A Study of One-to-One Computer Use in Mathematics and Science Instruction at the Secondary Level in Henrico County Public Schools

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Executive Summary

This report describes the findings of the evaluation of HCPS's Teaching and Learning Initiative, conducted by SRI International (SRI) and Education Development Center (EDC) and based on data collected through the end of the 2003-2004 school year. The study has been supported by a grant from the National Science Foundation (grant #REC-0231147) as part of a larger project supporting a network of evaluators working in many one-to-one computing sites across the United States. The overall goal of the project is to increase understanding of one-to-one computing initiatives, especially in mathematics and science education.

By giving laptop computers to more than 25,000 teachers and students in grades 6 to 12, Henrico County Public Schools (HCPS) in Virginia became the largest school district in the United States to implement one-to-one computing in its middle and high schools. HCPS established wireless local area networks in all of its schools, invested in new hardware and software, and provided a range of technology professional development to support the use the laptops in daily instruction.

The primary purpose of the evaluation was to collect data about the use of the wireless laptops in science and mathematics instruction in selected schools in HCPS. The SRI-EDC team was interested in documenting a variety of teaching and learning practices with laptops in which teachers and students participated, and identifying some of the structures and resources within the schools and the division that influenced laptop use. The evaluation team used a mixed-methods design, using a range of different data collection methods to address these topics. Primary data sources for the study included site visits in two middle schools and two high schools during the 2002-2003 and 2003-2004 school years; interviews and focus groups with more than 100 administrators, school staff, students, and parents; and analysis of extant documents. The evaluation team also collected survey data from 200 math and science teachers and more than 300 students. However, the survey data were not used in the analysis in this report because of concerns over potential bias associated with low response rates.

Key Findings

In a period of 3 years, HCPS has demonstrated that one-to-one computing can be implemented on a large scale within the context of a large school district (45,000 students enrolled). This summary finding is based on the analysis of data collected from a variety of school and district respondents in the following areas: classroom uses of the computers in four schools; impacts of the one-to-one computing initiative on students, teachers, and families as reported in interviews and focus groups; and our analysis of factors that facilitate or present barriers to the use of the laptops throughout HCPS. Specific findings are highlighted under each section below.

Classroom Uses of Laptop Computers

In the four schools we visited, we observed teachers and high school students using Apple iBook laptop computers in a variety of settings and for multiple purposes. Different teacher and student respondents reported that the computers were being used in all subjects, from physical education to foreign languages. Specific examples of laptop use in science and mathematics identified in this study include:

- **Science.** Virtual dissections, virtual field trips, student development and presentation of iMovies, WebQuests, laboratory write-ups, drill-and-practice for statewide tests, databases and spreadsheets, and the creation of Web pages.
- **Mathematics.** Larson's Algebra, The Geometer's Sketchpad, spreadsheets, drawing programs (for geometric figures), eduTest and Quia (sites that allow teachers to create tests students can access online).

Students used a variety of software packages and online Web sites to explore academic content, create projects, and complete homework assignments. Teachers also reported using the laptops as a tool to enhance their productivity and their ability to manage the different aspects of their professional work.

Impacts of the One-to-One Computing Initiative on Students, Teachers, and Families

Although the SRI-EDC study uncovered some difficulties associated with implementing the one-to-one initiative, overall, the teachers, students, and parents interviewed saw the use of laptop computers in school and at home as beneficial. According to those interviewees, using the laptops had the following influences on aspects of teaching and learning in HCPS:

- Greater access to resources and information for more students and families.
- Increased student motivation, engagement, interest, and self-directed learning.
- More student interaction with teachers.
- Better-organized students.
- Easier access by teachers and students to up-to-date instructional content.
- More flexibility for teachers during instruction.
- Increased professional productivity and greater collaboration among teachers.
- Improved home-school communication.
- An increased need for planning time to make good use of the laptops.
- Added challenges for teachers to manage classrooms and discipline.

Factors That Facilitate or Present Barriers to the Use of Laptops

HCPS central office leadership was able to provide extensive support to rapidly expand and sustain the implementation of the laptops in this initiative. Among the factors that facilitated the use of laptops for instructional purposes in HCPS are:

- **Support for and commitment to the initiative.** Administrative support, training and professional development, technical support, and licensed software maximized the benefits of laptops and the wireless Internet connections in schools.
- **School-based technology trainers.** Each school had technology trainers—usually former teachers with strong backgrounds using educational technology. These trainers worked in a variety of ways to help teachers use laptops effectively.

- **Professional development for teachers.** An extensive out-of-school, high-quality professional development program was available to teachers.
- **Hardware, software, and technical support.** Schools each had technology support technicians (TSTs), who were able to fix many hardware and network problems. TSTs were permitted by Apple Computer to do certain types of repairs on the laptops; other repairs, such as a broken screen, had to be made by Apple.

Teachers, students, and administrators also identified several barriers or problems that complicated the implementation of one-to-one computing in Henrico, including:

- **Laptop durability.** The incidence of breakage and the need for repair was high.
- **Laptop battery life.** Batteries often needed recharging during the school day, even if properly charged by students at home.
- **Students' forgetting laptops.** Some middle school teachers reported that a number of students did not bring their laptops to class, making it difficult to require their use as part of lessons.
- **Management and discipline issues.** Teachers and administrators found it difficult to monitor students' use of iBooks for appropriateness.
- **Time.** For teachers in particular, finding time to learn and practice new approaches to teaching that made use of the laptops was an issue. It was also time-consuming for teachers to simultaneously prepare and deliver electronic and paper-based lessons; the latter were needed for students who did not have laptops or whose parents preferred that they receive paper copies of all assignments.

Discussion and Conclusions

HCPS central office staff adopted a comprehensive approach to the laptop initiative. School district leaders involved all key groups, including parents. Teachers and students were provided with training and with extensive technical support. The hardware infrastructure, notably the wireless network, was upgraded so it would work with tens of thousands of users. Teachers were provided with classroom display devices. A variety of software products and Web sites were licensed, and teachers were paid to develop ways of effectively integrating technology into instruction. Teamwork was encouraged, and leadership was shared.

The purpose of the HCPS initiative was principally to improve teaching and learning. At the same time, HCPS also used the laptop initiative to improve communication with parents and to increase administrators' and teachers' productivity. Indeed, the findings about the teachers' use of laptops for their own professional purposes can be understood as reflecting a changing view of what it is teachers need in order to do high-quality work. By providing HCPS's middle and high school teachers with laptop computers, division leaders demonstrated that teachers, students, and parents benefit when the teachers are provided with the same kinds of multipurpose tools that are now mainstays for workers in business and government.

Despite the positive results to date, large-scale one-to-one initiatives are so new that there is still much for HCPS, and others, to learn about managing such a major undertaking. Division leaders will naturally encounter questions about allowing middle school students to take

computers home (an issue on which opinions in the division differ), managing the transition from textbooks to electronic learning, and other aspects of the laptop initiative. It may be useful for HCPS staff to communicate with leaders of the laptop initiative in Maine, the site of another large-scale laptop initiative, to exchange information and compare approaches.

As one looks into the future, HCPS's one-to-one initiative, like all others, will change and evolve in response to changes in technology and what HCPS learns about implementation. Given the positive findings about the laptop initiatives in HCPS, as well as the one in Maine, where all middle school students statewide have been provided with laptop computers, it is not surprising that many other districts and states are investigating and implementing one-to-one computing initiatives in some of their schools. The declining costs of digital equipment, combined with the reported benefits of providing computers to all teachers and students, suggests that one-to-one computing in schools will eventually include millions of students in schools across the country.

Contents

Contents (continued)

I. Introduction to the Study

In recent years, a growing number of school districts and states have provided one-to-one student-to-computer ratios by purchasing laptop computers or other computing devices for all students and teachers in certain grades (Bianchi, 2004; Silvernail & Lane, 2004; Michigan Department of Education, 2004; Texas Education Agency, 2004; Kenning, 2004; Office of the Governor of New Hampshire, 2003). Ubiquitous or one-to-one computing environments are different from what one traditionally finds in most school settings because they provide all students and teachers continuous access to a wide range of software, electronic documents, the Internet, and other digital resources for teaching and learning without the need to move the class to a computer lab outside the classroom. In contrast to typical school settings, where teachers consider the difficulty of routinely obtaining access to many computers a significant barrier to their use, in one-to-one computing environments all teachers and students have their own computers, which they can move from classroom to classroom.

In 2001, Henrico County Public Schools (HCPS) in Virginia became the largest school district in the United States to implement one-to-one computing in its middle and high schools. Through its Teaching and Learning Initiative, the division invested in upgrades to its existing infrastructure, new hardware and software, and a range of technology professional development so that teachers and students would be able to integrate laptop computers into instruction and use them at home. HCPS established local area networks in all of its schools, supporting wireless connectivity for Apple iBooks that were distributed to teachers and students. Each network connects all schools to Intranet servers, as well as to the Internet. By spring 2003, more than 25,000 teachers and students in grades 6 to 12 had been given computers for use at school and at home to collect information on the Internet, take notes, and create or complete assignments.

In January 2003, SRI International (SRI) and Education Development Center (EDC) proposed to conduct an evaluation study in HCPS focusing on the implementation of wireless laptops in the division's middle and high schools, especially in science and mathematics education. This report presents study findings based on data collected over more than a year. The study has been supported by a grant from the National Science Foundation (grant # REC-0231147) as part of a larger project supporting a network of evaluators working in many one-to-one computing sites across the United States. The overall goal of the project is to increase understanding of one-to-one computing initiatives, especially in mathematics and science education. (See http://ubiqcomputing.org for further information about the grant.)

This report describes the findings of the SRI-EDC evaluation of HCPS's Teaching and Learning Initiative, based on case study data collected through the end of the 2003-2004 school year. This chapter provides background about the initiative and the evaluation. Chapter II describes the study findings. Chapter III places these findings in a broader context and discusses the future of ubiquitous-computing initiatives.

Henrico County and the iBook Teaching and Learning Initiative

HCPS is adjacent to the city of Richmond and the Richmond City School District. There are 64 schools in the HCPS system, including 10 high schools and 11 middle schools; HCPS employs more than 3,000 teachers. In the 2003-2004 school year, the division reported that about 27% of the approximately 45,000 enrolled students were identified as needing federal free or reduced-price lunch subsidies, an indication of economic deprivation. There is wide variation in the demographics of different parts of the division, with the eastern portion of the school district

housing higher proportions of students from low-income families than the wealthier western portion of the district. The school district's operating budget for 2002-2003 was $306.2 million, or about $7,083 per pupil.

Every few years, HCPS conducts surveys of parents. In more than 20,000 surveys returned in 2002, the division received high marks from parents: 94% were satisfied with the quality of education at the school their child attended, and an identical percentage were satisfied that the school provided a safe environment for learning. At least 90% of parents reported feeling welcome when they visited their child's school and believed that the principal and assistant principal provided good leadership.

Origins and Goals of the Initiative

The iBook initiative[1] in HCPS grew out of a number of existing needs and demands within and outside the school system. The HCPS school board charged division administrators to develop a 6-year plan to enhance technology in the schools. According to the superintendent, HCPS had already invested millions of dollars for stand-alone computer labs but had not experienced major returns because students were using computers in the labs only an hour a week. While debating the notion of adopting mobile laptop labs, the then superintendent, Dr. Mark A. Edwards, and his division leadership team realized that almost half of all HCPS students did not have access to technology at home. Discussions led to the idea of adopting laptop computers and obtaining digital content to use with the laptops. The school district conducted a number of focus group meetings with different constituents in HCPS. When it became clear that there was support to move forward, division leaders began discussions with the Apple Computer Corporation about the details of implementing the iBook initiative.

Dr. Edwards (winner of the 2003 Harold W. McGraw, Jr. Prize in Education) was a major proponent of the laptop initiative from the start. "Preparing students for the 21st century" was an important goal of the initiative. School officials believed that the iBook initiative would help provide HCPS students with the skills needed to be competitive in the changing global economy. As the HCPS technology plan states, "We believe the future is now; we believe we must provide our students with 21st Century tools and learning experiences that reflect preparations for today's world…" (HCPS Technology Plan 2002-2005, p. 2). Addressing the "digital divide" by giving all students access to computers was another goal articulated by HCPS school leaders. Henrico School officials also felt that over the long term this initiative would help to reduce reliance on textbooks. They reasoned that the money saved by not purchasing large numbers of textbooks could be reallocated and used to purchase more computers.

The HCPS one-to-one initiative is consistent with Virginia's emphasis on online testing. In 2000, Virginia became one of the first states to begin an initiative for testing students online, an approach that provides efficiencies in administering, scoring, and reporting standardized tests, and offers the possibility of more closely linking assessment and instruction in ways that help students learn. Virginia is now working with NCS Pearson to pilot online tests at the high school level in a variety of subjects (http://etest.ncs.com/Customers/Virginia/index.htm). The state has offered funds to all districts to improve their network and hardware infrastructure so it will be

[1] In this document, the terms *Teaching and Learning Initiative* and *iBook initiative* are used interchangeably.

ready when online testing becomes widespread, and Virginia's technology plan envisions a 1-to-1 student-to-computer ratio in grades 3 to 12.

Budget

Beginning in 2001, HCPS dedicated 5% of its operating budget (approximately $20 million) to fund the lease of 25,000 iBook laptops from Apple Computer, Inc. The lease is for a 4-year period and includes a plan for replacing old equipment with new equipment over time, as well as maintenance support. Students and their families paid $50 for an insurance policy for the iBooks (with a $100 deductible), but alternative arrangements were made in cases where paying the fee presented a hardship.

Implementation of the iBook Initiative

Although the iBook initiative unfolded in HCPS schools in different ways, the creation of an infrastructure for the distribution and management of laptops was assigned to one of the assistant principals in each school. These school administrators, either by volunteering or under the direction of the school principal, supervised the technology committee and held meetings in which staff members talked about how to use technology for instruction. Assistant principals were responsible for the inventory, distribution, and collection of iBooks. With the help of school staff, the assistant principals used a system of barcodes on the laptops, collected insurance forms and payment from students and their parents, organized a school helpdesk to provide technical support to students, and managed all aspects of caring for laptops. This oversight also included ensuring that each laptop was in good condition, determining any willful damage, and making sure laptops were collected from students, boxed, and accurately labeled at the end of the school year.

High schools. In fall 2001, high school teachers were issued iBook laptops shortly before schools opened; students received their laptops at the opening of school. School staff discussed the use and care of the laptops, insurance, and other issues with the parents, who signed a paper saying they understood the acceptable use policy. Once students were provided with a computer, they were trained about laptop use.

Middle schools. On the basis of lessons learned from the timing of laptop distribution in the high schools, middle school teachers received their iBooks around December 2001 or January 2002, so they had a full year to use them before the middle school students received laptops. In fall 2002, middle school students received computer training from the physical education department. For example, students were taught to use the "virtual share," a file server that seemed to be organized by school, then by teachers within schools, and then by class. (This was the path used to find the proper folders.) At that time, the iBooks were on portable carts. The P.E. teachers created lessons for students that focused on the proper use of the computers. Middle school parents were also provided many opportunities for training during fall 2002—perhaps 12 different occasions in all (some for 90-minute mandatory training sessions before a student was allowed to have a laptop and others for those interested in more). "We were always packed for those [parent] sessions," said a teacher at one middle school. Middle school students then received their laptops at the end of January 2003.

Hardware, Software, and Network

The students' iBooks weighed less than 5 pounds and came equipped with USB and FireWire ports, 10-gigabyte hard drives, wireless cards to connect to the network, and other features. Because of concerns about network integrity and security, student e-mail capability was blocked in HCPS. Each classroom had a large television set to which the computers could be connected for whole-class displays. In addition, multiple computer projectors were available in each school.

A variety of software titles were installed on the students' laptops and the division licensed the use of many Web sites (see Exhibit 1 for additional information on this topic). HCPS also paid many of its teachers to help develop lessons and other resources for using the iBook computers. The pay scale for summer curriculum development work was $18 per hour.

Students were allowed to take their iBooks home. In some cases, siblings or parents also used the iBooks. HCPS also negotiated a low monthly rate for home Internet access (less than $10 per month if paid for a full year). Parents with access to a computer and Internet access could stay up-to-date about their student's grades, attendance, and other information via computer. For this purpose, HCPS licensed K12Planet® which is part of Mac School®, the student information system adopted by HCPS[2].

[2] A number of specific technology products used in HCPS are mentioned in this report. No endorsement of these products or claims for their efficacy should be inferred because they are named.

Exhibit 1

Software Resources in HCPS

As part of its laptop initiative, HCPS licensed a wide variety of software. Dr. Mark Edwards, the district's superintendent who championed the initiative, recognized the importance of licensing software and Web sites beyond what is available for free on the Internet, saying, "Content is the fuel if a laptop is the car; it's film to the camera."

Each laptop was loaded with a dictionary, thesaurus, calendar application, and Hog Bay note-taking software. When Apple's CEO, Steve Jobs, visited HCPS, he discovered that the laptops were not capable of running iMovie. He directed his staff to make a no-cost upgrade and to add the iLife software suite (iMovie, iPhoto, iTunes) to all the student machines. Many students then began using iMovie as part of their schoolwork.

Students also had access to SAT tutorial software and to online practice for state tests. The county licensed several Web sites—including Beyond Books, unitedstreaming video library, and DigitalCurriculum—that provide content for many topics and subjects.

Through Apex Learning, teachers had access to support for the Advanced Placement courses they taught, including online diagnostics and reports. Teachers had access to Quia, which offers the capability to create customized, online tests, quizzes, and interactive games. One application allows teachers' notes to be read aloud to students with learning disabilities. The county also used netTrekker, a search engine allowing teachers and students to search for educational resources, selected and reviewed for educational use, and aligned to particular Virginia standards of learning (SOLs), or to search by subject or key word. The K12Planet® Web site licensed by the county (part of the Mac School student information system) provides a password-protected portal for teachers, parents, and students to share information such as students' grades and assignments.

Specialized software licensed by HCPS for mathematics and science included Larson's Algebra, The Geometer's Sketchpad, Fathom, ExploreMath, and NIH Image. In language arts, software included NCS Mentor.

The district also actively created and disseminated its own content. Many resources created by staff are online (http://teachers.henrico.k12.va.us/elearning/index.html). In addition, resources were disseminated in other ways. Science teachers created a CD-ROM containing activities for different courses and distributed copies throughout the district.

Professional Development and Training

For several years before the iBook Teaching and Learning Initiative, HCPS made a major investment in professional development for administrators and teachers to improve staff performance. These efforts were part of a plan for continuous improvement and increased accountability. With the advent of the Teaching and Learning Initiative, administrators in HCPS acknowledged the importance of providing teachers with training that would allow them to take advantage of the new laptops. The division, through building-level instructional support, release time, and monetary incentives, supported many forms of teacher professional development for technology integration.

All HCPS teachers and staff participated in a "professional growth plan" to reach specific goals (including technology integration) each year. To help teachers incorporate laptops into the curriculum, every middle and high school had a full-time technology trainer who worked with teachers to integrate computers and other digital technologies (e.g., cameras, science probes) into teaching and learning. The goal was to improve students' mastery of basic and advanced academic skills and concepts. In addition, workshops and classes about technology integration were available to teachers, both during the academic year (e.g., at a Mathematics and Science Center located in Richmond) and during the summer. The technology trainers also met regularly as a group to exchange ideas, and they produced a quarterly publication for teachers highlighting innovative uses of the computers in the classroom (http://www.henrico.k12.va.us/ibook/tech_connect/404issue.pdf). The school system provided $300,000 annually for tuition assistance and training for teachers and staff.

At the high school level, the math and science departments met during the summer to plan technology integration activities and identify or develop course material. The science teachers produced a CD for each student containing the Henrico lesson materials.

A Framework for Research and Evaluation Focusing on One-to-One Computing

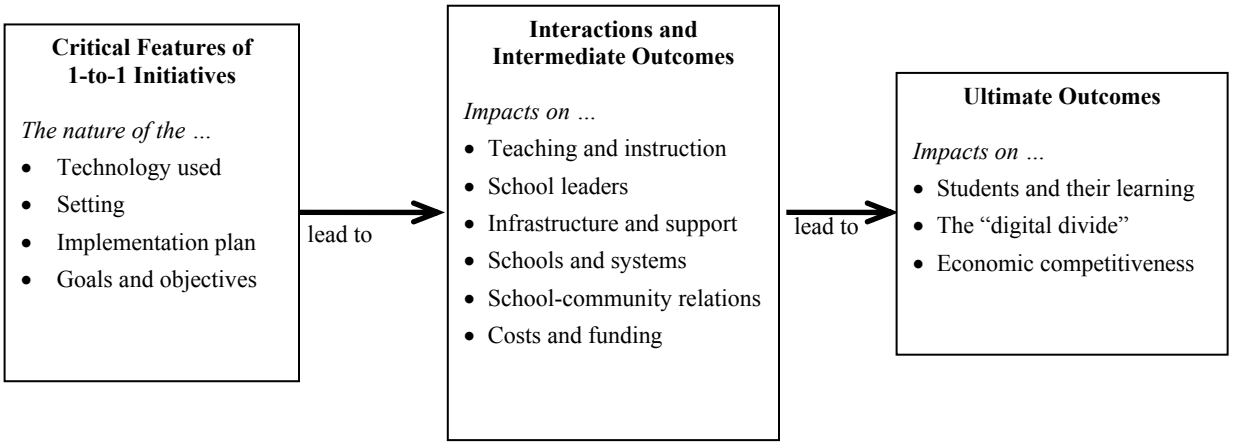
As a guide to this study design, the SRI-EDC researchers based their data collection activities around a conceptual framework for research and evaluation on one-to-one computing developed by Zucker (2004) (see Exhibit 2). The framework provides a starting point for understanding the implementation of one-to-one computing initiatives, illuminates the rationale for addressing the research questions, and helps identify issues that may be examined in future evaluation studies.

This framework displays the hypothesized relationships among three sets of variables to be examined in a school system implementing a one-to-one computing initiative. The box on the left represents the critical features of the one-to-one initiative. Important characteristics that need to be explored include the type of technology used, the local setting of implementation, the implementation plans, and the goals and objectives of the initiative. These variables represent important resources and conditions that will influence the implementation and the outcomes of a one-to-one initiative.

The box in the middle represents the interactions of different participants in the one-to-one initiative and the intermediate outcomes associated with the initiative. These interactions and outcomes include impacts on teaching and instruction, school leadership, infrastructure and support, schools and systems, school-community relations, and costs and funding.

The box on the right symbolizes the ultimate outcomes that might be achieved as the result of a one-to-one computing implementation. Of the many outcomes that could be measured, these outcomes are restricted to three that could be especially valuable to the broadest range of educators and policy-makers.

Exhibit 2
A Framework for Research and Evaluation of One-to-One Computing



Research Questions and Study Methods

The primary purpose of this evaluation was to collect data about the use of the wireless laptops in selected schools in HCPS, especially in science and mathematics instruction. The evaluation team was interested in documenting teaching and learning practices with laptops in which teachers and students participated, and identifying some of the structures and resources within the schools and the division that influenced laptop use. Research questions investigated by the SRI-EDC team included:

1. How, exactly, are laptops used, especially for mathematics and science instruction?
2. What types of teacher professional development support the development of skills to integrate laptops into instruction?
3. What are the academic and organizational support structures and resources that accompany the use of laptops, especially for science and mathematics instruction?
4. What factors facilitate the sustained use of these wireless laptops?
5. What are the barriers that make it difficult to use wireless laptops effectively? How are these barriers negotiated or overcome?

The evaluation team used an embedded, multiple-case design (Yin, 1994) to address questions relating to the implementation of the laptop initiative from the perspective of different respondents in four school sites and in the HCPS central office. The following section describes the procedures for conducting these case studies.

Case Studies

With the approval and assistance of HCPS, the SRI-EDC research team selected four school sites. The schools were selected to vary in size (from 800 to 1,700 students), poverty level of the students served (from 2% to 55%), racial composition of the student body (from more than 90% white to 85% nonwhite), geographic location within HCPS, and performance on standardized tests. We anticipated that sampling schools in this way would yield greater variation in the impact of using laptops based on a variety of socioeconomic factors linked to income and race. The literature on the digital divide (NTIA, 1995, 1998, 1999) identifies race and socioeconomic class as important factors in determining access to technology. The diversity of HCPS is demonstrated by the fact that at one of the schools visited, students speak 21 languages. Hence, the study team worked with the school district to select schools that represent a cross section of secondary schools found in HCPS.

During the 2002-2003 school year, all but one of the case study schools had been accredited by the state, meaning that the required percentages of students had passed the state's Standards of Learning (SOL) tests. By the fall of 2003, all regular schools in the division were fully accredited by the state.

Site visits took place in two middle schools and two high schools. A team of researchers conducted 1- and 2-day site visits to the four schools in May 2003 and again in spring of 2004. Case studies were based on site-visit protocols that included classroom observations; interviews or focus groups with teachers and parents (in 2004); interviews with school administrators; and analyses of documents, such as technology plans and professional development schedules. Interviews with division staff were conducted at the same time as these visits. More than 100 people (administrators; teachers; students; and, in 2004, parents) were interviewed or were part of focus groups (see examples of interview protocols in the Appendices).

The focus of each case study visit was to describe how the laptops were being used in math and science and to identify both factors that might explain sustained laptop use and barriers that hinder their use. Before each visit, we worked with the principal to identify a math and science teacher who regularly integrated the use of laptops into instruction. In addition to observing instruction in these two classes, site visitors conducted interviews with groups of math and science teachers and individual teachers who had been observed. Principals were instructed to select up to eight students from different grade and academic performance levels in math and science who participated in focus group interviews. During the second year of visits, principals invited active parents from the Parent Teacher Associations to participate in focus group interviews. Site visitors took extensive notes and used a common reporting template to create a case study report that, together with the others, was the basis of a cross-case analysis.

Surveys

Although student and teacher surveys were developed, piloted, and administered in HCPS's 10 high schools during the first semester of the 2003-2004 school year, the survey data results were not used in the analysis for this report because of concerns over potential bias associated with low response rates.

Working with HCPS officials, the evaluation team had designed a sampling plan that included all 540 science and mathematics teachers in the middle and high schools and 3,000 randomly selected students from HCPS's 10 high schools. The student sample was designed

proportionally, sampling across schools and course difficulty levels (e.g., introductory versus Advanced Placement). Following HCPS's requirement for research, the evaluation team sent notification letters and consent forms to parents and guardians of the students, requesting active consent from the 1,500 mathematics students and 1,500 science students. Teachers and students were assured that their responses would be used only for statistical purposes. However, response rates were much lower than expected, despite multiple efforts made by the evaluation team and division staff to encourage recipients to complete the surveys. In contrast to the difficulties experienced in obtaining reliable survey data, the evaluation team was able to collect the qualitative data from a variety of respondents with the assistance of each school's principal and assistant principal. Teachers, students, and parents voluntarily consented to participate in interviews and readily expressed a variety of opinions about the implementation of the laptops in their schools.

Data Analyses and Limitations

Case studies are used to develop an understanding of a general question, issue, or problem. The analysis focused on the underlying issues and relationships in using computers in a school setting that can help to generalize beyond the cases. Hence the cross-case analysis of the four cases selected in this study was conducted to identify themes, patterns, and differences across the cases that would help to explain how one-to-one computing was being implemented in selected schools in HCPS. For these analyses, the evaluation team created individual site visit reports and conducted several debriefings to identify common themes and cross-case conclusions that emerged across the four school sites. The team then wrote a cross-site analysis that used multiple sources of evidence to substantiate the claims made in the analysis. Several outside reviewers read the analysis and provided feedback that helped the team refine the thematic analysis and consolidate the structure of the report.

Because it was not possible to use the survey results, the findings presented in the next section are based largely on observations and interviews with teachers, students, parents, and administrators from the four schools. Although one cannot generalize findings to all schools within HCPS, in the following discussion themes are presented that cut across all four sites, which were selected to vary widely and represent the types of schools found in HCPS. As a result, the report offers a detailed description of some of the ways in which laptops were being used in science and mathematics instruction in HCPS schools.

Also, the SRI-EDC research team did not focus on quantifying the extent to which the laptops were being used (and, conversely, not being used). Because our primary focus was on documenting how laptops were being used in instruction, we deliberately sought out classrooms where we would be sure to see laptops in use. Consequently, we do not have specific data about teachers who were reluctant to make use of the laptops. According to administrators and teachers interviewed, some HCPS teachers have resisted integrating laptops into their instruction. Nonuse is an issue that HCPS—and anyone seeking to implement a similar initiative—must face, and thus it is an issue that merits further study.

Exhibit 3

Another Study of the HCPS iBook Initiative

A vocal minority of HCPS community members consistently voiced opposition to the iBook Teaching and Learning Initiative. In 2004, HCPS commissioned FGI Research to measure the satisfaction of students, parents, teachers, and administrators with one-to-one computing. The company received responses to short surveys from a total of 28,408 individuals between April 26 and May 18, 2004 (8,708 parents, 2,104 teachers and administrators, and 17,596 middle and high school students). Surveys were administered by telephone to 796 randomly selected parents and sent by mail to a much larger number of households. Web-based surveys were used for teachers, administrators, and students.

Overall, the findings show that the great majority of respondents supported the use of individual laptop computers in both middle and high school. A representative of FGI Research was quoted in the *Richmond Times-Dispatch* as saying, "What is apparent for us is a tremendously powerful, positive picture of attitudes of the community…. These are numbers that are staggering, that we don't see very often" (Ress, 2004).

Most respondents believed HCPS should continue to supply laptop computers to the students for use at home and at school. Support for high school use was higher than that for middle school use, with 86% of all respondents behind the program in high schools and the same percentage believing high school students should use laptops both at home and at school. Nearly two-thirds (65%) of respondents supported the initiative in middle schools, and about the same percentage believed middle school students should use laptops in both the home and school settings. About 66% of high school teachers and administrators believed middle school students should use laptops only in school.

The surveys also showed overall satisfaction with the training and practical application of the laptops. Almost 80% of respondents stated they were satisfied or somewhat satisfied with the laptop training available. Eighty percent of respondents were satisfied or somewhat satisfied with the instructional use of the laptops. Technical difficulties and content-filtering issues sometimes inhibited laptop use. Slightly fewer responded, though still the majority, expressed satisfaction regarding those issues. About 70% of respondents were satisfied or somewhat satisfied with filtering, while 60% of respondents were satisfied or somewhat satisfied with repairs.

The SRI-EDC study provides information about many questions not investigated by FGI Research. In areas where the research questions overlap, the SRI-EDC findings seem consistent with findings from the FGI Research study. [3]

[3] In February 2005, as this report was being completed, HCPS released the results of a second set of surveys of administrators, teachers, parents, and students (available online at http://www.henrico.k12.va.us/Announcements/tech_eval/index.htm). The surveys were conducted by Development Associates, which received responses from more than 29,000 people. The results show broad support for the iBook initiative, as did the FGI Research study.

II. Findings

The current study used case studies of four schools to provide information about HCPS's uses of laptop computers in grades 6 to 12. This chapter highlights findings organized into three sections: use of the laptops for teaching and learning; impacts of the one-to-one computing initiative on students, teachers, and families; and factors that facilitate or present barriers to the use of the laptops. It is interesting to note that, although the study team deliberately selected schools to capture the diversity within HCPS, most of the variations we encountered in the ways laptops were used and the impacts they had were not obviously related to student or school characteristics. This discussion specifically highlights instances in which school and student characteristics influenced the use of laptops.

HCPS has demonstrated that one-to-one computing can be implemented on a large scale within the context of a school district enrolling 45,000 students. This summary judgment is based on the analysis of data collected from a variety of school and district respondents in HCPS, as well as taking into account the local school district context, and it is an important finding in part because the HCPS's per-pupil expenditures are below the state average for Virginia, showing that one-to-one computing is not just for rich school districts or private schools. HCPS's experience demonstrates that a school system with below-average expenditures can provide its teachers with laptop computers, and that many teachers will use them for professional purposes and value them highly.

Use of Laptops for Teaching and Learning

Even a casual visit to a middle school or a high school in HCPS showed that students used their laptops frequently in school. The majority of students we saw were carrying the computers with them from class to class. Teachers in the schools we visited could create lessons in which the class made use of the laptops directly, in which case most students used their computers in the classroom. Often, however, the teachers and the students treated the laptops as they would treat any other resource, such as a notebook; for example, some students chose to use their laptop in a particular class at a particular time (to take notes, for example) while other students were not using a computer.

During the case study visits, principals and a variety of other respondents indicated that computers were being used for teaching and learning in all subjects, from physical education to foreign languages. However, the heaviest uses in the core subjects seemed to be in English and language arts, science, and social studies. Mathematics teachers—particularly in advanced courses—made less frequent use of the laptops. This pattern is consistent with what evaluators found in Maine (Silvernail & Lane, 2004).

An important factor that determines how students and teachers use the laptops in class is the availability of appropriate computer software. As a pioneer in one-to-one computing, HCPS was using a variety of electronic resources in an effort to find out what worked best for its students and teachers. As discussed in Chapter I, HCPS licensed a variety of Web sites and software titles, including some password-protected Web sites. Both the division science and mathematics supervisors also worked with teachers to develop lessons and other electronic resources that were later disseminated throughout HCPS on CD-ROMs.

Some Specific Uses in Mathematics and Science, with Classroom Examples

The evaluation team observed a wide range of variation in the classroom use of laptops in mathematics and science. Because we asked principals to recommend teachers who had integrated the laptops into their instruction, members of the evaluation team observed a number of lessons in which the laptops were used in mathematics and science classes. According to teachers we spoke with, the frequency with which laptops were used in classrooms varied from every day to occasional use. Some uses of the laptops were common across many subjects, such as word processing, access to content on the Beyond Books Web site, and class presentations by students using either iMovie or Keynote 2, Apple's presentation software. Other uses of the laptops were specific to a particular subject.

In the four schools visited, science students did "virtual dissections" on the subscription Web site Froguts.com, took virtual field trips, went on WebQuests, developed and presented iMovies about science topics, wrote up laboratory experiments using a word processor, and created their own Web pages—to name just a few of their laptop activities. In a seventh-grade life science classroom, for example, students presented iMovies they had created about specific topics in the curriculum, such as recycling. Later, during the same class, the teacher asked students each to complete an online quiz from Beyond Books. This single classroom period illustrates how students used the laptops both for drill and practice and to develop their own, unique documents.

Most of the science teachers who were interviewed and observed asked students to use laptops for many purposes, including cultivating the skills necessary for scientific inquiry: generating research questions; formulating hypotheses or predictions; developing models to describe or explain a phenomenon; and collecting, displaying, and analyzing data. For example, one high school biology teacher described how she asked students to do research online about infectious diseases and then create pamphlets about those diseases using a word processor. Noting that this activity allowed students to use their creativity while learning important content, the teacher told researchers that the student brochures were better than any she had seen in a doctor's office. The use of a wide variety of online resources also was seen in other high school science classes. For example, in physics, students went online and downloaded step-by-step instructions for building and testing egg-carrying rockets or rubber-band powered cars, along with pictures of each stage of construction.

Mathematics students in the four schools used Larson's Algebra, The Geometer's Sketchpad, ExploreMath, and other software licensed by the school system. Students reported that they made use of spreadsheets, drawing programs (to create geometric figures), and a variety of online Web sites that allow teachers to create tests and review activities that their students can access online. In a sixth-grade accelerated mathematics class, for example, the teacher had students solve a complex problem presented with software licensed by HCPS. Students worked independently to start, the teacher then led a discussion about the problem, and finally the students worked in pairs, to solve it. This case was unusual in that students were required to work in pairs, as suggested by the software package. In both math and science classes, students typically worked on their individual machines.

In one high school mathematics class, students used a software program on the iBooks to simplify radicals after working on math problems using graphing calculators. This program gave instantaneous feedback and hints to students so that they could successfully complete the problem set. As another example, a first-year mathematics teacher told a visitor that she would have her sixth-graders do an online review of a geometry unit in a format called Rags to Riches, in which the students could win a fictional $1-million prize by answering a series of questions correctly. "They will love it," she predicted—and she was right. Students, many of whom had failed their fifth-grade SOL tests, were on task, working individually answering questions about geometry throughout the allotted time. The teacher believed that the immediate feedback from the computer was helpful in maintaining students' attention, and she said of the computer initiative, "It has helped a lot of kids who want to succeed."

Exhibit 4 offers more detailed descriptions of two other classroom activities in which laptops were used.

Laptop Use beyond the Classroom

Many of the students and teachers who were making regular use of the laptops also capitalized on their versatility and portability, using them as more than just tools to enhance teaching and learning in the classroom. For example, HCPS allowed students to take their laptops home. According to data collected in our student focus groups, many students regularly used the laptops at home to do a variety of school- and non-school-related tasks. Many students we spoke with found the laptops helpful in their school assignments, especially those requiring outside research (e.g., projects or papers). They also explained how teachers' supplemental notes, provided in the virtual folders, and online tutorials were helpful methods of reviewing a lesson at home when they needed additional help with their homework.

Many students, especially at the two high schools, reported in focus groups that they used the iBooks often in non-school-related activities. One high school student described how her job required her to type, input data, and update her office Web site. Having worked with many of these software programs on her iBook, she found she was able to transfer what she learned in school to her job. Furthermore, students described how the iBooks helped to prepare them for the future. Students and parents alike described how the college application process was facilitated by obtaining information online about colleges and financial aid. A handful of students in one school reported that they did not use their laptops because they had faster computers to use at home.

Exhibit 4

Examples of Laptop Use in High School Mathematics and Science Classrooms

Honors Geometry

The room was organized into seven triangular desktop areas, for a class of nine boys and eight girls. Three of the students did not have laptops, and the two classroom Mac computers initially were not working. Ms. Smith had the three students who did not have laptops move beside other students so they could follow along.

Ms. Smith had prepared an exercise to teach the concept of the "golden rectangle," using The Geometer's Sketchpad software to let the students follow her presentation and then develop their own examples. The teacher used her laptop computer attached to a video projection unit so that the students could see a large image of what she did on the computer projected onto a screen at the front of the room.

This exercise proved to be challenging for both the students and the teacher. The students had no trouble following the presentation by the teacher and stayed engaged and on-task. However, when it came time for them to duplicate and then build on the material, progress slowed down dramatically. A few students were noticeably less proficient with the Geometer's Sketchpad software than others and required help from the teacher, which affected the discussion with the rest of the class.

Nevertheless, the students maintained a respectful attitude. It was obvious from the interactions that Ms. Smith (in her second year of teaching but already considered a "star" by other faculty) had impressed the students favorably. She told them what an important concept the golden ratio was and described how the ratio is a characteristic of growth in many natural forms, such as plants and seashells.

The Geometer's Sketchpad allowed the teacher and the students to create complex geometric figures that they could manipulate dynamically in ways that are not possible with paper and pencil.

Physics

The goal of one observed physics lesson was to review what students had learned about how to add and subtract colors. The lesson included an exercise in which students used the laptops to create color images that contained the primary colors. Several other activities were done by using a Web site tutorial that allows students to create different colors by manipulating overlapping ovals of complementary colors. While all the students worked in pairs on their laptops to manipulate the color combinations, the teacher moved through the class, helping students by posing questions and providing clarifying information. Students talked with each other about the activity and offered assistance to other groups of students.

During the second half of the class, the teacher gave a mini-lecture about the physics of colors. After distributing a handout to the entire class of 20 students, she displayed information from another Web site (using her laptop connected to the TV monitor) to demonstrate how to measure different shades of color using what are known as RGB values, each denoting the brightness of a particular color. The Web site allowed the user to move a tool over an image to measure its RGB values at any particular point. After the teacher guided students through a demonstration of how to calculate the RGB values, the students used their laptops to work on the same Web site and determine the RGB values of different colors on a common image hosted on the site. The teacher provided instructions, posed questions, and helped students who needed assistance. Students discussed the results of their work as they calculated RGB values.

In this class, laptops and the Internet were used as a science laboratory, but with much less setup and cleanup time and without the need to purchase and maintain specialized laboratory equipment. The Internet-based resources selected by the teacher helped students review previously introduced concepts, obtain feedback on their mastery of those concepts, and extend their learning by exploring related topics.

The vast majority of the teachers involved in this study found the computers valuable for their own professional use. Math and science teachers used the laptops for a variety of professional purposes: communicating via e-mail with colleagues inside and outside the school; managing student information, such as grades; and conducting research that contributes to instruction, such as searching online for lesson plans or materials. Teachers also reported using the laptops to develop materials for homework assignments or materials that they presented during lessons. A middle school math teacher told researchers that she used the laptop almost every day. She created presentations using AppleWorks, then pulled the notes from her laptop and distributed them to students. She added, "The iBook has also prepared us for using Excel to keep track of grades."

An important application of computer technology in HCPS has been to foster teachers' communication with parents. For that purpose, the school system licensed use of K12Planet®, a Web site that provides administrators, teachers, parents, and students with access to a variety of information, such as students' homework assignments and grades. Teachers are required to upload information about their middle and high school students to the Web site weekly; parents can then access that password-protected information from any computer connected to the Internet. In the experience of one math teacher, parents were using this resource. She noted, "Every Wednesday you have to export grades to K12Planet®. You must stay on top of that because sometimes parents will check for information." Students also knew that their parents could access assignments and grades through K12Planet®.

Impacts on Students, Teachers, and Families

This study did not directly assess the extent to which teaching and learning changed as a result of the laptops. Moreover, respondents interviewed for this study were predominantly regular users of laptops. However, observations, interviews, and focus groups with teachers, parents, administrators, and students from four schools do suggest that a variety of stakeholders believe that, overall, the laptops have positively influenced teaching and learning. As one algebra teacher said about teaching graphs, having a picture in the textbook is quite limited, but

> by using graphing calculators, using the Internet, and other [computer] resources you can make it dynamic, showing how changing this one number affects the graph. You can make it more of an exploratory activity where students develop their own thought processes and hopefully retain it better by going through it in that manner.

Students, who are enrolled in five or six classes at a time, often viewed the laptops in a broader perspective than any single subject. The laptops are a good thing, one middle school student said, "because we can look things up, and we don't have to carry a lot of books around." A high school student said, "I think with having to use a computer in college, I am a lot more prepared."

The great majority of teachers, parents, and administrators, too, often saw the benefits of the laptops in a broader perspective. "I think we are creating a student who is going to be able to function in the way the world is coming today," said one teacher. The parent of a high school student said, "I have seen a boost in self-confidence. By that, I mean confidence in the ability to problem-solve, complete tasks, to retrieve data that he knows he needs." One principal said, "These children have no idea how many learning skills they are developing through [the one-to-

one] program. I've had several letters from former students now in college, reporting on how much more they know about ways to use the computer than their peers."

The SRI-EDC evaluation revealed several additional, specific impacts—positive and negative—that the iBook initiative had on students, teachers, and families. The next three sections discuss some of the ways in which the laptops affected each of these groups.

Impacts on Students

Access to computers and information. One reason that policy-makers in HCPS started a laptop initiative was to bridge the "digital divide" that separates students in families that cannot afford computers or the Internet from those that can. Nationally, in late 2001, 80% of American families with annual household incomes over $75,000 had Internet connections at home, compared with only 25% of poor families.

By providing a laptop to every middle and high school student, HCPS's laptop initiative bridged the digital divide for thousands of students who otherwise would not have been able to use a computer at home (and who would also have had much more limited use at school). HCPS also made inexpensive Internet subscriptions available to families that did not previously have Internet access. The price ranged from $9.75 to $12.50 per month.

One parent said, "In the eastern region [of the division], the iBook may be the only technology available [to families]. [And] not every parent can take their child to the library." Speaking about students who did not have Internet access at home, a parent reported, "They come to the school parking lot early to get onto the AirPort [wireless network]."

Wealthy families often have multiple computers available in the home. Because of the iBook initiative, that situation became possible for more families in HCPS. As one parent told a researcher, "Having *your own* computer makes a big difference [to students], especially if you have several children." A principal made the same point, noting, "Every child is on a level playing field. Every child has the same potential for achieving. The computers are used at home and at school; there are no more haves and have-nots." For the principal of a school serving many students from low-income families, this access raised students' self-esteem, which the principal considered important because "with self-esteem you can get them to walk mountains."

Student motivation and independence. The prevailing view among the principals and teachers in the four schools visited was that the use of laptops motivated the students and fostered greater independence. According to one principal, students who were reluctant to do homework became more willing to do it once it was on the computer. Children who did not have excellent handwriting skills could produce neat work, and in general, students had the ability to produce more professional-looking products. Increased motivation was also leading to better behavior and increased attendance, according to many of those interviewed. "Technology is a way of turning the responsibility over to the students," one principal said. "It's amazing what they can learn in 90 minutes [the time that the school is using for each period]. The teacher is truly what an educator should be, a facilitator." Students agreed that they were doing more learning on their own with the iBooks.

Student organization. Many of the students, parents, and teachers interviewed agreed that the use of iBooks in HCPS helped students to be more organized. These teachers and students indicated that the overall structure and design of the iBooks provided a consistent way for students to keep track of their activities, assignments, and notes, regardless of class or teacher. In

the four schools visited, teachers, in particular, noted that the use of virtual shared folders offered an easy way for them to provide notes and assignments, reducing the likelihood that students were unable to work because of lost papers. Furthermore, students could create folders for each class and arrange their work systematically. As one student said, and others agreed, "What I like is that you can't lose your homework. Also, a notebook can get out of order sometimes. But on the computer you can make a folder for, like, Rome, or the other topics." Other students simply found it easier to study by using the iBooks. Students also described learning note-taking skills via the iBooks when some of their teachers provided "skeleton" notes and required students to fill in the blanks as the lesson progressed. For some students, however, the laptops did not help with organization. Some teachers found the need to use the laptops thoughtfully with special-needs students. For example, one teacher reported that parents of special education students often wanted their children to have a hard copy of every document, regardless of whether or not it was available online.

Access to various modes of learning. In numerous interviews, teachers mentioned that laptops provided sound, pictures, and movies, as well as text and animations. One teacher said, "It's another tool that they have.... It's a visual model, but it's also auditory and it can be kinesthetic." Teachers were able to include video clips in student copies of class notes, provide interactive manipulatives online to illustrate mathematics concepts, access three-dimensional displays that are not feasible on traditional overheads or chalkboards, and feature online dissections to prepare their students for real dissections.

In one school, the access to various modes of learning was identified as particularly advantageous for special education students. The chair of the department noted that he used laptops every day with special education students. "Immediate feedback—they love that," he said. "It's helping me in the classroom. It's like an instructional assistant in my class, because it helps me that much." Already, he reported, "I don't know what I would do without it."

Level of interaction with teachers. The picture is more complicated when considering how laptops affected the level of interaction between teachers and students. On one hand, some teachers and students reported *more* interactions because of the computer. "Kids are much more willing to ask me individual questions than ever before, and I've been doing this a long time," one teacher said. Another teacher indicated that the laptops opened up the channel for additional discussions with her students about course-related content. Students indicated that they visited their teachers' Web sites or e-mailed teachers with questions while at school or at home. In this way, as students explained, "teachers are more available to you." Other students, however, felt that the level of interaction had decreased because the laptop gave them opportunities to work independently of their teachers. In answer to the question about how instruction had changed because of the laptops, one student in a focus group responded this way: "We do more independent work because everyone has an iBook. In the computer lab, we had to buddy up and do it. We don't interact with the teacher as much because we go on a Web site and they tell you what to do." Another student in the same focus group said, "The teacher does a little less teaching because the Web site says exactly how to do it. It's good and bad because the teacher doesn't hassle you as much, but you may not understand."

Impacts on Teachers

Better instructional tools. Many of the teachers interviewed felt that although laptops would not replace specific hands-on activities or their vital roles as teachers, laptops made a number of better instructional tools available. Some teachers related that the use of the iBooks allowed for more engaging activities and topics for the students. In particular, teachers believed that the ability to visualize and manipulate data on the laptops kept the students more interested in the school work and consequently led to better student retention of the material. The teachers were learning to use these tools in their instruction. One teacher said, "It's making us think about what makes things interesting for kids, and instead of just memorizing a bunch of facts, we're learning there are better ways to teach them and they really retain the concept." Some parents agreed that the multisensory aspect of the laptops helped the students comprehend the material, citing a project in which the students watched on the iBooks a three-dimensional model of cement-making, then recreated the model and labeled it. Teachers also noted that students could connect their iBooks to TVs in the classrooms, enabling them to show their work more easily to others in the class. Some teachers cited the limitations of laptops, noting that laptops lose their usefulness when students do not bring them to class regularly.

In addition to providing access to engaging material, several teachers in the four schools noted that the laptops provided more flexibility in the classroom, since teachers could switch between activities more easily. One teacher noted, "The flexibility that having these laptops…provides me in the classroom is phenomenal. I'm teaching a lesson and a spreadsheet is something that would be a good idea to do to enhance this lesson, we can pull that out, do a spreadsheet, 5 minutes, put it away." One teacher also reported being able to capitalize on the spontaneity involved in teaching because the class could put a lesson on hold and look into something that seemed interesting.

Many teachers also appreciated the instantaneous feedback that laptops provided to students. For instance, in three schools, students were observed using math programs that indicated when they submitted incorrect answers, allowing the students to go back and fix their errors before completing an entire assignment in the wrong way. The feedback also helped the teachers identify and work with students who needed extra attention. A teacher reported, "The major impact for me is the fact the child [using the computer] knows [gets feedback], and as a result, if they're getting them wrong, they call me over and I help them. So it's wonderful. It lets me see where the problems are; it lets me address those quickly instead of when they take a test."

Up-to-date content. The majority of the science teachers interviewed believed that the availability of up-to-date information was one of the great benefits of access to the Internet. Many teachers reported no longer having to rely on outdated textbooks for answers. In particular, teachers valued the fact that current information was available almost at the touch of a button. For example, one teacher said that a student was able to look up a law about DNA databanks in the military and get an immediate answer to a question being discussed during a biology class. A middle school science teacher mentioned up-to-date information about new discoveries of moons around Jupiter. In the past, questions raised by students often went unanswered. "Now," one teacher reported, "I can just say 'Look it up,' and students will immediately do so. The immediacy, the accuracy—it's just fantastic. I don't know if I could live without it now."

There seemed to be a slight difference in how math teachers viewed the importance of laptops versus textbooks. Similar to the science teachers quoted above, one math teacher reflected that the ability to look up current information enabled the students to make connections between the data and their own lives. She said, "For math, in terms of data collection and all, [students] can go to the Internet and find the actual cost of things instead of using preconcocted worksheets. They can see a lot more how it's real data, how things connect to their lives, as opposed to worksheets where data's from 1980." A number of math teachers the team interviewed, on the other hand, valued assigning textbook work over using the laptops. It was unclear whether that preference was a function of the teacher's experience level, availability of materials for that particular math class, or some other influence.

Professional productivity. The majority of teachers interviewed in the four schools reported that the use of laptops enhanced their professional productivity in a variety of ways. Teachers said that computers allowed them to more efficiently design and create materials, prepare lesson plans, diagnose student weaknesses, and communicate with colleagues, parents, and students. Moreover, a technology trainer said that lines at the copy machines had disappeared because teachers were storing documents digitally for students. Another benefit cited by administrators and teachers was the increased level of sharing and collaboration that the Teaching and Learning Initiative fostered among teachers within the school district and in individual school buildings. In one school, teachers in the science department stated that the iBook initiative had made them a stronger professional community because they were pushed to have frequent conversations with their colleagues. A social studies teacher said, "We are all in this together," leading the department to share materials and instructional strategies. On the basis of teacher and administrator comments throughout HCPS, the iBook initiative appears to have fostered a collegial environment supporting collaborative planning, development of instructional materials, and efforts to improve instruction.

Exhibit 5
Laptops and Teachers' Professional Community

Research has established that a strong teacher professional community contributes to the effective integration of technology into instruction (Dexter, Seashore, & Anderson, 2002; Kozma, 2003; Means, Penuel, & Padilla, 2001). Groups of teachers who share information with colleagues, collaborate on instructional activities, and maintain a reflective professional dialogue will use complex technologies and integrate them into teaching more effectively than groups of teachers who are not part of a strong professional community.

As part of the laptop initiative, leaders in HCPS wanted to foster and strengthen the professional community of teachers and administrators (e.g., by providing many opportunities for professional development). One division-level curriculum specialist observed, "With 200 teachers in a single discipline, I knew we needed to be inclusive. Relationships and trust are very important to the success of the initiative, so we've worked hard on the mind-set part." According to a variety of school staff, the first year of the iBook initiative, when only the high schools were involved, was challenging in a number of ways. Parents raised concerns about inappropriate student use of the computers, the local press published some negative articles about the laptop initiative, and there were bandwidth and network connectivity problems. However, that situation changed. Although there is often a spirit of competition among the high schools, teachers and administrators in HCPS indicated that the challenges of the iBook initiative helped foster a sense of common purpose and shared interest in overcoming the difficulties of the first year of implementation. As a result, lessons learned have been shared freely, and a strong sense of community was achieved among the high school principals. According to many teachers, the laptops themselves also strengthen the professional community by providing new lines of communication via e-mail.

In the four schools visited, teachers reported that the laptops increased positive interactions with students, as noted above. At the same time, teaching a class of students, each of whom had a laptop, presented teachers with new challenges. Notably, teachers needed to develop new lessons that used the laptops. They also needed to learn to use the computers, the Internet, and software effectively, and to advise students about laptop use. In the event that students did not bring a working laptop to class, teachers typically designed paper alternatives for students even when they had planned laptop-based lessons. All of these issues have implications for the time teachers spend preparing to use the laptops. For a minority of teachers interviewed by researchers, these increased demands were onerous. According to one teacher, "With the need to have both paper and the iBook assignments available, it's twice as much preparation for the teacher."

Also, in the schools and classrooms visited for this study, the laptops seemed to be complicating classroom management. For example, HCPS had Internet filtering software, but it was still possible for students to browse Internet sites that were not germane to the lesson, so teachers had to be aware of what students were doing with the laptops during class. A teacher noted, "Being the iBook 'police' is hard," adding,

> You can't look at 28 iBooks at once. Using Remote Access [a software application], the administration of the school might call you during class and say so-and-so [a student] is on an inappropriate Web site. But if you're teaching at the front of the room, you don't always know who is on which Web site.

In light of these new demands on teachers, it is significant that nearly all teachers interviewed for the study believed that the benefits discussed above outweighed the difficulties associated with time and classroom management, lesson planning, and learning to use the laptops.

Impacts on Families

Communication with schools. Teachers and administrators across the four schools reported that communication with families had improved largely because of the capability to use e-mail. A biology teacher stated that sending e-mail proved valuable for increasing contact with her students' parents. Similarly, one middle school math teacher said she was pleased that the Internet allowed her to have conferences with parents whose schedules made it difficult for them to come to school during regular hours. According to one high school administrator, the iBook initiative was responsible for linking more parents than ever to the school through the use of K12Planet®. She reported that up to 85% of parents used it regularly, supporting and sustaining a constant stream of communication between teachers and parents about student academic progress. Not everyone was pleased with this development: As one student wryly lamented, her parents became more "in touch" with her assignments and grades, reminding her of due dates for projects and becoming better able to track her progress.

Parental access to computers. A related benefit was the elimination of the digital divide for entire households, opening up the resources of the Internet in many students' homes. According to one principal, 50% of the school's students did not have a computer before the implementation of the Teaching and Learning Initiative. HCPS families could get home access to the Internet at a discounted cost. Parents received training that allowed them to use the computer and the Internet, perhaps for the first time, which also opened the door for their further involvement in the school. Several of the parents interviewed also reported that when their children each had their own laptop to work on, it freed up other computers at home to be used by others in the family, making

it easier for families with multiple children to complete homework assignments in a more "peaceful" way. Another parent shared that she preferred to use her child's laptop rather than her own computer because the laptop was faster and had a better Internet connection.

Facilitators and Barriers to Technology Integration

In the opinion of teachers and administrators in HCPS, most schools appear to have made progress incorporating the laptops into the life of the schools during the first 3 years of implementing the initiative. Attention to the details of implementing this one-to-one computing initiative has been ongoing and comprehensive. HCPS has been able to identify a variety of problems and address them. Most of the teachers, students, parents, and administrators associated with the four case study schools believe that the benefits of the laptop initiative far outweigh any problems. The next section discusses some of the key factors that have contributed to the large-scale implementation of the iBook initiative in HCPS and explores some barriers that students, teachers, and administrators have faced during the implementation process.

Key Factors That Have Facilitated the Widespread Use of iBooks

Support for and commitment to the initiative. Central office support for the laptop initiative was strong, helping to explain why principals, teachers, and students expressed positive opinions about the initiative. By providing the middle and high school teachers and students with a high degree of administrative support, as well as training and professional development, technical support, and licensed software, division leaders in HCPS maximized the benefits of the laptops and the wireless Internet connections in the schools. The district also provided training to parents and administrators.

Broad support for the laptop initiative within HCPS was facilitated by the involvement and leadership of many people in a wide range of positions. From the outset, HCPS administration knew that leadership would need to be shared. "You have to engage as many people as possible, and everybody has to have a little piece of the action; everybody brings something to the table," said one division-level curriculum supervisor. Another said, "We see ourselves as support and problem-solvers." Working in the schools, principals, technology trainers, technology coordinators, department chairs, teachers, students, librarians, and others all had to help make the initiative a success. In addition, parents, who were required to attend information and training sessions before students were allowed to take the laptops home, also played a key role. However, a small but vocal minority of parents actively opposed the initiative.

Most of the math and science teachers in the schools visited indicated that their school principals supported use of the laptops. This enthusiastic support was apparent in conversations with administrators. One principal said, "I am so much for this initiative, especially for at-risk students. For a high-risk school, this [the laptop initiative] has been one of the best things." Another principal said, "I believe they're going to see our productivity level rise, [and] it's already very high at this school…. I'll use math as an example; I know children are working anywhere from 15 to 20 more problems than what you would do if you had a regular lecture situation in the classroom."

According to the principals interviewed, department chairs also played important roles in promoting use of the iBook computers. In one school, for example, the science department found money to pay for additional software, and the teachers perceived the department chair as very

supportive in their efforts to make effective use of technology. In another school, the science department acquired equipment to create CD-ROMs to use in teaching.

School-based technology trainers. Having the technology trainers in each school (described in Chapter I) was an important part of the initiative. They were usually former teachers who had strong backgrounds in using educational technology. In a few cases, the trainers served two schools.

One school technology trainer said his role with regard to teachers was to teach lessons for them, with them, and to them. Each week he offered a training session on a particular topic, such as "how to develop a class Web page." In another school, the trainer emphasized that she provided individualized help to teachers during planning periods and after school. "I've been very busy," she said. "I post announcements on my Web page each month to allow teachers to see what sessions I'm offering." She started with new teachers by setting up their e-mail, address books, and the like, noting that e-mail was especially important because of this school's large campus.

Sometimes entire departments signed up for sessions with the technology trainer. "I've worked with the science department several times to show them technology lessons aligned with SOLs that they can do with the kids," said one trainer. Also, she worked with grade-level teams of teachers (a team might include math, science, English, and social studies). For example, she showed them how to use databases as part of instruction.

Most of the teachers we interviewed agreed that the trainers were essential to making the initiative work well. Their attitudes, knowledge, and skills affected large numbers of people. The best trainers were calm, were good problem solvers, understood how to use technology to teach a wide range of subjects, and worked well with other people in the school. HCPS was fortunate to have many excellent technology trainers.

Additional professional development for teachers. As we have mentioned, a great deal of out-of-school, high-quality professional development was also available to teachers. There was widespread agreement among the Henrico school principals and others in the district that professional development in the use of technology was critical to the success of the iBook initiative. One principal said about the laptop initiative, "If it's just dropped on teachers, it's a problem." An educator said, "Teacher training was the most important reform effort in preparation for the iBook initiative." According to a technology coordinator in a middle school who was interviewed in 2003:

> There's a huge teacher training piece. Getting teachers to take chances is a challenge. We started bringing teachers on board a year ago. This year, they still had half a year to practice before students received the computers. Teacher training is key. We probably have 15% who are absolute devotees, 50% who are consistent learners, and 15% who are diligent. The remaining 20% are resistant—just doing what is needed to get by.

During summers and during the school year, HCPS offered classes on a variety of subjects. Teachers were paid an $18/hour stipend to take classes ranging in length from a day or less to as long as 2 weeks. In some cases, the courses carried graduate credit. However, the amounts of time spent by teachers on professional development in the uses of technology varied. At one school, teachers in a focus group estimated they had each had about 10 hours of professional

development, which is, at best, a modest amount. On the other hand, some teachers spent many weeks taking courses about educational technology.

In addition to workshops and conferences, and even apart from the help provided by the technology trainers, most of the teachers in the case study sites engaged in a great deal of informal professional development. At one school, for example, about 10 minutes were allotted at monthly department meetings for more expert teachers to instruct colleagues about a particular technology integration topic. The social studies and science departments were often leaders in using technology.

The ongoing use of technology for administrative purposes throughout the division also promoted learning about technology among teachers and administrators in the four case study schools. For example, at a school with a large campus, the principal said, "I very rarely receive a piece of paper," noting the efficiency of e-mail for sending and filing documents. Faculty throughout the division were strongly encouraged to use e-mail even before students received their laptops, which helped those teachers unfamiliar with computers to become more comfortable using them. Another principal said she received extensive training to use a computer system giving principals access to human resources information about job applicants.

The state also encourages teachers' technology proficiency. All teachers in Virginia are required to present a portfolio showing mastery of certain technology skills. In HCPS, new teachers are required to complete 12 hours of technology training in the evenings to help assure that their skills are adequate.

From our interviews with teachers, school administrators, and division-level staff, it became evident that expertise in technology was not regarded only as the domain of people with certain job titles in the school system; teachers themselves were often leaders in professional development. As an example, the technology coordinator at one of the case study schools noted that it was not he but a teacher who maintained the school's Web site, and other teachers often approached that person for help using computers. That technology coordinator added:

> Having teachers as resources is a key…. We have a ton of this spirit at this school—teachers reaching out for help to other teachers. A lot of it is framing it to teachers to show them the benefits of using technology. Professional development has to be ongoing at your site. We encourage teachers to steal from each other.

Hardware, Software, and Technical Support

Supporting tens of thousands of computers and a computer network encompassing dozens of schools was a critical part of making the laptop initiative work well. The first year of the initiative (the 2001-2002 school year), when only the high schools were involved with the initiative, there were bandwidth and network connectivity problems. Division leaders realized they needed a much more robust network to handle the thousands of computers connected to the Internet and substantially upgraded the HCPS network.

Assistant principals or other existing staff who were designated as part-time technology coordinators managed the hardware and network and worked with students and families in cases where computers had been damaged. In addition, the schools each had technology support technicians (known as TSTs) who were able to fix many hardware and network problems. Under the lease agreement, TSTs were permitted by Apple Computer to do certain types of repairs on the laptops; other repairs, such as a broken screen, had to be made by Apple. In the 2003-2004

school year, Apple established a local repair depot, reducing the turnaround time for computer repairs (which used to require shipping the computers to Apple and back again) from 3 to 6 weeks to less than a week.

Key Barriers to Using iBooks

As we have mentioned, not all teachers and students in the schools we visited and, by extension, in HCPS had fully integrated the laptops into their instruction. The SRI-EDC study revealed several factors that influenced laptop use; these factors are discussed below.

Laptop durability. In spite of the fact that technical support was excellent in HCPS, teachers we spoke with had a few concerns about computer hardware. For example, the incidence of breakage and the need for repair seemed high; some schools were sending a number of computers to Apple every week for repair. According to one school technology coordinator, "The repair issue is the most daunting piece of the whole puzzle to me." When major repairs were needed on a laptop, schools had to learn to back up document files before the computer got "re-imaged," so that students would not lose their electronic files.

Apple computers are generally rated highly for reliability (Metz, 2004), but daily use of the laptops by students presents challenges to any manufacturer's equipment. In response to its experience in HCPS, Apple redesigned several features of the iBook, including strengthening the hinges as well as replacing a CD-ROM tray (hardware that slides out when disks are inserted or ejected and that is damaged too easily) with a slot into which CD-ROMs are inserted. The newer laptops were more robust than earlier models. In addition, as discussed above, a local repair depot reduced the time that students were without their laptops.

Battery life. The battery life of the iBooks—which is rated as excellent compared with that of other laptop batteries (Metz, 2004)—was still an issue. When charged properly, the batteries lasted approximately 4 to 6 hours, which is shorter than the school day. Some staff reported that if heavy use was made of the Internet, battery life was less than 2 hours. Although students were asked to bring their laptops to school fully charged and the schools did provide ways to recharge the batteries during the day, it would be helpful if charging were needed less frequently.

Students coming to class without laptops. A barrier identified by a number of teachers in the middle schools visited for this study was that not all students brought their laptops to school and to class. One teacher said:

> … at times more than half the students don't have the computer. The computers may be at the help desk, or the students may have had them taken away [for misuse]. It's very frustrating if you're doing a lesson with technology. Last week in my class, 13 didn't have the computers. In my classes, at least 75% of the time, 25% of the students don't have the iBook…. And I have no printer in my room, so it's hard to print materials for the students who don't have their iBooks.

A related issue is whether and how middle school students were using the iBooks at home. According to one middle school teacher, "You can't assume students have access to the Internet [at home] to do homework using the iBook." Along these lines, another teacher had "stopped giving homework on the iBooks because I was seldom getting it back." A third middle school teacher—an enthusiastic supporter of using the laptops for teaching and learning—noted that inappropriate uses of the computers often occurred at home, adding:

> Ideally I would like the students to take the iBooks home. But what I have seen is that when they do take it home, they do not know how to use it properly. They create all kinds of things [they shouldn't], [and] download pictures and music. If we had classroom sets [that stayed at school], they wouldn't have the same access to the materials…. It is a tough choice; there is a trade-off.

These teachers agreed that they wanted the iBook initiative to continue, but they would prefer that the computers not go home with students. Many staff shared these concerns: More than half of the 2,100 administrators and teachers responding to the FGI Research survey believed that middle school students should use laptops only in school and not take them home. Yet, at the same time, FGI Research reported that large majorities of the students and the parents surveyed believed that middle school students should be allowed to take the computers home. In any case, large majorities of all groups surveyed by FGI Research agreed that high school students should be allowed to take the laptops home.

Management and discipline issues around the computers. Assistant principals and other administrators spent a lot of time managing the laptop initiative, with one of them indicating that it could be a full-time job. Through the use of Web site blocks and nonerasable Web site histories, administrators were working to prevent students from being exposed to inappropriate Web sites. Teachers, too, were spending time on management and discipline issues. One teacher said, "I know at least once a block I catch somebody playing a computer game in my class."

Having distractions was not a new problem for teachers to contend with, but managing instant messaging, e-mail, inappropriate Web sites, and computer games was new. As a result, teachers and administrators had to learn appropriate management strategies, such as checking computers to see whether students had visited inappropriate Web sites, looking for students who quickly closed their computers when adults passed by because they were engaged in inappropriate activities, or requiring all students to put the computer screens down to listen to the teacher. Another teacher said that she arranged the desks in the classroom so that she could monitor computer screens from different places in the classroom.

Time. As in other school districts throughout the country, HCPS still struggled to find time for staff development and for teachers to practice what had been learned—even with the increased emphasis on integrating technology into instruction there. As one principal explained, "We have four-person team meetings, department meetings, cluster meetings, data meetings, etc. So finding time is hard. Summers become important; and the technology doesn't stand still—it is always changing." Many teachers reported that finding time and support in the summer was also difficult because spaces in the summer institutes were limited by the lack of teachers to lead the sessions. Although many schools had a technology coordinator who provided additional one-on-one help and professional development activities during planning periods throughout the year, these decreased the time teachers could spend on other planning activities. Planning time was often being crowded out by the new technology demands, according to some teachers. Furthermore, for teachers who were less technologically savvy, integrating the iBooks into their lesson plans required more preparation time.

Personal preferences. According to principals' reports, fewer than 2% of all students, or their families, chose not to receive an iBook. For some students, it was important to have paper copies of materials rather than electronic copies. In addition, some teachers had not made much use of the computers. A school administrator said, "What do you do with the resistant teacher?

Somehow you have to reach them, be a cheerleader, put a positive spin on their activity, and let them know that they have support."

Summary

Despite these challenges with computer hardware, wireless networking, and the need for teachers to learn new skills, the prevailing view among people we interviewed in HCPS was that the benefits of one-to-one computing outweighed any difficulties. According to a variety of respondents across the four school sites, the use of laptops helped students, teachers, and parents alike to reach greater levels of communication and productivity. The majority of teachers found the laptops to be especially helpful in affording them greater flexibility and versatility for professional and instructional purposes. These teachers used multimedia software and Internet Web sites that not only were beneficial in creating lesson plans but also helped to increase student engagement and motivation. The students interviewed also reported that the laptop helped them manage and organize their work inside and outside of class. The main benefit to parents was increased communication with teachers, which resulted in "in-touch" parents who were actively involved in their students' progress.

It is clear that in spite of the positive impacts reported by respondents, there were some barriers that made the implementation of the laptops more difficult. These barriers, however, did not appear to be dampening enthusiasm for implementing one-to-one initiatives in Henrico, either at the district level or in the schools we visited.

This initiative has more work to do to reach its full potential, but the work in HCPS can be informed by learning from other examples of one-to-one implementation. In the next chapter, we will examine lessons learned from other initiatives and discuss the future of one-to-one computing initiatives in K-12 education.

III. Discussion

Teachers, students, and administrators in HCPS reported a wide range of benefits from the Teaching and Learning Initiative, while also acknowledging challenges and difficulties. Across the different schools and different academic subjects, and in grade levels from 6 to 12, the teachers and students we interviewed reported that the laptops were being used in a variety of teaching and learning activities. Findings from the SRI-EDC evaluation study, which involved hundreds of people (administrators, parents, teachers, and students), and from the separate FGI Research study involving more than 28,000 respondents (see Chapter I) are consistent in showing widespread support for the HCPS laptop initiative.

HCPS is not the only large-scale one-to-one initiative reporting positive results. In 2002, the state of Maine began a laptop initiative for students in grades 7 and 8, the Maine Learning Technology Initiative. Because Maine's per-capita personal income is below the average for the United States, the Governor was interested in promoting economic growth through a laptop initiative. More than 34,000 teachers and students in grades 7 and 8 received laptop computers (Apple iBooks) paid for by the state. As in HCPS, all the participating schools in Maine were provided with wireless Internet access. A recent evaluation of Maine's one-to-one program found that principals, teachers, and students reported benefits similar to those identified in HCPS; as with HCPS, participants in Maine valued the use of laptops for teaching, learning, and administrative purposes (Silvernail & Lane, 2004).

The convergence of findings from multiple studies is significant, especially because the laptop initiatives in Maine and HCPS are, so far, the largest one-to-one initiatives in schools in the United States. HCPS and Maine have demonstrated that one-to-one computing using powerful computers and wireless Internet access is technically, politically, and financially feasible in school districts (HCPS) and states (Maine) that are not wealthy compared with their peers.

The first section below identifies "lessons learned" from HCPS. The next section discusses future studies of one-to-one computing. The last section addresses the growing number of one-to-one initiatives.

Lessons Learned

One of the lessons learned from HCPS's experience is that school leaders need to articulate a broad vision and a systemic approach of how to introduce and use the laptops. Their breadth of vision contributed to the initiative's success and shows the importance of a comprehensive approach. The division leaders involved all key groups, including parents. Teachers and students were provided with training and with extensive technical support. The hardware infrastructure, notably the wireless network, was upgraded so it would work with tens of thousands of users. Teachers were provided with classroom display devices. A lot of thought, effort, and money were invested in appropriate software, licensed Web sites, databases, and other digital resources. Individual teachers were *not* asked to create all of their own materials. Teamwork was encouraged, and leadership was shared. This comprehensive approach is a far cry from simply handing out laptops.

Not all laptop initiatives have demonstrated the same scope and breadth of vision. For example, an evaluation of the Quaker Valley Digital School District laptop initiative in Pennsylvania reported that teachers needed more professional development than was provided in

order to effectively integrate technology into instruction. In addition, many mathematics and science teachers wanted additional content-specific software and curricular tools. Teachers were being asked to do a great deal of work on their own; a year after the laptops were deployed in Quaker Valley, work had not begun to revise curricula to better integrate technology or to make content-specific software available to teachers (Kerr, Pane, & Barney, 2003).

The purpose of the HCPS initiative is principally to improve teaching and learning. At the same time, HCPS also used the laptop initiative to improve communication with parents and to increase administrators' and teachers' productivity. Indeed, the findings about the teachers' use of laptops for their own professional purposes can be understood as reflecting a changing view of what teachers need in order to do high-quality work. In many school districts across the nation, teachers are not provided with some basic tools for their jobs, such as easy access to telephones or to quiet office space where they can confer with colleagues or students. By providing HCPS's middle and high school teachers with laptop computers, division leaders demonstrated that teachers, students, and parents benefit when the teachers are provided with the powerful, multipurpose tools—computers—that are already ubiquitous in most business and government environments.

Despite the positive results to date, large-scale one-to-one initiatives are so new that there is still much for HCPS and others to learn about managing such a major undertaking. For example, leaders in HCPS are likely to give more thought to the question of whether middle school students should continue to be permitted to take laptops home, as they are now. They might wish to communicate with leaders of the laptop initiative in Maine about this question. About half the middle schools in Maine allow the computers to go home, and half do not. In those that do, few problems have been reported with middle school students' not bringing their computers to school and to class. In one Maine school, the principal calls the parents of any student who does not come to school with his or her computer and asks the parents to bring it to school. Similarly, there appear to be fewer computers needing repair in Maine schools than in HCPS. It may be that providing students with better-cushioned carrying cases or taking other inexpensive steps could significantly reduce laptop repair problems in HCPS schools.

Another important challenge facing HCPS—and others seeking to implement one-to-one computing—is the issue of nonuse. Although it was beyond the scope of this study to focus on the extent to which iBooks were not being used in HCPS classrooms, from our observations and interviews it was apparent that not all students and teachers were using the laptops regularly. Reasons for nonuse ranged from teachers' being reluctant to embrace electronic modes of instruction to students' not having laptops in class, for whatever reason, to parents' and students' preferring hard copies to electronic files. In the four case study schools, the issue of nonuse had implications for lesson planning, time and classroom management, and parent-teacher communication and relations. These difficulties serve as a reminder that although we may be moving toward a paperless society (and education system), the shift is not complete, and managing the transition might require considerable planning and accommodations.

Enough has been learned from experiences with laptop programs across the United States that the Northeast and the Islands Regional Technology in Education Consortium (NEIRTEC) prepared a paper called *Lessons Learned About Providing Laptops for All Students* (Bonifaz & Zucker, 2004). The paper identifies some of the essential conditions needed to successfully implement a laptop initiative, such as professional development for teachers and administrators and ongoing program monitoring and evaluation. However, there are many areas in which we

know too little about laptop programs, including their impacts on students' learning and ways of assessing their overall costs and benefits.

Future Studies of One-to-One Initiatives

The research and evaluation framework presented in Exhibit I (Chapter I) identifies many different aspects of one-to-one initiatives that deserve to be studied, ranging from impacts of these initiatives on teaching and learning to the effects on home-school connections and on the economic competitiveness of the states and districts that sponsor the programs. As new studies take place, HCPS's one-to-one initiative, like all others, will evolve in response to changes in technology and what HCPS learns about implementation; and education systems themselves will evolve, for example, in response to state and federal legislation. It will be important to focus new studies on the most important research and evaluation questions and topics, such as the following three.

Evaluating Students' Learning

The framework introduced in Chapter I identifies improving student learning as one of the more significant outcomes of one-to-one computing initiatives. People in HCPS and elsewhere are interested in whether and how one-to-one computing is linked to better outcomes for students. Studying the links between one-to-one computing initiatives and students' learning is important, but at the same time, studying the impacts of computers on learning is also complex.

Fortunately, considerable work in this area is under way. The U.S. Department of Education and the National Science Foundation have sponsored many ongoing studies, costing tens of millions of dollars, to examine the impacts of technology on student outcomes (see, for example, http://www.ed.gov/news/pressreleases/2003/11/11102003.html). To take one example, the U.S. Department of Education is funding a 3-year research study that focuses on teaching middle school mathematics with laptops. This study, a randomized experimental field trial (a form of study that can provide a high degree of certainty about the cause of changes in student outcomes), will cost nearly $2 million. Another multiyear study focuses on the impacts of a virtual (online) education program for teaching Spanish. The U.S. Department of Education is also supporting congressionally mandated studies of the impacts of discrete education software packages, such as those designed to teach early reading (http://www.ed.gov/about/offices/list/os/technology/evaluation.html). Those studies, which use random assignment, will involve dozens of schools, take years, and cost many millions of dollars.

Experimental studies of the impacts of computers on students' learning in natural settings are expensive and time-consuming, and require expert attention to detail. Not every school district or state that supports one-to-one computing needs to conduct its own study of impacts on student learning. HCPS and other places with laptop programs, however, should at least consider becoming part of such studies, because without rigorous research it will be difficult for policy-makers and the public to fully understand the benefits of one-to-one computing.

New research about student learning in one-to-one schools is likely to require the development of more high-quality assessments. For example, better assessments are needed to measure students' problem-solving and higher-order-thinking skills, their technology proficiency, and their ability to reason and solve problems in the information-rich environments created by the Internet. Again, HCPS and other places with laptop programs can play a

constructive role by being part of larger efforts to develop and validate new measures of student learning.

For those states and districts interested in studying the impacts of laptop programs on student achievement, a critical rule of thumb is to figure out what it is the laptop program is especially helping students learn, and measure that (Means & Haertel, 2004). For example, if substantial time and money have been spent focusing a laptop initiative on the teaching of algebra, that might be an appropriate focus for a study. On the other hand, some one-to-one initiatives have focused special attention (including teacher professional development and the creation of new curriculum resources) on teaching writing by using laptops and have documented gains in student achievement in that domain (Jeroski, 2003).

Although evaluating the impact of Henrico's Teaching and Learning Initiative on student achievement was beyond the scope of this study, the four school case studies do provide information that can help researchers identify ideas for focused, quantitative studies of student outcomes. For example, students' use of Larson's Algebra in mathematics and the increased access by science students and teachers to up-to-date information might be fruitful topics for studies designed to document impacts on student outcomes. If possible, such studies should include a comparison group in which students are taught with conventional approaches.

Studying the Evolution of Digital Media

As explained in this report, HCPS has attempted to use the laptop program to increase teachers' productivity, enhance communication with parents, and make a wide range of digital resources available to students and teachers. Nonetheless, because one-to-one computing initiatives are so new, education systems are not yet designed to take full advantage of computers. Students' use of textbooks could be much more tightly linked to their use of online or computer-based resources—such as animations, interactive exercises, computer-based tools, better access to primary sources as well as to current information, development of multimedia products, and integration with assistive technologies for students with learning disabilities. Tests and assessments could be more commonly delivered to students online, thereby providing quicker, more useful feedback and forging closer ties among instruction, remediation, and assessment. School, district, and state data systems could more rapidly and effectively make use of the results of student testing. Tests could also incorporate the computer-based tools that teachers and students increasingly include as part of instruction (and that workers use in offices), such as spreadsheets for science and mathematics. (As noted in Chapter I, the state of Virginia has been a leader in developing and using online assessments.)

What is happening in HCPS, and in other schools where computers are used frequently, may be part of a gradual transition from relying on paper resources in schools to a primary emphasis on "digital content." Already, major corporations and key nonprofit groups are developing electronic supplements and alternatives to paper-based textbooks, online schools, and many other digital education resources. (See Exhibit 1). Over time, this transition may lead to improvements in students' learning, cost savings, greater flexibility for students and teachers, more individualization of instruction, stronger connections among students across geographic boundaries, and other benefits. Future studies of one-to-one computing, whether in HCPS or elsewhere, may show more pervasive and profound impacts of computer use because

Exhibit 6
The Move to Digital Content

Textbooks are being revised to reflect increased student access to computers. During the 1990s, for example, teachers in Montana, with funding from the National Science Foundation, developed an integrated high school mathematics textbook series (*SIMMS Integrated Mathematics: A Modeling Approach Using Technology*) that incorporates dozens of computer-based activities that rely on spreadsheets and other software. The National Council of Teachers of Mathematics sponsors *ON-Math* (http://my.nctm.org/eresources/), an online journal providing applets and articles on the use of technology in mathematics teaching. So many digital materials are already available for teaching science that Education Development Center has published a guide for teachers called *Selecting Computer-Based High School Science Curricula*. The National Science Teachers Association sponsors *SciLinks* (http://www.scilinks.org), a collaboration with selected textbook publishers that provides users with information linking specific textbook pages and selected science Web sites. There are thousands of education-related Web sites, online computer-based tools, and education software products.

IBM has recently teamed with a company called VitalSource Technologies to provide a district in Texas with laptop computers loaded with electronic books, including more than 2,000 classics of literature, history, political science, and other subjects, as well as electronic copies of current textbooks. The laptops also include software for searching and annotating electronic texts.

Institutions of higher education have also been "going digital" and there are now more than 100 campuses where all students use laptops (Brown & Petitto, 2003). In the fall of 2004, for example, 400 students at the University of Virginia will use Tablet PCs in biochemistry, psychology, and statistics classes. The students and their professors will be able to use statistical models, simulations, online exercises, and other "learning objects" routinely, and even incorporate them into their notes. Microsoft and Thomson Learning are funding the project, which will incorporate a computer-based media package developed by Thomson to accompany a biochemistry textbook. The media package includes such materials as animations and PowerPoint presentations.

education systems will have more fully adapted to the digital world in which we live. As decades of experience in business have demonstrated, such pervasive change does not happen overnight.

Some future studies will take a comprehensive approach, examining large and complex systems as a whole. Other studies ought to focus on one or another component of the system, such as the impacts on parent-school-student relationships that result from the use of laptops and software systems like the one Henrico County adopted (K12Planet®).

Studying the Costs of One-to-One Computing

The cost of one-to-one computing is another area that deserves greater study. The rapidly declining costs of laptop computers with wireless Internet connectivity is allowing a growing number of states, districts, and schools to support laptop initiatives. From 1999 to 2003 alone, the average price of a computer system sold to schools and colleges declined by almost 40% (eSchool News, 2004). Computers are also becoming smaller; some new "ultra-portable" computers weighing less than a pound are able to run the same operating systems as most desktop computers. For the time being, however, the cost of one-to-one computing is still a concern, even for policy-makers who support the concept of providing every teacher and student with a computing device.

HCPS demonstrates that it is not necessary for schools to spend above-average amounts to support a large one-to-one initiative. According to the Virginia Department of Education, in 2002-2003 the average per-pupil operating expenditure for all divisions in the state was $8,186, while the comparable figure for Henrico County Public Schools was $7,083, or 13.5% less than the state average (Virginia Department of Education, 2003).

Additional information about the cost of one-to-one computing is needed. Cost is not a simple topic, but the Consortium for School Networking (CoSN) has made a contribution to understanding the costs of educational computing by publishing case studies of the cost of ownership of computers in eight varied school districts across the United States (http://classroomtco.cosn.org/gartner_intro.html). Each report is more than a dozen pages long. Although none focuses on a district using one-to-one computing, the case studies illustrate the fact that a school district's budget for computers can be carefully analyzed whether or not the district supports one-to-one computing. There is also a CoSN Web site that allows schools or districts to compute the "total cost of ownership" of computers in their schools (see classroomtco.cosn.org/) based on dozens of pieces of information.

Volume purchasing reduces some costs of one-to-one computing. By bundling software, working with distributors to obtain discounts, and collaborating with corporations (e.g., by acting as a test site for new software or Web services), HCPS staff estimate that HCPS saves approximately $700 per student relative to the normal retail cost of an iBook and the digital resources provided to students. In addition, HCPS had existing memberships in regional and other consortia that provide the division with access to electronic resources, such as online databases. These resources are now available from students' laptops, and the value of these resources is reported to be more than $1,100 per student, if the student had to pay individually.

There may also be some cost savings due to one-to-one computing. For example, HCPS no longer needs to equip and maintain so many dedicated computer laboratories, which may result in more efficient use of classroom space, thus saving money. Meeting the needs of students with learning disabilities may also cost less when every student has a computer. The use of some computer-based science experiments may reduce certain science laboratory costs.

Listing, quantifying, and adding up the benefits and the costs of one-to-one computing in dollar terms is difficult, at best. Nonetheless, responsibility for deciding how to spend education dollars, and whether to support one-to-one computing, rests with key policy-makers and the public. For them, a key to maximizing the benefits of one-to-one computing is to link these initiatives to school systems' core education goals (which include not only raising student achievement but many others, as well).

The value of one-to-one computing initiatives may not lie only in a small number of major benefits, such as raising test scores in academic subjects. Instead, the benefits of one-to-one computing appear to come in numerous forms.

An Increasing Number of One-to-One Computing Initiatives

Given the success of laptop initiatives in HCPS and in Maine, it is not surprising to learn that many other districts and states—including Michigan, New Hampshire, New Mexico, Texas, and Vermont—are investigating and implementing one-to-one computing initiatives in some of their schools. For example, the Texas Education Agency is supporting a Technology Immersion Pilot (TIP) program that provides laptops to students and teachers in many school districts across the state. In some cases, these programs are large. For example, Irving Independent School District, near Dallas, has more than 8,000 laptops in grades 3 to 12. Texas is also conducting an evaluation of the TIP program, supported by federal funds.

As additional studies of one-to-one computing become available, they will help build a body of knowledge that can guide policy-makers and practitioners who implement new laptop programs. The history of computing suggests that the price of computers will continue to decline for decades to come, even while hardware capabilities improve. This remarkable trend, combined with the reported benefits of providing computers to all teachers and students, suggests that one-to-one computing will, in time, reach millions of students in schools across the country.

Exhibit 7
Additional Information about One-to-One Computing

Sharing the lessons learned from major one-to-one initiatives will help maximize the benefits and minimize the costs as more funds are invested by school systems. Links to many evaluations and studies can be found online at http://ubiqcomputing.org.

The former superintendent of HCPS, Dr. Mark Edwards, wrote an article with suggestions for other school systems interested in one-to-one computing (Edwards, 2004). The article is available at http://eschoolnews.com/news/showStory.cfm?ArticleID=4848. Henrico County Public Schools also posts information about the iBook initiative online, including newsletters (http://www.henrico.k12.va.us/iBook/).

Maine provides a lot of information about its one-to-one computing initiative on two Web sites (http://mainelearns.org and http://www.state.me.us/mlte).

Computer vendors often provide information about one-to-one computing on their Web sites. For example, Apple Computer has a Web site that provides information about a number of one-to-one computer initiatives (http://www.apple.com/education/onetoone/).

Learning With Laptops (http://www.learningwithlaptops.com/) provides a list of independent schools supporting laptop programs, as well as frequently updated news, articles, and opinions about laptop initiatives.

As a way of helping states and districts interested in laptop initiatives, NEIRTEC has reviewed published lessons learned from many laptop initiatives around the country and has prepared a paper, *Lessons Learned About Providing Laptops for All Students* (http://www.neirtec.org/laptop).

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Appendix
Focus Group and Interview Guides

Appendix
Parent Focus Group Guide

I. Introduction

Let's start by going around the room so you can introduce yourself. Give me your first name, your child's grade level(s), and his/her math or science class. (Note that we will not use your names in anything we write.)

II. Learning with Laptops

1. Do you have a personal computer at home? How long have you had it?
2. How have the laptops affected your child's learning of math or science? Performance? Achievement?
3. What kinds of activities does your child do with the laptops?
4. How often does he/she use them at home for any purpose? For homework?
5. How does your child feel about the laptop?
6. What kinds of software or hardware does your child use with the laptops? What are the benefits or barriers to using these resources?
7. Do you think your child has adequate teacher and/or administrative support in using the laptops?

III. Challenges and Facilitators

8. What are some challenges or barriers to your child using the laptops? What things make it easier for them to use laptops in their school work?

IV. Benefits

9. What are the benefits or unique contributions of the laptops for students of science or math?
10. What are the costs of the laptops? What do you feel, if anything, has been sacrificed for this program? Is it worth it?

V. Wrap-Up

11. Is there anything else you would like to tell me about your child's use of the laptop or the laptop initiative?

Student Focus Group Guide

I. Introduction

Let's start by going around the room so you can introduce yourself. Give me your first name, grade level, and a brief description of your experience using technology. (We will not use your names in anything we write.)

II. School Culture Ice breaker

Now I want each of you to think about what you like best about studying at this school and what you like least about this school.

III. Students and School work

Now think about how you do your school work using the laptops.

1. How are laptops used by you and your peers in science and math? How is what you do in your class different from other classes?
   - Types of homework assignments you complete
   - In-class assignments or experiments
   - Exams and other Assessments
   - Research and information gathering
   - Team work and collaboration
2. Do you find the laptop helpful in learning math/science? Why or why not?
3. Do you find your teacher helpful/knowledgeable in using the laptops?
4. Have the roles and/or interactions of teachers and students changed at all because of the use of IBooks?
5. What kinds of software and hardware resources have you used with the laptops? How often do you use them?
6. Do you feel comfortable working with these programs or tools on your own?
7. Has using laptops changed the kinds of collaboration you engage in?

IV. Implementation Facilitators and Challenges

8. What factors help to make it easy to use laptops in your science and math classes? What have been some of the barriers to using the laptops?
9. Who helps you if you have any problems with your laptop? Are they easily accessible?

V. Benefits/Costs

10. How have students at this school benefited from using laptops in math and science courses? Give me a personal example or examples from your peers.
11. What might be the downside to using laptops? Do you think anything has been sacrificed for the laptops?

12. How have your families benefited from you being able to take the laptops home for use?
13. What are the unique contributions of the laptops? (increased student engagement, improved teaching, provides resources that would otherwise not be available)

VI. Wrap-up

Is there anything else you would like to tell us about using laptops in your school that we haven't covered already?

Exemplary Teacher Interview

I. Introduction

Please give me your first name, grade level(s) and subject(s) taught, tenure, and a brief description of your experience using technology.

(Note that we will not use your name in anything we write.)

II. School Teaching Culture

1. How do teaching and learning in your classroom, and in the school more generally, compare with teaching and learning in other schools in the division?
2. How would you describe the sense of community you and other teachers have in your department?
3. Describe the leadership style of leaders (department head and principal) and the degree of input teachers have in governance and school policy.

III. Teaching with Technology

4. Did you use technology in your teaching before the implementation of the initiative? If so, what and/or how?
5. What changes have you seen in teaching since the introduction of laptops? (probe on the topics below as necessary)
   - curricula and/or organization of the content
   - time in class
   - standards and assessment practices changed
   - teaching practices
   - professional relationships and collaboration among teachers
   - roles or relationships of teachers and students
   - level of input or influence on school decisions changed
   - organization of the school?
6. What kinds of activities do you and your students engage in with your iBooks? (Probe on the topics below)
   - Are there certain lessons that are more conducive to laptop use?
   - How do you find and choose the materials to use with the laptops?
   - Do you get or share ideas and resources with other teachers? How does that usually happen?
7. What kinds of software and hardware resources have you used with the laptops? How often do you use the programs or tools?

8. How well do these programs fit in with the curriculum? How do you determine which programs to use and when?
9. Who trains you in using the software or tools? Is the training ongoing? Adequate?
10. How well is the software linked to standardized tests?
11. Has using laptops changed the kinds of collaboration students engage in? How often do students work in groups (not including sharing a laptop when someone's breaks down)?
12. How is your classroom different from other classrooms in the school?

IV. Implementation Facilitators and Challenges?

13. What are some of the facilitating factors that have helped you and your students use the laptops?
14. What are some of the factors that make it hard to use laptops in mathematics and science courses?

V. Benefits/Costs

15. What are the benefits or unique contributions of the laptops for students and teachers of math and science at this school?
16. What are the costs of the initiative? What has been sacrificed for it? Is it worth it?
17. How have the laptops affected the connections between the home/community and the school?
18. What do you think about the controversy over the laptop initiative? Do you think the program should continue? What do the parents think?

VI. Wrap-up

Is there anything else you would like to tell me about using laptops in your school that we haven't covered already?

School Principal Interview Guide

I. Introduction

- Name
- Position/Job title
- Duration of position

II. Policy Context:

1. What is distinctive about this school and what are some of school policies that make this place different? (Use the following probes)
    - Curriculum, Standards, and Assessment
    - Professional Development
    - School organization
    - Teacher professional community

III. Implementation

2. What changes have you seen in teaching since the introduction of laptops? (probe on the topics below as necessary)
    - curricula and/or organization of the content
    - organization of the school
    - standards and assessment practices
    - teaching practices
    - professional relationships and collaboration among teachers
    - roles or relationships of teachers and students
    - community and parental involvement
3. How has the teaching of math/science changed since the initiative? (Listen for teacher preparation and collaboration in addition to teaching practices)
4. What kind of support is available for teachers using laptops for science and math instruction? Do teachers make use of these resources?
5. How well is software and technology linked to curriculum and standardized tests?

IV. Barriers / Challenges

6. What kinds of barriers/challenges has this program presented? What are the factors that have enhanced your program implementation?
7. How would you improve your implementation of this program?

8. What do you think about the controversy over the laptop initiative? Do you think the program should continue? What do the parents think?

V. Benefits/Costs

9. What kinds of benefits has the laptop program brought to your school? Unique contributions? (Probe on the following)
    - School organizational improvements
    - Student performance
    - Teachers and Instruction
    - Home-School-Community Links
10. What are the costs of the initiative? What has the district had to sacrifice for this program? Is the money worth it?

VI. Wrap-up

11. Is there anything else you would like tell us about the laptop initiative?

School District Administrator

I. Introduction

1. What are your roles and responsibilities within the school division?

   Background and previous positions

   Duration in current position

   Leadership responsibilities

II. Policy Context

2. Describe how policy making and governance occur in the school division.
3. How have your interactions with the following policymaking groups changed as result of the laptop initiative?
   - School Board
   - Local Community / Business
   - State Education Department
   - Others?

III. Vision and Culture

4. How would you describe the school division's vision for teaching and learning? How does the iBook initiative factor into this vision? How has the vision changed because of the iBook initiative?
5. How have beliefs about technology changed among teachers and administrators since implementation?
6. As you look back over the years, how has the school division changed because of the initiative? What has been the most significant change?

IV. Implementation

7. What would you change about the school division's implementation process for one-to-one computing if you could do it all over again?
8. How has curriculum and instruction changed as you have implemented the use of laptops over time? Professional development? (Probe for specifics with math and science coordinators).
9. How has data informed your decision making throughout the implementation of this initiative? What have been the most important data sources that have helped you? Why?
10. How have costs for the leasing of the laptops been managed over time? Are they consistent with previous estimates (4-5%) of the cost of the program?

11. How has the use of laptops by teachers and students changed over the course of the program?
12. What has facilitated the use of laptops in the school division's classrooms? What are the barriers that have made it difficult to implement as you envisioned?

V. Benefits/Costs

13. What are the benefits and unique contributions of the laptop program? (Listen and probe for)
    - School/division organizational improvements
    - Administrator/leadership outcomes
    - Home-School-Community Links
    - Student performance outcomes
    - Teacher outcomes
    - Unexpected Benefits
14. What has the division sacrificed for this program? Has it been worth it?
15. How have community members responded to the iBook initiative? Have community views changed over the course of the program?
16. What do you think about the controversy over the laptop initiative? Do you think the program should continue? What do the parents think it?

VI. Wrap-up

17. Is there anything you would like to add about the iBook program in your school division?