority of the observations recorded high-level, individualized exercises that were learner-, assessment-, knowledge- and community-centred.

Across sites, teachers used drill and practice exercises for instruction, remediation, reinforcement and assessment of concepts. In observed math and science classes, teachers often used the laptops to conduct drill and practice exercises while they circulated throughout the room providing individual instruction. The students worked individually to solve math problems and games on websites such as Algebra Notes (http://www.algebranotes.com/), Math Forum (http://www.mathforum.org/) and AAA Math (http://www.aaamth.com/). Language arts teachers used drill and practice programmes such as Scholastic Reading Inventory and Accelerated Reader to instruct and asses various topics mainly pertaining to reading comprehension. The majority of these websites and programmes had unique features, which scaffolded tasks, explained concepts and provided relevant and timely feedback.

An example of drill and practice use emphasizes the role of feedback and individualized instruction in a 1:1 student to networked laptop classroom. After instructing the students on how to 'play' a monomial exercise found on a website, an algebra teacher circulated among the students providing individual coaching and direction as needed. The laptops were used primarily to complete learning exercises that drilled the students on previously covered concepts and to assess student comprehension. The websites used had 'hint', 'help' and 'show me' buttons to assist students. In addition, the programs provided immediate visual and audio ('Wonderful', 'Perfect', 'Way to go', 'Fantastic', etc.) feedback to the students regarding their performance. During this observation, the teacher told the class, 'I should hear "Perfect" and "Good Job" all the time'. There was a significant amount of peer assistance regarding the computer games and the students were obviously aware of their performance versus their peers. At the end of the individual exercises, the students brought their laptops up to the teacher's desk in order to confirm completion and understanding before going on to the next exercise.

The 1:1 student to networked laptop ratio in this drill and practice example provided added value in five main ways: (i) an increased ability to formatively assess; (ii) an increased ability to individualize instruction and pacing; (iii) an increased ability to provide timely feedback; (iv) an increase in the student interaction and collaboration; and (v) an increase in student engagement.

The multi-sensory visual and audio feedback enabled the teacher to quickly assess the knowledge state of the class and individual students. Using the audio and visual cues, the teacher circulated providing individualized instruction to students who were having problems. At the same time, the laptop-based programme also provided individual coaching. For example, when one student was having trouble, she asked the teacher 'How do I do this one?' and the teacher responded, 'Click "show me" down at the bottom . . . and it tells your right here'. The student followed the teacher's directions and was satisfied with the help she got from the 'show me' feature. This is an added value of the 1:1 student to networked laptop instruction because it frees the teacher from having to answer every question, which also results in students waiting for help. Instead, the students are empowered to use the 'show me' feature to answer their own questions and the teacher has more flexibility to target instruction. As a result, the students were able to practice to the point of fluency in a self-paced manner, thereby creating a learning environment that was centred on and congruent with their cognitive ability.

This ability to provide explicit guidance on what mastery looks like and to provide opportunities for the students to refine their understandings in real time at the individual level would be impossible save for the 1:1 networked laptops and is the essence of a learner-, knowledge- and assessment-centred learning environment. Furthermore, by working individually on a laptop, the students had a certain amount of privacy that possibly encouraged them to ask questions that they would not ask in front of their peers. Another added value of the 1:1 ratio of laptops to students is the automatic grading and reporting feature that enables the teacher to immediately begin remediation at the class or individual level. Furthermore, the combination of the software and the 1:1 networked laptops allowed the teacher to better ascertain the 'knowledge state' of each student as well as the entire class (Bransford *et al*. 2000a, p. 63). This added value gives the teacher a better understanding of how much time he or she needs to spend on certain areas of knowledge that may be isolated to an individual student or representative of the entire class.

In addition, the 1:1 student to networked laptop ratio in this example allowed the students to proceed at their own pace while supporting peer collaboration and feedback. Students frequently asked each other how to solve problems or offered assistance to peers who were struggling. The 1:1 student to networked laptop ratio facilitated this interactive and social environment. Finally, the majority of the students observed across sites were highly engaged in these computer-based drill and practice games and exercise. It was obvious that the students enjoyed the feedback capability of the games, which encouraged and empowered students to practice a discrete skill set until mastery or fluency was achieved. Several teachers interviewed individually also reported a significant increase in student engagement and willingness to work.

Teachers reported few challenges in the use of the laptops for drill and practice beyond the previously mentioned concern of accessing inappropriate websites. However, observations revealed that drill and practice websites ranged widely in instructional quality and rigour. On several occasions, teachers used websites as a reward and playtime rather than an opportunity to learn. This challenge is increased with the 1:1 networked laptops as there are many content-based websites that can provide engaging distraction, but may not deliver challenging curricula-aligned exercises. Furthermore, the use of the laptops to assess certain concepts is limited. For example, computer-based math games or exercises use a multiple choice format to assess comprehension. In observed lessons, the students would work the problems out on a piece of paper next to the computer, but then select one of the multiple choice answers provided to check their work. However, there was no place or capacity for the machines to incorporate the students' work into the assessment. In other words, the student could have worked a five-step problem correctly for four of the five steps only to make a mistake on the last step. But the laptops will not be able to differentiate and therefore the student will not know which step he or she made a mistake. This is a significant weakness of the laptops versus a teacher and presents a challenge to the teacher that is easily remedied once he or she is aware of the problem. In addition, the downside of the audio feedback is a cacophony of 'Good Job' which is potentially distracting and/or embarrassing for students who are not doing well.

ECommunications video/audio/data online environments

The third most frequent use by teachers and students of the laptops in the observed classrooms was online environments, such as classroom websites and video to disseminate information, facilitate communication and enhance instruction. Collectively, we will refer to the categories as eCommunications (NCREL 2003). The 1:1 student to networked laptop ratio provided added value in all of the observations within this category and in some cases it would have been impossible to conduct the lesson save for the 1:1 networked environment. As seen in the previous examples, the eCommunications uses present unique management challenges for the teacher that could possibly detract from effective instruction.

Across sites, teachers used classroom websites such as School Notes (http://www.schoolnotes.com/), Nicenet (http://www.nicenet.org/) and k12Planet (http://www.k12planet.com/) to disseminate information, synchronously and asynchronously communicate, and build local communities within and among different classes. A typical website would contain the classroom mission statement, rules, goals, objectives, assignments, homework, calendar, research web links and the

individual day's agenda. Teachers would also personalize the pages with interesting quotations, community news, exemplary student work and class photographs. Often these web pages were hyperlinked in a way that lets the students and parents receive more detailed information as they clicked through the site. In addition, these websites were used as mediums for publishing work and grades, turning in assignments, soliciting feedback on written work from peers or teachers, and other forms of communication.

An example from an eighth grade English class exemplifies the added value of the 1:1 student to networked laptop ratio in facilitating synchronous and asynchronous communication among students as well as supporting student autonomy and parental awareness. The lesson observed was a collaborative poetry-writing exercise using an Internet-based website called NiceNet (see http://www.nicenet.org/), to compose and share poetry in an iterative, accretive process. The teacher informed the students that they were going to use the threaded discussion section of the website for a collaborative poetry-writing exercise. The teacher first instructed the students to write a short, five- to ten-verse, poem in the threaded discussion area and post it so that the class could view it. She then asked each student to read the poem of the person on their immediate left, choose a word, phrase, or verse from the poem, and copy and paste it into a new message window. The teacher then instructed the students to write a new poem incorporating the chosen phrase of their neighbour. The teacher gave the students approximately 8 min for each poem-writing session and then had the student repeat the process three times. The teacher circulated throughout the exercise facilitating and coaching as needed. Each student produced an original poem and three additional poems that incorporated pieces of their peers' poetry. The entire lesson used the threaded discussion interface to write and share the poetry. At the end of the lesson, the students copied and pasted the collection of written poems into a Word document and turned it in via a shared server.

While this lesson could have been accomplished with paper and pencil, the 1:1 student to networked laptop ratio added value in several ways. First, the use of the laptops to exchange the poems removed the shuffling and passing of papers thereby minimizing wasted time and management problems while making the transition from writing to reading and writing to rewriting seamlessly. In addition, the students did not have to decipher each other's handwriting, which can often be a problem. Second, the students were able to see each other's poems, incorporate portions of their peers' poems into their own poetry and determine how their individual poems blended or fit into the overall theme that was chosen for their table in a virtual environment. This allowed for 'opportunities to revise and improve thinking, help students see their own progress over the course of' the class (Bransford *et al*. 2000b, p. 25). Third, according to the observed teacher, when teaching this lesson with paper, the student writing degenerates after the second round because the students are tired of writing and passing papers back and forth. When using the laptops, the student writing did not deteriorate in quality and the students maintained a relatively higher level of engagement with the exercise. Fourth, the teacher used the website to communicate what she wanted the students to know, what she wanted the students to complete and what she wanted the students to be able to do by the end of the lesson as well as by the end of the year. Communications such as these can contribute to the development of the deep understanding associated with knowledge-centred environments. Because students were able to access these eCommunications as they worked through the assignment, they could reference and proceed with them at their own pace, and follow links to additional information or directions more seamlessly. Fifth, because these class materials are online, students and parents alike can access the class information outside of class using the laptops. This supports student autonomy and independence as well as parental awareness. Finally, the use of the shared server saved time and paper, provided a permanent record and made the process easier and more efficient.

The use of eCommunications in a classroom with a 1:1 student to networked laptop ratio presents several management and procedural challenges to the teacher. As documented in the drill and practice section, the use of video in the classroom can lead to a high level of distracting noise as 15–30 individual laptops begin playing videos at different intervals. Some students used this as an opportunity to disrupt the class by intentionally restarting the video or turning up the volume beyond the necessary level. While this audio problem can be partially remedied with headphones for each student, this in itself presents possible management issues of which teachers need to be aware. A second potential

challenge for teachers is the complexity of the activities, which required multiple explanations of the steps necessary to complete a task. The poetry-writing exercise, which had multiple steps, necessitated clearly presented directions. The teacher in this observation posted step-by-step directions on the classroom wall and, when presented with a procedural questions, referred the student to the posted directions. If this had not been done, the lesson may have become bogged down in procedural explanations.

Challenges

In addition to the specific challenges presented by the 1:1 student to networked laptop ratio detailed above, more general challenges unique to 1:1 environments were documented as well. The challenges fall generally into two categories: (i) classroom management; and (ii) hardware issues.

Teachers across sites reported that classroom management had become more problematic. One teacher explained, 'It makes classroom management – it raises the management to a whole other level, if you let it'. While the computers are powerful tools, they can also serve as a competitive or disruptive distraction. Across sites, the authors observed teachers having to repeatedly instruct the students to close their laptops when not using them for the lesson and to navigate to the appropriate page. They also recorded isolated, but significant examples of teachers unable to successfully manage the 1:1 student to networked laptop ratio. In this environment, if the teacher does not have strong class management skills, the computers simply add another layer of management complexity that is possibly overwhelming.

Hardware problems present another challenge with a 1:1 student to networked laptop ratio. These challenges consist of students forgetting to bring their machines to class, students not having machines because of repair issues and students arriving to class without a fully charged battery. The most frequently observed challenge was the battery issue. Invariably one to three students arrive to class without a functional computer because of a lack of charge. In the worst-case scenario, if the classrooms do not have well-positioned outlets, extra computers and/or a flexible teacher, these students are essentially locked out of the planned lesson and consequently often create a disturbance.

Previous research on 1:1 classrooms supports our findings that the 1:1 computing classroom frequently presents unique challenges and barriers to successful instruction (Turnbull & Gilmour 1991; Newhouse 2001; Hill *et al*. 2002; Kerr *et al*. 2003; Zucker & McGhee 2005).

Discussion

In our observations, the 1:1 student to networked laptop ratio added value to the teaching and learning process by providing an increased: (i) ability to formatively assess learning; (ii) ability to individualize instruction; (iii) capacity for self-guided pacing; (iv) ability to access online resources; (v) capacity for student interaction and collaboration; and (vi) capacity for networked communication and materials management. Each of these added value categories is congruent with one or more of the four interrelated design principles of effective learning environments, as we discuss below.

Ongoing assessments that make whole class and individual student understandings visible are essential to an assessment-centred environment (Bransford *et al.* 2000b). As evidenced in this study, a 1:1 student to networked laptop ratio provides added value to formative assessments by increasing the frequency and quality of the assessments while decreasing the time and labour required for such intensive assessments. These assessments are fast, efficient, and greatly facilitate the teacher's ability to target remediation and to meet lesson objectives. The real-time monitoring of students' understanding represented in observations of this study would be impossible without a 1:1 environment. Furthermore, the combination of 1:1 computers with the embedded scaffolding and coaching features found within many of the computer applications has the potential to shift our current understanding of drill and practice from a low-level didactic learning approach to a high-level constructivist approach.

The increased abilities to individualize instruction and provide self-paced instruction are critical qualities for a learner-centred environment. Across sites, the 1:1 student to networked laptop ratio empowered teachers to cultivate these principles within their classrooms. By capitalizing on the greater frequency and higher-quality formative assessments, teachers were better able to ascertain each student's level of understanding and design learning tasks that were individualized. This is

one of ways that technology has been seen to create an effective learning environment effectively 'increasing opportunities for learners to receive feedback from software tutors, teachers, and peers; to engage in reflection on their own learning processes; and to receive guidance towards progressive revision that improve their learning and reasoning' (Bransford *et al*. 2000b, p. 243). Perhaps more significant and indicative of the future, each student had the ability to proceed through a series of learning tasks at his or her own pace in an engaging, but challenging laptop or web-based program.

The increased capacities for student interaction, collaboration, communication and materials management as well as the ability to access online resources via the networked laptops are critical qualities for community-centred and knowledge-centred environments.

The added value that the 1:1 student to laptop ratio brings to these capacities was clearly exemplified across sites. While different teachers used the laptops to reinforce or support divergent norms, e.g. competitive versus collaborative, the laptops brought added value to each. The drill and practice findings clearly represent the use of the laptops to reinforce a competitive classroom norm while the poetry-writing exercise emphasized collaboration. In the latter example, the 1:1 ratio allowed the teacher and students to create virtual communities that communicated synchronously and asynchronously to share ideas, solicit writing feedback, or ask relevant questions about the learning task. One of the more surprising findings from this particular case was the continuation of asynchronous student communication concerning poetry via a class-based website for 2 weeks after the last day of school. The added value the laptops created in building these virtual communities warrants further research.

Another practical aspect of our findings is the efficiency and speed of materials management that is possible within the 1:1 environment. The shared server is a powerful tool and it could be hypothesized that in the future it will be the main medium by which students and teachers exchange work (i.e. quizzes, homework, assignments, etc.). In addition, classroom websites are used as mediums for publishing work and grades, turning in assignments, soliciting feedback on written work from peers or teachers and other forms of communication. While not explicitly pedagogically driven, the use of these tools to manage class assignments and activities is an important component of a fully functional 1:1 environment and worth further investigation and documentation.

The challenges of teaching in a 1:1 environment can be substantial. The findings from this study revealed the unique hardware issues, the complexity of the learning tasks, and the potentially distracting characteristics of laptop instruction (i.e. video, audio, unlimited Internet access) intensify the need for effective classroom management skills. In addition, the observation that certain teachers interacted less with their students or taught less in the 1:1 classroom is significant. In these cases, we hypothesize that the teachers mistakenly viewed the laptops as proxy instructors relieving them of their teaching responsibilities.

Implications and conclusion

Laptops not only can add value to the teaching and learning process but can also contribute to classroom management problems. In addition, the presence of 1:1 laptops does not automatically add value and their high financial costs underscore the need to provide teachers with high-quality professional development to ensure effective teaching. In order to create effective learning environments, teachers need opportunities to learn what instruction and assessment practices, curricular resources, and classroom management skills work best in a 1:1 student to networked laptop classroom setting.

The documentation of both high- and low-end laptop uses within this study supports the assertion that teachers would benefit from explicit instruction about an evaluative framework to apply to potential curricular resources and software applications. If combined with district-level or school-level support for locating and acquiring these resources, such a framework would focus teachers' instructional decision making on the integration of high-quality resources that provide documented added value to teaching and learning. A large number of such resources must be located and aligned to the desired student outcomes in order to use laptops in the classroom on a regular basis in meaningful ways.

In addition to professional development that helps teachers adapt their instruction to leverage unique pedagogical capabilities within a 1:1 environment, these findings suggest special attention should be paid to help teachers realize how laptops can support assessment-centred learning environments. Formative

assessments are a powerful support for learning yet many teachers do not regularly employ them. Further, the drill and practice-oriented software that can be used to support formative assessment is often considered a low-level use of computers and one that many technology enthusiasts dismiss. Yet, when every student has a laptop, drill and practice programmes embedded within digital textbooks have the potential to increase the frequency, quality, and speed of whole class and individual student formative assessment. This suggests the need for professional development for this pedagogy in general as well as support in locating assessment tools and aligning them to key student learning outcomes.

Technology specialists and other technology leaders at schools with laptop programmes will need opportunities to learn about and plan for the challenges of managing ubiquitous laptops in the K-12 environment. It is critical that the leadership implement policies and routines that allow teachers to focus on the significant tasks of integration, rather than distracting management issues such as charging the laptops' batteries or preventing students from accessing inappropriate Internet sites. Associated with this management might be additional costs for carts, electrical work, insurance policies, and loaner laptops, parent education programmes, and school board approval of new policies. This suggests a need for careful 'What if?' planning that brainstorms all the things that could go wrong when several hundred adolescents are simultaneously given delicate and expensive machinery that is vulnerable to viruses and other malfunctions.

The implication of the above for policymakers is that alongside the costs of purchasing hardware, the costs of well-thought-out professional development and management programmes must be budgeted for as well. If the teachers and the technology specialists do not have opportunities to learn about and plan for meaningful and well-managed 1:1 uses, it is less likely that the laptop programmes' goals will be reached, and the related investments warranted.

The instructional uses of laptop computers detailed above warrant further investigation into the relationship among instructional approaches to learning, the complexity of learning attempted and the authenticity of learning (NCREL 2003). It is really not about the laptops. It is about what the 1:1 laptops enable in terms of new ways of teaching and learning. Our results indicate that the 1:1 student to networked laptop ratio contributes generally and significantly to the effectiveness of the learning environments per the design criteria of being more learner-, assessment-, community- and knowledge-centred. However, without a congruent professional development programme and clear definition in programme objectives, certain uses of the technology for effective teaching may be ignored or overlooked. Further research is needed to answer questions such as: what are the conditional variables that influence the uses recorded? How does high-stakes testing influence the uses of technology in the 1:1 classroom? How do expert teachers use technology when given 1:1 computer resources? From the teachers' perspective, what are the conditions that facilitate or hinder successful integration of computers in the 1:1 classroom? Do ethnic, economic, or gender-based subgroups benefit more or less with the introduction of 1:1 computing? These and other questions need to be fully explored in future research studies to fully leverage the power and potential of 1:1 computing in the K-12 environment.

References

Apple Computer. (1995) *Changing the Conversation About Teaching, Learning and Technology*: *A Report on 10 Years of ACOT Research.* Available at: http://images.apple.com/education/k12/leadership/acot/pdf/10yr.pdf (retrieved 20 June 2005).

Baker E.L., Gearhart M. & Herman J.L. (1993) *The Apple Classrooms of Tomorrow: 1990 Evaluation Study.* University of California. Center for the Study of Evaluation/Center for Technology, Los Angeles, CA.

Bartels F. (2002) *Reflections on the rcds Laptop Program after Three Years.* Rye County Day School, Rye, NY.

Bransford J., Brophy S. & William S. (2000a) When computer technologies meet the learning sciences. *Journal of Applied Developmental Psychology* **21**, 59.

Bransford J., Brown A. & Cocking R. (2000b) *How People Learn: Brain, Mind, Experience, and School*. National Academy Press, Washington, DC.

Brown D.G.E. (2003) *Ubiquitous Computing: The Universal Use of Computers on College Campuses*. Anker Publishing Co, Bolton, MA.

Cuban L. (2001) *Oversold and Underused: Computers in the Classroom*. Harvard University Press, Cambridge, MA.

Dexter S. (2002) Etips-educational technology integration and implementation principles. In: *Designing Instruction for Technology-Enhanced Learning* (ed. P. Rodgers), pp. 56–70. Idea Group Publishing, New York.

Efaw J., Hampton S., Martinez S. & Smith S. (2004) Teaching and learning with laptop computers in the classroom. *Educause Quarterly* **3**, 10–18.

Fouts J.T. & Stuen C. (1997) *Copernicus Project: Learning with Laptops: Year 1 Evaluation Report.* Seattle Pacific University, Seattle, WA. ERIC No. ED 416 847.

Garas N., Davis D., Hopstock P., Kellum A. & Stephenson T. (2005) *Henrico County Public Schools Ibook Survey Report*. Development Associates, Arlington, VA.

Hill J.R. & Reeves T.C. (2004) *A Report of a 4-Year Evaluation on the Laptop Initiative at Athens Academy.* The University of Georgia, Athens, GA.

Hill J.R., Reeves T.C., Grant M.M., Wang S.-K. & Han S. (2002) *The Impact of Portable Technologies on Teaching and Learning: Year Three Report*. The University of Georgia, Athens, GA.

Jeroski S. (2003) *Wireless Writing Project. School District No 60 (Peace River North) Research Report: Phase 2*. Horizon Research & Evaluation, Vancouver, BC.

Johnstone B. (2003) *Never Mind the Laptops: Kids, Computers, and the Transformation of Learning.* iUniverse, Lincoln, NE.

Kerr K.A., Pane J.F. & Barney H. (2003) *Quaker Valley Digital School District: Early Effects and Plans for Future Evaluation*. RAND Corporation, Santa Monica, CA.

Lemke C. & Martin C. (2003) *One-to-one Computing in Maine: a State Profile*. Metiri Group, Culver City, CA.

Lowther D.L., Ross S.M. & Morrison G.M. (2003) When each one has one: the influence on teaching strategies and student achievement of using laptops in the classroom. *Educational Technology Research and Development* **51**, 23–44.

Miles M.B. & Huberman M.A. (1994) *Qualitative Data Analysis: An Expanded Sourcebook*, 2nd edn. SAGE Publications, Thousand Oaks, CA.

NCREL. (2003) *Indicator: Range of Use.* Available at: http://www.ncrel.org/engauge/framewk/efp/range/efpranin.htm (retrieved 19 September 2005).

Newhouse P. (2001) A follow-up study of students using portable computers at a secondary school. *British Journal of Educational Technology* **32**, 209–219.

Oppenheimer T. (2003) *The Flickering Mind: The False Promise of Technology in the Classroom and How Learning Can Be Saved*. Random House, New York.

Papert S. (1980) *Mindstorms: Children, Computers and Powerful Ideas*. Basic Books, New York.

Papert S. (1993) *The Children's Machine: Rethinking School in the Age of the Computer*. Basic Books, New York.

Penuel W.R. (2005) *Research: What It Says about 1–1 Learning.* Apple Computer, Cupertino, CA.

Ricci C. (1999) *Program Evaluation: The New York City Board of Education Community School District Six Laptop Project*. Metis Associates, New York.

Rockman. (1997) *Report of a Laptop Program Pilot.* Rockman Et Al, San Francisco, CA.

Rockman. (1998) *Powerful Tools for Schooling: Second Year Study of the Laptop Program.* Rockman Et Al, San Francisco, CA.

Rockman. (1999) *A More Complex Picture: Laptop Use and Impact in the Context of Changing Home and School Access.* Rockman Et Al, San Francisco, CA.

Ross S.M., Lowther D.L., Wilson-Relyea B. & Wang W. (2003) *Anytime, Anywhere Learning Final Evaluation Report of the Laptop Program: Year 3.* The University of Memphis, Memphis, TN.

Russell M., Bebell D., Cowan J. & Corbelli M. (2003) An alphasmart for each student: do teaching and learning change with full access to word processors? *Computers and Composition* **20**, 51–76.

Russell M., Bebell D. & Higgins J. (2004) Laptop learning: a comparison of teaching and learning in upper elementary classrooms equipped with shared carts of laptops and permanent 1:1 laptops. *Journal of Educational Computing Research* **30**, 313.

Sandholtz J., Ringstaff C. & Dwyer D.C. (1997) *Teaching with Technology: Creating Student-Centered Classrooms*. Teachers College Press, New York.

Schaumburg H. (2001) *The Impact of Mobile Computers in the Classroom-Results from an Ongoing Video Study*. Freie Universitaet Berlin, Berlin.

Silvernail D.L. & Lane D.M. (2004) *The Impact of Maine's One-to-One Laptop Program on Middle School Teachers and Students: Research Report #1.* Maine Education Policy Research Institute, University of Southern Maine, ME.

Stager G. (1995) In Australia . . . Laptop schools lead the way in professional development. *Educational Leadership* **53**, 78–81.

Stake R. (1995) *The Art of Case Study Research*. Sage Publications, Thousand Oaks, CA.

Turnbull G. & Gilmour T. (1991) Laptops in the Scottish primary school: interim report. *Educational Media Internation* **28**, 63–66.

Yin R.K. (2003) *Case Study Research: Design and Methods*, 3rd edn. Sage Publications, Thousand Oaks, CA.

Zucker A. (2004) Developing a research agenda for ubiquitous computing in schools. *Journal of Educational Computing Research* **30**, 371.

Zucker A. & McGhee R. (2005) *A Study of One-to-One Computer Use in Mathematics and Science Instruction at the Secondary Level in Henrico County Public Schools* (No. 0231147). SRI International, Washington, DC.