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Abstract:

Rapid technological advances in the last decade have sparked educational practitioners' interest in utilizing laptops as an instructional tool to improve student learning. There is substantial evidence that using technology as an instructional tool enhances student learning and educational outcomes. Past research suggests that compared to their non-laptop counterparts, students in classrooms that provide all students with their own laptops spend more time involved in collaborative work, participate in more project-based instruction, produce writing of higher quality and greater length, gain increased access to information, improve research analysis skills, and spend more time doing homework on computers. Research has also shown that these students direct their own learning, report a greater reliance on active learning strategies, readily engage in problem solving and critical thinking, and consistently show deeper and more flexible uses of technology than students without individual laptops. The study presented here examined the impact of participation in a laptop program on student achievement. A total of 259 middle school students were followed via cohorts. The data collection measures included students' overall cumulative grade point averages (GPAs), end-of-course grades, writing test scores, and state-mandated norm- and criterion-referenced standardized test scores. The baseline data for all measures showed that there was no statistically significant difference in English language arts, mathematics, writing, and overall grade point average achievement between laptop and non-laptop students prior to enrollment in the program. However, laptop students showed significantly higher achievement in nearly all measures after one year in the program. Cross-sectional analyses in Year 2 and Year 3 concurred with the results from the Year 1. Longitudinal analysis also proved to be an independent verification of the substantial impact of laptop use on student learning outcomes.

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Learning With Technology: The Impact of Laptop Use on Student Achievement

Introduction

Technological advances, such as more powerful personal computers, directly affect the way people live in this information age. In the analysis of *Fifty Trends Now Changing the World,* Cetron and Davies (2001) noted that technology is increasingly dominating both the economy and society. Schools are no exception. *The Digest of Education Statistics* (National Center for Education Statistics, 2000) reports that the percent of students using computers at school more than doubled between 1984 and 1997. Similarly, *Education Week* notes that the United States, along with Australia, leads the world in the number of students per computer, with a ratio of five to one in 2003 (Technology Counts, 2004). *Education Week* (Technology Counts, 2004) also notes that 98 percent of nation's schools have Internet access and that more than 12 percent of the nation's schools have used laptops as an instructional tool. In addition, 38 states standards for teacher certification include technology, 15 states require technology training or coursework for an initial teacher license, and 9 states require a technology test for an initial teacher license. There is no doubt that educational leaders are increasingly looking for ways to increase instructional uses of technology.

Over the past decade, rapid technological advances have sparked interest in utilizing laptops as an instructional tool to improve student learning. According to *The New Lab for Teaching and Learning's Dalton Council Task Force Report in Laptop Technology* (2001), Beaufort County in South Carolina launched a pilot program in 1994 using laptops for instruction with 330 sixth graders. The program was expanded to all middle school students by 2000. The same report indicates that Clovis Unified School District in California and New York City Community School District Six (with 2,700 students in grades four through seven) launched similar laptop immersion programs in 1996 (*Dalton Council Task Force Report,* 2001).

Similarly, in 2000, the state of Maine piloted a laptop immersion program with one middle school, expanding it to 241 middle schools in 2001, and increasing to a total of 36,000 laptops with 33,000 students and 3,000 teachers by 2003. The second largest initiative occurred in Henrico County Schools in Virginia, which piloted a laptop program in 2001 and expanded enrollment to 23,000 students by the end of 2003. Texas is the most recent state to join this trend. More than 7,300 students in thirteen schools will be given wireless laptop computers next fall for use at home and at school as part of a Technology Immersion Project that is expected to fundamentally change the way students learn.

On a smaller scale, in 1996 Microsoft Corporation launched the *Anytime Anywhere Learning Project* in partnership with Toshiba America Information Systems' Notebooks for Schools. The following year, full implementation of the program occurred in 52 schools across the United States. By the year 2000, 800 schools with 125,000 students and teachers participated in the laptop program. To evaluate the effectiveness of Microsoft's laptop program, an independent research organization in San Francisco, California, was contracted. Multiple evaluations of Microsoft's laptop immersion program yielded positive results on student learning and curriculum delivery (Rockman et al., 1997, 1998, 2000). Key evaluation findings fall into two categories: student outcomes and teacher outcomes.

Student outcomes include:

- Laptop students spend more time engaging in collaborative work than non-laptop students
- Laptop students participate in more project-based instruction
- Laptops lead to more student writing and to writing of higher quality
- Laptops increase access to information and improve research analysis skills
- Laptop students become collaborators (interact with each other about their work)
- Laptop students direct their own learning
- Laptop students report a greater reliance on active learning strategies
- Laptop students readily engage in problem solving and critical thinking
- Laptop students consistently show deeper and more flexible uses of technology
- Laptop students spend more time doing homework on computers

Teacher outcomes include:

- Teachers who use laptops use a more constructivist approach to teaching
- Teachers who use laptops feel more empowered in their classrooms
- Teachers who use laptops spend less time lecturing

As reported by Rockman et al. (1997, 1998, 2000), laptop use not only reinforces the utilization of successful learning strategies but also enables students to transfer the knowledge across disciplines. This is believed to occur because laptop students are involved in: (1) highly engaged and focused activities (spending more time on their work and completing larger projects); (2) frequently apply active learning strategies; (3) interact with each other about their work; (4) problem solve through project-based activities, which usually involve more critical thinking; and (5) regularly find information, make sense of it, and communicate it. Research provides evidence that students who engage in collaborative work, participating in more project-based learning, have higher levels of motivation (Wigfield et al., 1998; Guthrie & Wigfield, 2000). When students are motivated, they demonstrate improved achievement (White, 1989; Roth & Paris, 1991; Roderick & Engel, 2001; Haydel & Roeser, 2002; Gulek, 2003), they produce longer and higher quality writing samples (Reeves, 2001; Goldberg, Russell & Cook, 2003), and they spend more time doing homework (Parschal, Weinstein & Walberg, 1984; Walberg, 1984,1994; Walberg & Haertel, 1997). Similarly, teachers using a constructivist approach feel more empowered and spend less time lecturing (von Glaserfeld, 1995, 1995b), have fewer classroom management problems (Marzano et al., 2003), and have more engaged learners in their classrooms (von Glaserfeld, 1987; Jonassen, 1991; Fosnot, 1996; Marzano et al., 2003). As seen in the evaluations conducted by Rockman et al. (1997, 1998, 2000), many of these outcomes were observed when students were provided with their own laptop through the *Anytime Anywhere Learning Project*.

Examining the Impact of the Harvest Park Laptop Immersion Program

There is substantial evidence that using technology as an instructional tool enhances student learning and educational outcomes (Berger, 1984; Choi & Gennaro, 1987; White & Horowitz, 1988; Garza, 1991; Geban, Askar & Ozkan, 1992; Secules, Herron & Tomasello, 1992; Njoo & de Jong, 1993; Lehman, 1994; Beauvois, 1997; Soloway et al., 1997; Gonzalez-Bueno, 1998; Schecker, 1998; Spitulnik et al., 1998; Hanna & de Nooy, 2003). The study presented in this article examines the impact of the Harvest Park Middle School's laptop immersion program on student learning. Specific research questions include the following:

1. Does the laptop program have an impact on students' grade point average?
2. Does the laptop program have an impact on students' end-of-course grades?
3. Does the laptop program have an impact on students' essay writing skills?
4. Does the laptop program have an impact on students' standardized test scores?

Learning outcomes examined in this study include overall grade point averages (GPAs), end-of-course grades, District Writing Assessment results for sixth and eighth grade students, results of the Standardized Testing and Reporting (STAR) Norm-Referenced Test (NRT-CAT/6), and California Standards Tests in English-language arts and mathematics.

Description of the Laptop Immersion Program

Harvest Park Middle School, located in Pleasanton Unified School District in Pleasanton, California, established its Laptop Immersion Program in 2001. Located 40 miles southeast of San Francisco, in the center of what is rapidly becoming the new "Silicon Valley," suburban Pleasanton has experienced considerable growth in its residential and business base over the last two decades and is now home to an increasingly diverse population of more than 60,000. A highly educated, high-income community has developed in the midst of what not too long ago were acres of fruit orchards and cattle fields on the edge of Alameda County. As a school experiencing rapid growth over a short period of time, the challenge of Harvest Park was to maintain the same high level of academic excellence, while building an infrastructure that would meet the demands of its student population. Harvest Park's laptop program emerged out of a partnership between the offerings of the high-tech businesses in the community and schools' search for innovative programs.

How Does the Laptop Program Work?

Students in the Laptop Immersion Program receive the same grade level curriculum offered to all students in the district. The differences are seen in the method of curriculum delivery and in the latitude of options students are given to demonstrate curriculum mastery through the use of technology.

All students are eligible to participate in the program. Parents purchase the laptops used by their students in this program. For families who cannot afford to purchase a laptop, a Laptop Advisory Committee, comprised of an administrator, and teacher and parent representatives, reviews parent requests for loaner laptops. The loaner applications are reviewed during the spring enrollment period for the program. To date, no student has been denied an opportunity to participate in the Laptop Program. The loaner program provides students computers approximately one week before the start of the school year and allows students to keep them until the end of the school year. At the end of the year, students in the loaner program are required to return their computers to the school.

All students participate in computer camp where they are introduced to the basics of using the computer. Teachers who regularly teach in the Laptop Program also teach the Computer Camp. Students are trained in understanding the capabilities of laptops, in navigating and operating the computer, and in installing the software that they will use later in the year. The session also covers the rules and expectations around laptop use in the classroom, internet/e-mail safety, and virus safety. Students receive hands-on training in all of these areas.

Students then use laptops on a daily basis during the school year. The laptop use varies depending on the subject matter. The most common laptop applications in the classroom include essay writing and on-line grading in English, researching information on the web , and developing power point presentations for projects in history/social science classes. Students also use laptops to develop websites, access web-based lab projects and activities in science, and design posters and logos. Note-taking for all subjects in the classroom is also performed with laptops.

Program Enrollment

The Laptop Immersion Program started with sixth grade students as a pilot program in the 2001–02 school year and was subsequently expanded to seventh and eighth grade students. Students were allowed to join the program at any point during their middle school years, as long as any course scheduling conflicts were resolved. The program caught the growing interest of many students and expanded to a current enrollment of 259. Table 1 shows the enrollment in the program and school-wide enrollment by grade level in 2003–04.

Table 1: Laptop Immersion Program Enrollment by Grade

Grade	Laptop Program Enrollment	Total School Enrollment
6	91	353
7	93	361
8	75	371
Total	259	1085

Student Demographics

To compare the demographics of students enrolled in the Laptop Program to the demographics of students school-wide at Harvest Park Middle School, several key indicators were identified. These key demographics data included students' ethnic background, gender, Gifted and Talented (GATE) program enrollment, special education status, enrollment in the National School Lunch Program (NSLP; economically disadvantaged status), English Learner status, and parent education level. The data are summarized in Table 2.

(Table 2 is shown on the following page.)

Table 2: Student Demographics – Laptop Immersion Program Versus School-Wide

Student Demographics	Laptop	School-wide
Ethnicity		
Asian	14%	16%
Filipino	1%	2%
Hispanic/Latino	6%	7%
African American	0%	1%
White	79%	74%
Gender		
Female	44%	49%
Male	56%	51%
Gifted and Talented	27%	24%
Special Education	5%	10%
Economically Disadvantaged	1%	4%
English Learner	1%	3%
Parent Education Level		
Graduate School	42%	37%
College Graduate	46%	44%
Some College	10%	12%
High School Graduate	2%	6%
Not High School Graduate	0%	1%

Table 2 indicates that all demographic indicators show no more than five percentage points difference between laptop and non-laptop students. This indicates the demographic composition of students enrolled in the program closely mirror those of the entire school population.

The baseline data for three measures (NRT language arts and math, and the district writing test) show that there is no statistically significant difference in achievement between laptop and non-laptop students prior to the enrollment in the program. However, the comparison between the two groups after one year in the program indicate that laptop students showed significantly higher achievement in NRT language arts ($F=9.84$, $p< .005$) and NRT mathematics ($F=13.89$, $p<.001$). The difference between the two groups in writing achievement at the end of Year 1 in the program was not significant; however, the Year 3 results significantly favored the laptop students ($F=5.53$, $p< .05$).

Although there was no baseline data available to assess the prior achievement for STAR CST and NRT, and overall GPA, statistical comparisons between laptop and non-laptop students were made for these measures as well. Cross-sectional analyses comparing the difference in mean scores indicate that laptop students consistently scored higher than non-laptop students in CST English-language arts at the end of Year 1 ($F=10.68$, $p< .005$), Year 2 ($F=6.87$, $p< .01$), and Year 3 ($F=6.88$, $p< .01$). The difference between laptop and non-laptop students in CST math performance was significant in Year 1 ($F=8.57$, $p< .005$), but non-significant in Year 2 and Year 3. The STAR NRT results indicate that there is no statistically significant difference between laptop and non-laptop students in terms of language and math achievement in Year 2 and Year 3. The comparison of overall GPA scores demonstrated that laptop students obtained higher GPAs throughout their enrollment in the program. The differences were statistically significant in Year 1 ($F=14.47$, $p< .001$), and Year 2 ($F=12.65$, $p< .001$), but not in Year 3.

Cohort 2 Analyses

Cohort 2 members were seventh grade students in the 2003–04 school year. Those who participated in the Laptop Program completed their second year. Their baseline data were extracted from the 2001–2002 school year test scores, when they were fifth graders. The STAR CST in English-language arts and mathematics were the two data points available for comparison between the baseline and follow-up achievement for this cohort group. The CST scores were reported in terms of the percent of students scoring proficient or advanced (meeting or exceeding the [state] standard). Table 11 shows the results for students in Cohort 2.

Table 11: Prior Differences in Achievement for Cohort 2 by Program Enrollment

		Baseline Data (2001–02) *(Prior to Laptop Enrollment)*	**Year 1** (2002–03)	**Change**
NRT Language	Laptop	92% *(N=85)*	88% *(N=91)*	-4
	Non-laptop	79% *(N=205)*	72% *(N=231)*	-7
NRT Mathematics	Laptop	93% *(N=85)*	89% *(N=91)*	-4
	Non-laptop	80% *(N=205)*	75% *(N=231)*	-5
CST ELA	Laptop	75% *(N=85)*	87% *(N=91)*	+12
	Non-laptop	67% *(N=205)*	68% *(N=231)*	+1
CST Math	Laptop	73% *(N=85)*	81% *(N=91)*	+8
	Non-laptop	62% *(N=204)*	59% *(N=232)*	-3

Notes: 1. GPAs and End-of-Course grades are not reported at grade 5.
2. Writing assessment changed from 6-point scoring rubric in 2001–02 to 4-point scoring rubric in 2003.
3. Norm-Referenced Test changed from SAT/9 in 2002 to CAT/6 in 2003.

Data presented in Table 11 indicate that Cohort 2 laptop students showed notable differences in both English-language arts and math achievement prior to enrolling in the program. After one year in the program, students in the Laptop Program experienced larger positive change in their CST English-language arts and math achievement than students not in the program. NRT results showed a decline in language and math scores for both groups.

A series of T-tests were conducted with cross-sectional data to investigate the significance of differences in student achievement in English-language arts and mathematics prior to, and one year after, enrolling in the program. Scaled scores were used for analysis. In addition, mean score differences in GPAs between laptop and non-laptop students were also compared in Year 2. Table 12 presents the results.

Table 12: Cross-Sectional Analysis of Cohort 2 Achievement by Program Enrollment

		Baseline (2001–02)		Year 1 (2002–03)		Year 2 (2003–04)	
Measure	**Statistics**	**Laptop**	**Non-Laptop**	**Laptop**	**Non-Laptop**	**Laptop**	**Non-Laptop**
STAR NRT Language Arts	Mean SS	689	681	701	680	698	688
	SD	28	37	46	43	35	45
	N	85	205	91	232	92	241
	F-value	3.12		0.81		2.86	
	p-value	p> .05 (NS)		p> .1 (NS)		p> .05 (NS)	
STAR NRT Mathematics	Mean SS	697	684	709	689	719	700
	SD	36	38	42	50	51	51
	N	86	206	90	232	92	241
	F-value	0.58		0.74		0.04	
	p-value	p> .1 (NS)		p> .1 (NS)		p> .1 (NS)	
STAR CST English-Language Arts	Mean SS	381	365	397	372	387	370
	SD	39	45	40	54	49	58
	N	85	204	91	232	92	240
	F-value	1.68		10.12		9.42	
	p-value	p>.1 (NS)		p<.005		p<.005	
STAR CST Mathematics	Mean SS	401	379	394	369	395	368
	SD	65	68	53	72	69	70
	N	85	205	91	231	92	241
	F-value	0.02		9.22		0.27	
	p-value	p>.1 (NS)		p<.005		p> .1 (NS)	
District Writing Assessment	Mean SS	3.5	3.5	3.0	2.9	*District writing assessment not offered at this grade level*	
	SD	0.8	0.9	0.5	0.6		
	N	82	193	72	210		
	F-value	2.79		7.73			
	p-value	p>.05 (NS)		p< .01			
Overall GPA	Mean SS	*GPAs not calculated at Grade 5*		3.48	3.15	3.28	2.94
	SD			0.50	0.79	0.60	0.81
	N			92	240	92	252
	F-value			19.97		12.06	
	p-value			p< .001		p< .005	

Baseline data show that the difference in both English-language arts and math performance between laptop and non-laptop students prior to enrolling in the program was not statistically significant. However, Year 1 results showed that laptop students, as compared to their non-laptop counterparts, demonstrated significantly higher achievement in CST English-language arts ($F=10.12$, $p< .005$) and CST mathematics ($F=9.22$, $p< .005$). The district writing assessment results for Cohort 2 were consistent with CST results. The cross-sectional mean comparison for writing achievement indicated that students' prior writing skills did not differ significantly, but laptop students demonstrated significantly higher achievement at the end of Year 1 ($F=7.73$, $p< .01$). However, STAR NRT scores for language arts and mathematics did not show any significant differences for all comparisons. Because overall GPAs are not calculated at Grade 5, baseline data was not available for comparison. Nevertheless, cross-sectional comparison between laptop and non-laptop students show that laptop students obtained significantly higher overall GPAs in both Year 1 ($F=19.97$, $p< .001$) and in Year 2 ($F=12.06$, $p< .005$).

Cohort 3 Analyses

Cohort 3 members were the sixth grade students in the 2003–04 school year who were enrolled in the program for one school year. Their baseline data came from the 2002–03 school year test scores, when students were in the fifth grade. STAR NRT and CST results in English-language arts and math, and district writing assessment results were used to evaluate student achievement. Table 13 presents student achievement results prior to enrolling, and after completing one year in the program.

Table 13: Prior Differences in Writing Achievement for Cohort 3 by Program Enrollment

		Baseline Data (Prior to Laptop Enrollment)	End of Year 1	Change
STAR NRT LA	Laptop	92% *(N=67)*	88% *(N=70)*	-4
	Non-laptop	81% *(N=202)*	78% *(N=228)*	-3
STAR NRT Math	Laptop	97% *(N=66)*	96% *(N=70)*	-1
	Non-laptop	83% *(N=203)*	83% *(N=235)*	0
STAR CST ELA	Laptop	89% *(N=66)*	80% *(N=70)*	-9
	Non-laptop	73% *(N=214)*	68% *(N=228)*	-5
STAR CST Math	Laptop	92% *(N=66)*	86% *(N=70)*	-6
	Non-laptop	71% *(N=214)*	66% *(N=228)*	-5
District Writing Test	Laptop	76% *(N=63)*	95% *(N=68)*	+19
	Non-laptop	68% *(N=210)*	79% *(N=230)*	+11

Results presented in Table 13 indicate that there were notable differences in achievement between laptop and non-laptop students in the baseline year. The change in scores after enrolling one year in the program provided mixed results. Whereas STAR CST and NRT scores did not show notable differences in achievement, laptop students showed a substantially more positive change in writing achievement after enrolling one year in the program. A cross-sectional comparison of mean scores was made to test the difference in achievement.

As seen in Table 14, results from the cross-sectional comparison of achievement for laptop and non-laptop students indicate that the differences at the baseline data were not statistically significant for all measures. However, laptop students showed significantly higher achievement in writing after the first year of enrollment in the laptop program ($F=4.02$, $p < .05$). STAR CST and NRT scores in English-language arts and mathematics indicate that there is no statistically significant difference in baseline achievement between laptop and non-laptop students. Whereas English-language arts scores did not show any statistical differences after enrolling one year in the program, laptop students demonstrated significantly higher math achievement in NRT ($F=5.09$, $p < .05$) and CST ($F=4.91$, $p < .05$) in Year 1. In addition, laptop students obtained significantly higher overall GPAs after their first year in the program ($F=17.29$, $p < .001$). Although there is no baseline data to conclude whether student achievement prior to the enrollment in the program had any impact on the higher overall GPAs, it is reasonable to expect that the baseline STAR results for this cohort and results from other cohorts are consistent with these findings.

(Table 14 is shown on the following page.)

Table 14: Cross-Sectional Analysis of Cohort 3 Achievement by Program Enrollment

		Baseline (2002–03)		Year 1 (2003–04)	
Measure	**Statistics**	**Laptop**	**Non-Laptop**	**Laptop**	**Non-Laptop**
STAR NRT Language Arts	Mean SS	690	681	704	691
	SD	30	39	49	44
	N	88	255	90	272
	F	3.57		1.46	
	p	*p*>.05 (NS)		*p*> .1 (NS)	
STAR NRT Mathematics	Mean SS	700	685	711	699
	SD	43	51	33	46
	N	88	256	90	273
	F	1.56		5.09	
	p	*p*>.1 (NS)		*p*<.05	
STAR CST English-Language Arts	Mean SS	387	374	389	371
	SD	37	43	44	51
	N	88	255	90	273
	F	2.60		1.57	
	p	*p*>.1 (NS)		*p*>.1 (NS)	
STAR CST Mathematics	Mean SS	428	394	403	380
	SD	65	76	53	66
	N	88	255	90	273
	F	2.17		4.91	
	p	*p*>.1 (NS)		*p*<.05	
District Writing Assessment	Mean SS	2.9	2.8	3.1	2.9
	SD	0.6	0.6	0.4	0.6
	N	86	244	89	261
	F	2.63		4.02	
	p	*p*>.1 (NS)		*p*<.05	
Overall GPA	Mean SS	*GPAs not calculated at Grade 5*		3.50	3.13
	SD			0.54	0.82
	N			90	279
	F			17.29	
	p			*p*<.001	

Model-Based Statistical Analyses

Analyses presented above compare performance of students at single points in time. In this section, more sophisticated statistical methods are employed to conduct longitudinal analyses of the effects of participation in the laptop program. This model-based statistical approach addresses the complications introduced by missing data and correlations among outcomes that may not be captured in cross-sectional analyses. For more information about the key issues of the model-based statistical approach and longitudinal data analysis, please see Technical Notes at the end of this paper.

The NRT mathematics and language arts scaled scores, and overall cumulative GPA scores, were used for analysis in this section. In addition, cumulative math GPAs were also incorporated into the longitudinal analysis. Student scores for this analysis were derived from the Cohort 1 and Cohort 2 students in the Laptop Program. These two cohorts were selected for analysis simply because scores were available longitudinally, providing the most comprehensive information about the long-term structure of learning outcomes. Furthermore, although SAT/9 and CAT/6 are different norm-referenced tests, SAT/9 2001 and 2002 scores were combined with CAT/6 2003 and 2004 scores because a linking study conducted by the California Department of Education (2003) indicates that the two tests measure comparable content knowledge. Also, the scores in the linking study exhibited similar trends, particularly at the seventh and eighth grade level from which CAT/6 scores were extracted for this analysis. In addition, the mean and median scores between CAT/6 and SAT/9 were nearly identical, with a correlation of approximately 0.7 between 2002 SAT/9 and 2003 CAT/6 scores. The longitudinal analysis of overall cumulative GPAs and math cumulative GPAs was based on data from 2002, 2003, and 2004.

Four separate analyses were conducted for each of the longitudinal math, language, and overall GPA scores. Linear Mixed-Modeling (LMM) software, developed by Schafer (1998), was employed to analyze repeated measures data (see Technical Notes). Results are presented in Table 15.

(Table 15 is shown on the following page.)

Table 15: Longitudinal Analysis of the Effect of Laptop Use on Individual Scores

	Indicator	Coefficient Cohort 1	Coefficient Cohort 2	Standard Error Cohort 1	Standard Error Cohort 2	t-ratio Cohort 1	t-ratio Cohort 2	*p* Cohort 1	*p* Cohort 2
Math	Intercept	685.93	680.59	2.78	2.98	247.09	228.31	0.000	0.000
	Year	9.42	8.94	0.75	1.29	12.57	6.94	0.000	0.000
	Laptop	15.50	17.21	5.96	5.56	2.60	3.10	0.009	0.002
	Year by Laptop	-1.16	1.95	1.55	2.37	-0.75	0.82	0.453	0.411
Language	Intercept	680.20	677.24	2.32	2.63	293.04	257.60	0.000	0.000
	Year	4.03	4.33	0.67	1.27	5.99	3.43	0.000	0.001
	Laptop	10.79	15.15	4.94	4.89	2.18	3.10	0.029	0.002
	Year by Laptop	0.69	-0.51	1.38	2.34	0.50	-0.22	0.620	0.827
Math GPA	Intercept	2.85	2.84	0.06	0.09	45.47	31.21	0.000	0.000
	Year	-0.16	-0.05	0.03	0.04	-5.28	-1.23	0.000	0.221
	Laptop	0.40	0.40	0.14	0.17	2.99	2.36	0.003	0.018
	Year by Laptop	-0.06	-0.01	0.06	0.08	-0.97	-0.15	0.332	0.884
Overall GPA	Intercept	3.12	3.33	0.04	0.06	75.48	57.36	0.000	0.000
	Year	-0.05	-0.20	0.01	0.02	-3.36	-8.37	0.001	0.000
	Laptop	0.34	0.34	0.09	0.11	3.70	3.06	0.000	0.002
	Year by Laptop	-0.08	0.01	0.03	0.05	-2.76	0.18	0.006	0.860

Notes: 1. The fraction of missing values for learning outcomes analyzed range from 5–25 percent.

2. For this analysis, population-averaged effects were included in the fixed effects component and subject-specific effects in the random component. For the random component of math and language scores, random slope and intercept for time trends were incorporated. For the fixed component, an intercept, Laptop Enrollment, Year, and Year by Laptop interaction were used.

3. Throughout the analysis, missing values were assumed to be Missing At Random. Multiple imputation (see Technical Notes), assuming Missing At Random, was also conducted (results are not shown for brevity) where missing values are replaced with multiple values with some plausible mechanism, and performed linear mixed modeling analysis for the completed datasets. Little or no discernible differences were found. This suggests that there is no systematic pattern of missing value occurrences.

Results presented in Table 15 indicate that laptop enrollment has a significant effect on mathematics and language scores. Specifically, participation in the laptop program is associated with an average per student gain of 16 points for mathematics scores and 13 points for language scores obtained from the state-mandated standardized NRTs. Year (number of years in the program) by laptop enrollment interaction results were not significant in both math and language arts results, suggesting that the effectiveness of laptop use on test scores is not influenced by time, once its overall effect is accounted for. Results also indicate that laptop enrollment seems to improve math cumulative GPA and overall cumulative GPA, yielding a 0.40 increase in math cumulative GPA and 0.34 increase in the overall cumulative GPA.

Discussion

Numerous studies have examined the link between technology use and its impact on student socio-emotional factors, such as student motivation, disruptive classroom behavior, classroom participation/engagement, and students' interaction with their peers or teachers (Rockman et al., 1997, 1998, 2000; Fisher & Stolarchuk, 1998; Harris & Smith, 2004; Shaver, 2004). Other studies have attempted to estimate the effect of technology use on student achievement in writing (Goldberg, Russell & Cook, 2003), science (Fisher & Stolarchuk, 1998; Gabel, 2004), foreign language (Met, 2004), and social studies (Shaver, 2004). The contribution of this study to the body of educational research is that it explored students' achievement with not just one indicator, but with multiple indicators of learning (state and district test results and overall grade point averages). The purpose of this study was to examine the effect of participation in a laptop immersion program on student achievement. Although students were not randomly assigned to participate in the laptop immersion program, an examination of indicators of achievement indicate that students who participated in the program and those that did not participate performed similarly prior to start of the laptop program. Analyses of outcome measures collected after participation in the laptop program, however, indicate that students who did participate in the program tended to earn significantly higher test scores and grades for writing, English-language arts, mathematics, and overall Grade Point Averages (GPAs).

The findings related to writing are consistent with results of a recent meta-analysis of studies that investigated the effect of computers on student writing (Goldberg, Russell & Cook, 2003). This meta-analysis found that students who use computers when learning to write are not only more engaged and motivated in their writing, but also produce work that is of greater length and higher quality, especially at the secondary level. The study presented above indicates that participation in the laptop immersion program had significant positive effects on students writing skills.

Due to the small sample size, this study did not analyze the data for special education students. However, laptop use with special education students certainly seems to be a promising classroom-instruction strategy and an avenue for future research. Laptop computers offer students with disabilities an opportunity for success that may not be otherwise offered. Laptops provide special education students an additional visual representation of learning material, which directly addresses the needs of these students. As evidenced by Goldberg, Russell and Cook (2003), the effect of computers on student writing had the strongest positive impact on students with disabilities. In addition, Harris and Smith (2004) found that teachers' rating of special education students' appropriate behavior, motivation, engagement/interest, independent work, and retention of material increased with their exposure to and use of laptop computers.

One limitation that might have a confounding effect on student achievement in this study is the teacher assignment into the Laptop Program. Participating teachers volunteer for the program. As with most field-based research in education, in the absence of random assignment into the program, the differences in student performance may be partly because of differences in teachers volunteering for this program.

A second limitation stems from the lack of data regarding the extent to which students used laptops for specific types of learning. As Bebell, Russell, and O'Dwyer (2004) demonstrate, technology can be used in many different ways by students and teachers. Depending upon how technology use is measured, the lessons learned from a study of technology can vary dramatically. In the study presented here, we know that students who participated in the laptop immersion program had full access to a laptop computer. Anecdotal evidence indicates that students did use the laptops for a variety of purposes. But, since we did not systematically collect information about how individual students used their laptops or other types of technology (e.g., desktop computers), we are unable to provide estimates of the effect of specific technology uses on student achievement.

Despite these shortcomings, this study provides evidence that participation in the laptop immersion program had a significant impact on student achievement. Given the cost of creating a one-to-one laptop environment, this finding raises important questions about equity. Clearly, school systems are not technologically or financially equal (Jameson, 1999). Inequities also exist between schools within the same district and within classrooms within the same school building. These inequities result from differences in funding, technical infrastructure, access to technology, instructional practices, and teachers' experiences. Given the potential benefits that may come from learning in laptop settings, it is important that schools begin taking steps to create more equitable settings with respect to technology access and skills. These steps include: (1) remediating students who lack experience with technology; (2) increasing teachers' technology skills; (3) providing students with greater access to a computer; and (4) developing teacher and student standards for technology proficiency. While concerns about technology equity often focus on the development of technology-related skills and preventing an information society that is divided into haves and have-nots, the findings from this study suggest that the digital divide may also create society that is divided by academic achievement. To increase the achievement of all students, findings from this study suggest that all students must have equal access to technology rich environments in which technology is no longer a shared commodity.

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Appendix A: Technical Notes

A key strength of repeated measurements (longitudinal) research is that this type of design makes it possible to obtain information concerning individual patterns of change. The main advantage is to economize on participants, using the maximum possible learning outcome data for each student. For example, when studying the effects of laptop use over time, it is usually desirable to observe the same participants repeatedly rather than to observe different participants at each specified time point. A final consideration is that data can often be collected more reliably in a study in which the same participants are followed repeatedly than in a cross-sectional study.

There is one major challenge to the analysis of data from repeated measures studies. Namely, the analysis is complicated by the dependence upon repeated observations made on the same experimental unit. The investigator often cannot control the circumstances in obtaining measurements, so the data may be unbalanced or partially incomplete. For example, in a longitudinal study, the response from a participant may be missing at one or more of the time points due to factors that may or may not be unrelated to the outcome of interest (Little & Rubin, 2002; Demirtas & Schafer, 2003).

Missing observations are common in longitudinal studies. In the presence of incomplete data, the risk of reaching incorrect conclusions is higher, because missing data may degrade the performance of confidence intervals, bias parameter estimates, and reduce statistical power. Handling incomplete data generally requires special techniques and inferential tools. The properties of missing-data methods depend on the manner in which data became missing; every missing-data technique makes implicit or explicit assumptions about the missing-data mechanism. Many missing-data procedures in use today assume that missing values are missing at random (MAR) (Rubin, 1976). Under MAR, the probability distribution of the indicators of missingness may depend on the observed data but must be conditionally independent of the missing data given the observed data. Intuitively, MAR means that once appropriate account is taken of what we have observed, there remains no dependence of the missingness on unobserved quantities. An important special case of MAR is missing completely at random (MCAR). Under MCAR, the response probabilities are independent of both the observed and unobserved random variables in the dataset. If MAR is violated, the response probabilities depend on unobserved data in some fundamental way. In this case, the missing values are said to be missing not at random (MNAR). MNAR situations require special care; to obtain correct inferences, one must specify a joint probability model for the complete data and the indicators of missingness.

Another important concept in the theory of missing data, closely related to MAR, is ignorability. Together with a minor technical condition called distinctness, a missingness mechanism is said to be ignorable when the missing values are MAR. Under ignorability, one does not need to explicitly model the missingness mechanism. In most cases, the plausibility of MAR cannot be verified nor contradicted by the examination of the observed data; it needs to be treated as an assumption (Little & Rubin, 2002).

Linear-mixed models (Laird & Ware, 1982; Verbeke & Molenberghs, 2000) have become very popular for analyzing incomplete repeated measures data. In linear-mixed models, the variation in participants' longitudinal profiles arises at two levels. In the first level, the vector of repeated measures for each participant is related to time and time-varying covariates by a relatively small number of estimated participant-specific regression coefficients. In the second level, one relates these coefficients to additional time-varying and static covariates such as the laptop group, baseline characteristics, gender and so forth. Additional levels of clustering can easily be handled by augmenting the model. The linear-mixed model paradigm combines these two or more stages into a single modeling procedure. These models are also known as multilevel models, random-coefficient models, random regression models and hierarchical linear models. In linear-mixed effects models, the vector of repeated measures on each participant follows a linear regression model where some of the regression coefficients are common to the population, whereas other coefficients vary by participant. In other words, one can model commonalities and heterogeneities among participants by separating participant-specific and population-averaged effects. The fixed effect design matrix contains the variables that are thought to estimate population-averaged effects, whereas the random effects design matrix is used to assess perturbations due to inter-participant variation. These regressor matrices do not assume any particular form, therefore the overall model can handle time-varying covariates and unequally spaced measurements. By varying forms of regressor matrices, one can test a wide range of hypotheses.

Imputation, the practice of filling in missing data with plausible values, is an attractive approach to analyzing incomplete data. It apparently solves the missing-data problem at the beginning of analysis. The question of how to obtain valid inferences from imputed data was addressed by Rubin's (1987) book on multiple imputation (MI). MI is a Monte Carlo technique in which the missing values are replaced by $m>1$ simulated versions, where m is typically small. In Rubin's method for repeated imputation inference, each of the simulated complete datasets is analyzed by standard methods, and the results are combined to produce estimates and confidence intervals that incorporate missing-data uncertainty.

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