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Simon J. Crook[a], Manjula D. Sharma[a] & Rachel Wilson[b]
[a] Sydney University Physics Education Research (SUPER) Group, The University of Sydney, 226E, Physics Building A28, Sydney, NSW 2006, Australia
[b] Faculty of Education & Social Work, The University of Sydney, Rm 526, Building A35, Sydney, NSW 2006, Australia
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An Evaluation of the Impact of 1:1 Laptops on Student Attainment in Senior High School Sciences

Simon J. Crook[a*], Manjula D. Sharma[a] and Rachel Wilson[b]
[a]*Sydney University Physics Education Research (SUPER) Group, The University of Sydney, 226E, Physics Building A28, Sydney, NSW 2006, Australia;* [b]*Faculty of Education & Social Work, The University of Sydney, Rm 526, Building A35, Sydney, NSW 2006, Australia*

Our study capitalized on a unique natural experiment rather than a researcher-designed, randomized experiment whereby, thanks to the Australian Government's Digital Education Revolution, half of grade 9 students in 2008 received laptops and half did not. Consequently in late 2011, when these students sat for their grade 12 external examinations based on the same curriculum implemented across the state of New South Wales, half of them had been schooled with 1:1 laptops for over three years, and half without. With school principals and district administrators asking the question 'what will these laptops do to our examination results?' this dichotomous scenario presented us with a unique opportunity to find out. The aim of this study was to evaluate if having 1:1 laptops was a predictor of success in the sciences in the external examinations. The science students ($N = 967$) from 12 high schools in Sydney, Australia were studied. Using socio-demographic, school and examination data, multiple regression analyses were performed to measure the impact of the 1:1 laptop provision and other variables on student attainment in biology, chemistry and physics. We found that being schooled with 1:1 laptops had statistically significant and positive standardized regression coefficients with student attainment, with a medium effect size in physics (0.38), and small effect sizes in biology (0.26) and chemistry (0.23). Upon further investigation, exploring data provided by student and teacher questionnaires, we found that the greater effect size in physics corresponded with greater use of simulations and spreadsheets by students and teachers.

Keywords: *1:1 Laptops; Australia; Digital Education Revolution; Science education; Student attainment*

*Corresponding author. Sydney University Physics Education Research (SUPER) Group, 226E, Physics Building A28, The University of Sydney, Sydney, NSW 2006, Australia. Email: simon@simoncrook.com

Introduction

In a time when data and testing are increasingly occurring across states, nations and even internationally, for example, Trends in International Mathematics and Science Study (TIMMS) and Programme for International Student Assessment (PISA), the interrogation of these data is not necessarily occurring at a level adequate to inform strategic directions of governments and local schools. More often, such data are used to provide metrics for school and system performance, and is often presented in a highly emotive fashion and viewed as threatening. In this paper, we interrogate the high-stakes data for the Higher School Certificate (HSC) examinations in New South Wales (NSW), Australia, with the intent of distilling insights that can be used to inform practice and guide the best use of the dollars invested in technologies in schools.

Individual schools and whole school districts are currently investigating the concept of 1:1 iPads® or tablets, particularly in science, technology, engineering and mathematics (STEM) education (Miller, Krockover, & Doughty, 2013; Weiss, 2013). Consequently, is there anything that can be learnt from recent 1:1 laptop initiatives that might better inform the decision-makers? Our study examines three science subjects studied in senior high school, and measures the impact of 1:1 laptops and other variables on student attainment within the different science disciplines using multiple regression analysis and effect sizes. Using student and teacher questionnaires, we drill down into the activities that give rise to the standardized regression coefficients and effect sizes calculated.

In their analysis of the criticism leveled at 1:1 laptop initiatives, Weston and Bain highlight the 'naked truth' that the fact that most 1:1 initiatives provide 'little or no sustained and scaled effects on teaching, learning, and achievement' is symptomatic of the failure of most educational initiatives period, aimed at change, innovation and reform (2010, p. 8). Regarding the nature of 1:1 laptop and educational technology research in general, it is argued that the 'overall lack of methodological precision and validity is of particular concern ... currently, decision makers contemplating the merits of educational technology are often forced to make decisions about the expenditure of millions of dollars with only weak and limited evidence' (Bebell, O'Dwyer, Russell, & Hoffmann, 2010, p. 47). A systematization of the most salient evidence about 1:1 initiatives by the Organisation for Economic Co-operation and Development (OECD) found that given the limited body of evidence there are many 'unsolved questions about the cost-effectiveness and educational impacts of 1:1 computing in education' (Valiente, 2010, p. 4).

The study presented here addresses these criticisms by providing an analysis of a 1:1 implementation that examines the learning outcomes of laptop introduction.

The Digital Education Revolution

The Australian Government initiated the National Secondary School Computer Fund (NSSCF) in 2008 as part of the Digital Education Revolution (DER). The objective was to create a 1:1 computer-to-student ratio for grades 9–12 in all schools within 5 years (Dandolopartners, 2013). Schools across the nation were split into 2 groups, Rounds 1 and 2. Round 1 schools equipped grade 9 with laptops from 2008. Consequently, by the time these students finished grade 12 in 2011, they had been schooled with 1:1 laptops, that is, they had ubiquitous access to their laptops at school and at home (Wurst, Smarkola, & Gaffney, 2008), for over 3 years. However, Round 2 schools only equipped grade 9 with laptops from 2009. Accordingly, the Round 2 2008 grade 9 cohort missed out, and were schooled through to grade 12, in 2011, without laptops.

In 2011, within the state of NSW, the Catholic Education Office (CEO) Sydney system of schools had representative schools in both rounds. During this time, all students sat for statewide, high-stakes, external, standardized examinations at the end of grade 10 (School Certificate (SC) including mandatory Science) and grade 12 (Higher School Certificate (HSC) examinations including optional sciences). Consequently, in 2011, CEO Sydney had the unique dichotomous scenario where half of its candidature for the grade 12 HSC had been schooled for over 3 years with 1:1 laptops, and half without (Crook, Sharma, Wilson & Muller, 2013). With school principals and district administrators asking the question 'what will these laptops do to our examination results?', this dichotomous scenario presented us with an interesting natural experiment to investigate (Murnane & Willett, 2011).

Review of the Literature

1:1 Laptop Initiatives

There have been many studies across the world of the various 1:1 laptop initiatives implemented by schools, sectors, states and even whole countries. Arguably, the most famous implementation, attracting the most research, was the Maine Learning Technology Initiative (MLTI), when in 2002 the state of Maine began issuing a laptop to every seventh- and eighth-grade student and their teachers (Berry & Wintle, 2009; Muir, Knezek, & Christensen, 2004; Silvernail, Pinkham, Wintle, Walker, & Bartlett, 2011). Overall, the Maine research found that the role of the teacher in integrating the use of laptops was key to any gain in student attainment. Findings from the state of Michigan's similar Freedom to Learn (FTL) 1:1 initiative, also launched in 2002, found that FTL students performed similarly to control students, but with greater acquisition of the twenty-first century skills (Lowther, Inan, Ross, & Strahl, 2012).

A recent report from the European Commission analyzed 31 recent 1:1 initiatives that involved approximately 47,000 schools and 17,500,000 students in K-12 education from across 19 European countries (Balanskat et al., 2013). Almost all of the initiatives in the European study found that motivation increased in 1:1 classrooms. There were also inconsistent reports of improvements in student-centered learning, teaching and learning practices and parental attitudes. The majority of studies showed that there were little or no increases in learning outcomes associated with these 1:1 laptop initiatives.

The most notable synthesis of 1:1 laptop initiatives was by Penuel (2006). Penuel found that 'outcome studies with rigorous designs are few, but those studies that did measure outcomes consistently reported positive effects on technology use, technology literacy, and writing skill' (p. 329). However, as Kposowa and Valdez point out, only one of the twelve studies Penuel examined was in a peer-reviewed journal (2013, p. 348).

In their commentary on various international 1:1 laptop programs, Zucker and Light (2009) emphasize that to achieve the desired impact on teaching and learning, more has to be done than simply providing laptops and the technical infrastructure; 'laptop programs will be most successful as part of balanced, comprehensive initiatives that address changes in education goals, curricula, teacher training, and assessment' (p. 82). Cognizant of this, our study also inquires into pedagogical shifts at schools implementing 1:1 laptops. While it is not possible here to review research on the effectiveness of the numerous pedagogical shifts possible with a 1:1 laptop implementation, one invaluable source is Hattie's (2009) exhaustive study of over 800 meta-analyses of pedagogies, characteristics and processes associated with educational effectiveness.

Quantitative Research: 1:1 Laptop Initiatives

Despite the large number of studies into the impact of 1:1 laptops, including the seminal ones outlined above, 'there is a paucity of research that examines their effectiveness, especially their impact on student academic achievement' (Kposowa & Valdez, 2013, p. 348). While there are many studies reporting on broad themes, such as impact on motivation, very few focus on learning outcomes. Within this paucity, there is even less research using in-depth quantitative analysis. One of the notable exceptions to this came from Bebell and Kay (2010). Bebell and Kay compared the students and teachers of five schools participating in the 1:1 laptop Berkshire Wireless Learning Initiative with two comparison schools. Comparing student and teacher survey results with test scores, Bebell and Kay performed bivariate correlation analyses. They also developed linear regression models to determine the overall program effect on student performance in the state standardized tests for English language arts (ELA) and mathematics. The 1:1 laptop student score increases were found to be statistically greater than those in the non-1:1 setting in ELA, but not mathematics. However, nearly all of the technology use measures were not statistically significant once prior attainment was accounted for.

Using an analysis of covariance approach, Dunleavy and Heinecke (2008) used a pretest–posttest control-group design to compare mathematics and science standardized test scores for students randomly assigned to 1:1 laptop classrooms with students in classrooms without 1:1 laptops in the same middle school. They found that 1:1 laptop instruction enhanced student science attainment, but there was no significant effect observed in mathematics attainment. The reasons for these results were inconclusive.

Gulek and Demirtas (2005) analyzed the data from grade point averages (GPAs), end-of-course grades, writing test scores, and state-mandated norm- and criterion-referenced standardized test scores in ELA, mathematics and writing for students (not randomly assigned) with and without 1:1 laptops in the same middle school. Using *t*-tests and longitudinal linear mixed-modeling, they found that students who participated in the 1:1 laptop program attained significantly higher test scores and grades for writing, ELA, mathematics and overall GPAs. However, the reasons why these significantly higher test scores occurred were not investigated since the researchers did not systematically collect information about how individual students used their laptops.

In their recent study into laptop use and standardized test scores, Kposowa and Valdez (2013) used bivariate and multiple regression analyses plus independent sample *t*-tests to examine data from an elementary school. Their results in general reported that students with 1:1 laptops performed significantly better than those without in ELA, mathematics and science.

Among the various extant literature, the findings regarding the impact of 1:1 laptops on student attainment are inconclusive and inconsistent. Most of the research has been around ELA and mathematics, usually within middle school. There is a need for more research around 1:1 laptops within the sciences and within senior school. In terms of a quantitative approach, studies employing multi-level modeling and/or structural equation modeling would be of benefit to the field. However, these approaches are not always possible, given the contexts (or in the case of this study, the natural experiments) presented.

Laptops in Science

Regarding the use of laptops specifically in science, there is some extant literature. In their study of the Denver School of Science and Technology, Zucker and Hug found that 1:1 laptops provided physics students with high-quality tools to explore scientific concepts (2007, 2008). In a study of 25,000 teachers and students in grades 6–12 in Henrico County Public Schools in Virginia, Zucker and McGhee (2005) found that most of the teachers they 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' (p. 12).

As part of the MLTI research, Berry and Wintle (2009) used a variety of activities and pretest and posttest results to compare students instructed with and without laptops. They found higher levels of comprehension, retention and engagement in those students studying science with laptops. In an interesting change of emphasis, it has also been found that performing scientific inquiry on laptops and computers and providing the academic context can increase proficiency in the use of technology (Ebenezer, Kaya, & Ebenezer, 2011). However, as highlighted earlier, there is a relative void regarding 1:1 laptop research in a science context, particularly in sciences other than physics.

Quantitative Research: Capitalizing on the use of high-stakes examination data

As mentioned, quantitative research within the school setting has been summarized by Hattie (2009). However, in terms of outcomes, what the students learnt, the literature is more limited. At the international level, PISA and TIMMS provide benchmarks and comparisons (Martin & Mullis, 2013; OECD, 2010b). Large-scale national and state examinations can also provide large sample sizes that should be analyzed to determine whether certain large-scale interventions or processes have impacted outcomes. For example, in NSW in Australia, the statewide examination results could be correlated against state or national initiatives such as the DER. If one had access to this large data set and could correlate with local interventions, one could analyze and establish the success or otherwise of these interventions. Furthermore, in this digital age, students and teachers can more readily provide data of practices through online means (Howard & Carceller, 2011). This has the potential to provide holistic rich quantitative data on outcomes as well as processes to better inform future policies and practices.

Purpose of the Study

In view of the extant literature, this paper is positioning itself to fill some of the voids identified and provide an in-depth quantitative analysis to explore correlations between the use of 1:1 laptops and student attainment in the senior high school science subjects of biology, chemistry and physics, across a large sample size of students from a good number of schools, using data from high-stakes standardized external examinations. Data provided by the students and teachers in exit questionnaires are used to drill down into and identify any pedagogies and activities that emerge that might explain any correlations and nuances.

Research Questions

(1) Does learning within a 1:1 laptop environment affect senior high school student attainment in statewide-examined biology, chemistry and physics?
(2) If there is an effect, what are the types of use of the laptops that might indicate the advantage the 1:1 laptops afford?

Methods

Socio-demographic and Technological Data for Schools and Students

The students from 12 comprehensive high schools in CEO Sydney of varying socio-economic, gender and grade profiles were studied. These schools were split into Round 1 ($n = 7$) and Round 2 ($n = 5$), ostensibly based on need. However, as is discussed below, the resulting split was somewhat arbitrary with equivalence across both groups in terms of their socio-demographic and technological profiles.

As can be seen in Table 1, both groups, schools with and without laptops, were roughly equivalent in terms of school type, socioeconomic status and their spread in prior attainment. Considering the technological data, an average of 94% of students with DER laptops reported having access to a computer other than their issued laptop (in fact, the school that reported 80% was very much an outlier with the next lowest figure being 94%), and an average of 98% reported having access to the Internet. Impressively, 100% of the students without laptops reported having access to a computer at home, and again, 100% reported having access to the Internet at home. These results are not too dissimilar to those reported for Australian students by OECD (2010a), based on 2006 data, of 96.3% and 91.9% for home computer and Internet access, respectively; and the Australian Bureau of Statistics (2012), based on 2010–2011 data, reported 94.7% and 92.6% for home computer and Internet

Table 1. Socio-demographic and technological data for schools and students

Schools with laptops	There were 7 schools with laptops: 2 boys', 1 girls' and 4 co-educational schools; the schools ranged in socioeconomic status[a] from 980 to 1088; the total number of grade 12 HSC science students within these schools ranged from 65 to 201; the schools' average score for grade 10 SC Science[b] (an indicator of prior attainment) ranged from 77.9 to 84.8 Regarding access to technology, for the schools with laptops, the proportion of students with access to another computer at home ranged from 80% to 100%; the proportion of students with access to the Internet at home ranged from 94.7% to 100%. Prior to the DER, the computer-to-student ratio[c] for the schools that did receive laptops in Round 1 ranged from 1:3 to 1:9
Schools without laptops	There were 5 schools without laptops: 1 boys', 0 girls' and 4 co-educational schools; the schools ranged in socioeconomic status[a] from 998 to 1071; the total number of grade 12 HSC science students within these schools ranged from 32 to 76; the schools' average score for grade 10 SC Science[b] ranged from 74.6 to 88.2 Regarding access to technology, for the schools without laptops, 100% of all students had access to a computer at home; equally, 100% of all students had access to home Internet. Prior to the DER, the computer-to-student ratio[c] for the schools that did not receive laptops in Round 1 ranged from 1:2 to 1:3
Summary	The two groups of schools, with and without laptops, are very similar in terms of gender profiles, range of socioeconomic status and prior attainment as indicated by grade 10 SC Science scores; the main differences are that there was only one girls' school (they had laptops), the schools without laptops had smaller cohorts of students, the schools without laptops had greater access to a home computer and home Internet and the schools without laptops already enjoyed a far better computer-to-student ratio within school

[a]The school socioeconomic status (SES) was obtained from the Index of Community Socio-Educational Advantage for 2011 as presented on the MySchool website (http://www.myschool.edu.au/).

[b]Grade 10 School Certificate (SC) Science score out of 100—a measure of prior attainment.

[c]Computer-to-student ratios calculated following a 2007 audit by comparing all computers within a school, whatever the age of machine, with the total number of students.

access for families with children. It is interesting to observe that families where the child received a DER laptop were slightly more likely to have home Internet than another home computer. It can be surmised that some families undertook to provide home Internet to capitalize on their child receiving a DER laptop. In a similar vein, with 100% of students who did not receive a DER laptop having both home computer and Internet access, it can be surmised that at least some families compensated on missing out on a DER laptop by providing a home computer and the Internet; the families were proactive in eradicating any perceived digital divide (Vigdor & Ladd, 2010; Warschauer, Zheng, Niiya, Cotten, & Farkas, 2014).

Although the Australian Government dictated the splitting of schools into Rounds 1 and 2, for this sample of 12 schools, the split was somewhat random in terms of their socio-demographic profiles and not too varied in terms of their technological profiles.

Procedure

A total of 759 individual students studied the various science subjects within the sample schools. With a number of students studying more than one science, this presented a total of $N = 967$ 'students-within-subject'. The subjects were analyzed separately; hence, the data for a student in two or more subjects were mutually exclusive. As a consequence, for the ease of the reader, the term 'students' is used in place of 'students-within-subject'. The data for every student, $N = 967$ (see External Database S1 in the supplementary materials), were collected for the 5 sciences studied in the senior years of high school in NSW: biology, chemistry, physics, senior science, and earth and environmental science. All five subjects are included when calculating the number of sciences studied. The curricula for all of the subjects are statewide (Board of Studies NSW, 2009) and followed by all students within the subjects, irrespective of access to laptops.

Within this study, a combined approach of three methods used in conjunction with each other was used: (a) multiple regression analysis of natural, non-researcher-influenced, high-stakes examination data; (b) calculation of effect sizes using the same examination data; and (c) exit questionnaires of student and teacher practices. The analysis of classroom practices as found by the questionnaires was used to help explain the significant correlations and nuances found in the multiple regressions and effect sizes.

It is important to note that this was not a researcher-designed randomized experiment. As already highlighted, the dichotomous scenario was imposed arbitrarily by external agencies (the Australian Government). As a consequence, the considerable design and methodology that would normally be present to achieve the randomization (Murnane & Willett, 2011) were not possible in our study. However, by definition, they were superseded by the natural experiment itself.

Multiple regression of natural experiment data. The data were used to generate variables (discussed below) to be used in a multiple regression analysis: z-score of the examination mark for the respective grade 12 HSC science subject (*ZA12HSC*); *z*-score of the examination mark for the prior grade 10 SC science (*ZA10SC*); number of sciences studied (*NSciences*); socioeconomic status (*SES*); and dummy variables for 1:1 laptops (*Laptop*); boys' school (*BoysS*); girls' school (*GirlsS*); gender (*Gender*); and senior school (*SeniorS*). Details regarding the variables can be found in Table 2.

These data were historical and readily available to those with access rights, that is, they were natural data without any influence from researchers. Bivariate correlation analysis (Table 3) was used to examine the variables and determine an appropriate regression model. The multiple regression assumptions were also checked through residual analysis to confirm that the data were appropriate for regressing.

In every subject, there were statistically significant associations of varying magnitudes between some of the variables. To treat each subject to the same initial regression, we retained the variables in all subjects. *ZA12HSC* was required as the independent variable and measure of student attainment in each subject. *ZA10SC*, as a measure of prior attainment, not surprisingly, had highly significant and sizeable correlation with *ZA12HSC* in every subject. Being the main focus of this study, *Laptop* needed to be included in the regression for every subject. *NSciences* provided an interesting discriminator for enculturation in the study of sciences (unpacked in Results and Discussion). *BoysS*, *GirlsS* and *SeniorS* provided discriminators, given the spread of profiles in the schools. As an educational analysis, we were obliged to include *Gender* and *SES*. Initial consideration might elicit a response of collinearity between *Gender* and *BoysS*/*GirlsS*. However, given that some students were in single-sex schools and the others in coeducational schools, it was appropriate to include all three variables.

Table 2. Variables used in the multiple regression

Variable	Overview for 12 schools; $N = 967$ students
ZA12HSC	see External Database S1
ZA10SC	see External Database S1
Laptop	710 with laptop; 257 without
NSciences	1 subject: $n = 565$; 2 subjects: $n = 360$[a]; 3 subjects: $n = 42$[b]
BoysS	3 boys' schools[c]; $n = 227$
GirlsS	1 girls' school[c]; $n = 65$
Gender	$n = 380$ girls; $n = 587$ boys
SeniorS	2 senior schools, grades 11–12[d]; $n = 266$
SES	see Table 1

[a]180 students studying 2 subjects presented 360 students-within-subject.

[b]14 students studying 3 subjects presented 42 students-within-subject.

[c]c.f. 8 coeducational schools.

[d]c.f. 10 grade 7–12 schools.

Table 3. Bivariate correlations of variables

	ZA12HSC	*ZA10SC*	*Laptop*	*NSciences*	*BoysS*	*GirlsS*	*Gender*	*SeniorS*	*SES*
Biology									
ZA12HSC	1.000	0.757**	0.114*	0.290**	−0.160*	−0.108*	0.070	0.156**	0.250**
ZA10SC		1.000	0.018	0.239**	−0.268*	−0.138*	0.092	0.258**	0.311**
Laptop			1.000	0.098	0.060	0.210**	0.028	0.378**	0.051
NSciences				1.000	−0.013	−0.068	−0.135*	0.150**	0.064
BoysS					1.000	−0.183**	−0.562**	−0.329**	−0.377**
GirlsS						1.000	0.325**	−0.213**	−0.475**
Gender							1.000	0.124*	0.090
SeniorS								1.000	0.539**
SES									1.000
Chemistry									
ZA12HSC	1.000	0.558**	0.106	0.054	0.089	−0.130	−0.149*	0.045	0.075
ZA10SC		1.000	−0.217**	−0.066	−0.116	−0.082	−0.085	0.038	0.143
Laptop			1.000	0.107	−0.070	0.213**	0.199**	0.374**	−0.028
NSciences				1.000	0.052	−0.076	−0.114	0.077	−0.031
BoysS					1.000	−0.180*	−0.438**	−0.317**	−0.431**
GirlsS						1.000	0.411**	−0.180*	−0.477**
Gender							1.000	0.143	0.025
SeniorS								1.000	0.407**
SES									1.000
Physics									
ZA12HSC	1.000	0.597**	0.176*	0.418**	0.112	−0.038	0.095	0.159*	−0.019
ZA10SC		1.000	−0.048	0.290**	−0.093	0.009	0.165*	0.068	0.100
Laptop			1.000	0.084	−0.009	0.179*	0.138	0.281**	0.014
NSciences				1.000	−0.067	0.042	0.257**	0.142	−0.014
BoysS					1.000	−0.161*	−0.311**	−0.254**	−0.510**
GirlsS						1.000	0.520**	−0.101	−0.373**
Gender							1.000	0.171*	−0.092
SeniorS								1.000	0.242**
SES									1.000

$^{*}p < 0.05$.

$^{**}p < 0.001$.

The relationship to be regressed for each subject is described by Equation (1).

$$ZA12HSC = f\,(ZA10SC, Laptop, NSciences, BoysS, \\ GirlsS, Gender, SeniorS, SES). \tag{1}$$

For each of the three sciences, a multiple regression analysis was performed, gradually removing non-significant variables ($p > 0.05$) to leave optimal regressions for each subject, that is, all variables were significant ($p <.05$).

Effect sizes of natural experiment data. Within secondary education, rather than utilizing regression correlation coefficients, academics and policy-makers tend to compare effect sizes. Often, these are benchmarked against those collated by Hattie (2009) from more than 800 meta-analyses. Using the 'pooled' standard deviations (Field, 2013) for the full data sets for each subject, the effect size of introducing 1:1 laptops was calculated for each science subject.

Questionnaire. For this paper, we sought student and teacher responses via questionnaires in terms of what students and teachers used their computers for (Beckman, Bennett, & Lockyer, 2014), comparing between classes where students had 1:1 laptops and those without. It should be noted that all teachers had personal laptops provided for them by their schools whether their students received laptops or not.

For the students with laptops, the questionnaire asked a variety of questions about the frequency and types of use of the laptops, in school and at home for the various sciences. For the students without laptops, similar questions were asked regarding the frequency and types of use of school computers within their science subjects. In addition, questions were asked about the frequency and types of use of any computers at home for science study. Teachers were asked near identical questions to those of the students in terms of their own practices. The questions analyzed in this paper can be found in the supplementary materials.

The questionnaires were administered online during the last month of their HSC curriculum and two months prior to the students sitting their final examinations in 2011. The questionnaires were administered via *Google Doc Forms* for ease, efficiency, security (128-bit encryption), anonymity and minimizing errors due to transcription.

Results and Discussion

Multiple Regression of Natural Experiment Data

The outputs for the multiple regression analyses are presented in Table 4. For completeness, the standard errors are included for unstandardized coefficients; both the unstandardized and standardized coefficients are used in the discussions.

The results show some interesting consistencies and contrasts. All subject models have significance throughout ($p < .05$, in fact mostly $p < .001$, that is, highly

Table 4. Multiple regression output by subject

	Unstandardized coefficients		Standardized coefficients	
	B	*Standard error*	*β*	*p*
Biology $n = 340$ $R^2 = 0.61$ $SEE = 0.63$				
ZA10SC	0.849	0.043	0.738	<0.001
Laptop	0.330	0.085	0.146	<0.001
NSciences	0.229	0.065	0.125	0.001
SeniorS	−0.368	0.102	−0.163	<0.001
SES	0.003	0.001	0.092	0.030
Chemistry $n = 181$ $R^2 = 0.40$ $SEE = 0.78$				
ZA10SC	0.890	0.085	0.634	<0.001
Laptop	0.560	0.129	0.260	<0.001
BoysS	0.403	0.138	0.172	0.004
Physics $n = 178$ $R^2 = 0.51$ $SEE = 0.70$				
ZA10SC	0.799	0.081	0.554	<0.001
Laptop	0.424	0.112	0.205	<0.001
NSciences	0.423	0.094	0.253	<0.001
BoysS	0.486	0.118	0.221	<0.001

significant, even by recent, more stringent standards (Johnson, 2013)). In biology and physics, these models account for over 50% of the variability in student attainment ($R^2 = 0.61, 0.51$, respectively). Similarly, the standard errors of the estimate (*SEE*) are quite respectable, that is, each model performs its predictive capacity within 0.63–0.78 standard deviations. In all three subjects, prior attainment in science (*ZA10SC*) is the greatest predictor of higher level science attainment (β is greatest for *ZA10SC* in all cases). This is to be expected from the extant literature (Martin, Wilson, Liem, & Ginns, 2013; Sadler & Tai, 2007).

Of particular interest to this study is that being schooled with 1:1 laptops is significant in each of biology, chemistry and physics. Of equal importance, in each case, 1:1 laptops have a sizeable, standardized regression (β) coefficient, that is, 1:1 laptops correlate with greater student attainment in biology, chemistry and physics, in the schools studied, in 2011. In biology, chemistry and physics, the unstandardized coefficient for 1:1 laptops is $B = 0.330$, 0.560 and 0.424, respectively. This means that having a 1:1 laptop increased *ZA12HSC* (z-score of grade 12 HSC attainment) by 0.330 in biology; in other words, this increased a student's attainment in the external standardized biology examination by around one-third of a standard deviation. In terms of raw scores (out of 100), this corresponded to an increase in 3 marks (see Table 5). In chemistry, having a 1:1 laptop accounts for over half of a standard deviation increase in attainment, or 5 marks. In physics, it is over 40% of a standard deviation or about $3\frac{1}{2}$ marks.

Socioeconomic status of the school (*SES*) only features in biology and with a very small standardized regression coefficient (smallest β). This goes against most extant literature (Gorard & See, 2009; Sirin, 2005). However, it is recognized that CEO

Table 5. Examination raw score descriptives by subject

Subject	*A10SC* mean	*A10SC* SD	*A12HSC* mean	*A12HSC* SD
Biology	82.2	7.0	74.7	9.9
Chemistry	87.5	5.7	78.5	8.9
Physics	86.7	5.5	77.7	8.5

Sydney has made substantial and concerted investment in low SES schools, possibly explaining this result (Australian Government, 2011; Cardak & Vecci, 2013). Similarly, student gender does not feature as being statistically significant (Hyde & Linn, 2006). However, attending a boys' school is significantly positive when studying chemistry and physics ($B = 0.403, 0.486$, respectively), suggesting the importance of the peer effect for boys in these traditionally male subjects rather than simply gender per se (Archer, DeWitt, & Willis, 2013). Attending a girls' school was non-significant, although given that there was only one girls' school, we cannot comment in any way conclusively.

Interestingly, attending a senior school had a negative impact on student attainment in biology ($B = -0.368$). This would appear to imply that in this subject, with traditionally greater female representation, both boys and girls perform less well in a new coeducational environment after attending single-sex schools for grades 7–10, as was the case here. This is in contrast to the extant literature (Lavy & Schlosser, 2011).

The number of science subjects studied (*NSciences*) was an interesting variable to include. It can be conceived of as a proxy for interest and enculturation in the sciences (Fullarton, Walker, Ainley, & Hillman, 2003; Sadler & Tai, 2007). While *NSciences* was significantly positive in biology and physics ($B = 0.229, 0.423$, respectively), it was non-significant in chemistry. Students often pair physics with chemistry; or biology with chemistry; rarely studying physics with biology (Fullarton et al., 2003). One speculative perspective would be that studying chemistry in parallel with either biology or physics does provide a level of enculturation in the sciences benefitting both physics and biology. However, this makes the chemistry cohort somewhat disparate resulting in *NSciences* not being significant for chemistry and a poor fit for the chemistry model as a whole (low R^2).

Effect Sizes of Natural Experiment Data

The effect sizes, also known as Cohen's *d* (Cohen, 1988), for the impact of 1:1 laptops on student attainment were calculated for biology (0.26), chemistry (0.23) and physics (0.38) using 'pooled' standard deviations. With effect sizes of 0.26 and 0.23, respectively, the impact of 1:1 laptops in biology and chemistry would be considered small (Hattie, 2009). However, with an effect size of 0.38, the impact of 1:1 laptops in physics would be considered medium. In fact, this is very close to Hattie's average effect size of 0.40 relating to student achievement. Of particular interest are comparable effect sizes. For example, within the context of our study, studying biology or chemistry with 1:1 laptops corresponds to a slightly higher effect size than reducing class sizes ($d = 0.21$). Whereas, the use of 1:1 laptops in physics is comparable with time on task ($d = 0.38$), attitude to science ($d = 0.36$) and science curricula programs ($d = 0.40$). Of particular note and adding validity to our findings, Hattie finds that the average effect size for computer-assisted instruction is 0.37; this average effect is usually observed in experimentally controlled and targeted intensive educational interventions. Hattie remarks that most of the research examines dichotomous scenarios, that is, with or without certain technology interventions. While this study is dichotomous, an important distinction is that the dichotomy was imposed by external agencies, that is, the Australian Government, thereby creating a natural experiment rather than a researcher-designed randomized experiment (Murnane & Willett, 2011). In a meta-analysis of 61 studies from the USA, specifically regarding the effects of teaching strategies on student achievement in science, the average effect size for instructional technology (i.e. the use of computers in classroom teaching) was 0.48 (Schroeder, Scott, Tolson, Huang, & Lee, 2007).

Comparing within, it is interesting to note the substantially larger effect size of 1:1 laptops in physics compared to biology and chemistry. Finding a difference between subjects is to be expected when considering the extant literature (Bebell & Kay, 2010; Dunleavy & Heinecke, 2008). Analyses of the questionnaires shine light on this result.

Questionnaires

For the questionnaires, the response rate for all science students was 54% (522 out of 967). For all science teachers, the response rate was 75% (47 out of a possible 63). These response rates far exceed the average response rate for online surveys of 25% (Kaplowitz, Hadlock, & Levine, 2004). The sample size is large capturing the diversity in the sample.

Having found significant, positive standardized regression coefficients for 1:1 laptop schooling in biology, chemistry and physics (Table 4), we looked to the questionnaire data to see if there were any differences in practice apparent between those students with laptops and those without, similarly with the teachers of those classes, and also between subjects.

Table 6 shows the percentage of students who used their laptops (or school/home computers where they had no laptops) for various activities/applications by subject. We first compared with and without laptops for the subjects as presented in the differences, Δ. Biology has the greatest spread in differences of use, that is, there are many negative values as well as positive. Chemistry has almost as many negative differences as Biology, though not as large a spread. Physics has consistently positive differences. By simply observing the grayed out values, we observe that physics has most differences grayed out, with six $10 < \Delta < 20$ and six $\Delta > 20$, including the five largest differences of all of the subjects. Biology, has the next largest values with two $10 < \Delta < 20$, one $\Delta > 20$ and, interestingly, one $\Delta < -20$ for electronic text books. Chemistry has two $\Delta > 20$ and, surprisingly, one $\Delta < -20$ for simulations. These results are

Table 6. Percentage student use of applications with and without laptops by subject

Application	Biology			Chemistry			Physics		
	Laptop	No laptop	Δ	Laptop	No laptop	Δ	Laptop	No laptop	Δ
Word processing	93.3	93.4	−0.1	89.6	91.9	−2.3	91.9	87.1	4.8
Spreadsheets	15.7	17.1	−1.4	28.6	21.6	7.0	41.9	3.2	38.7[a]
Presentations	60.4	56.6	3.8	42.9	24.3	18.6	67.7	41.9	25.8
Simulations	18.7	21.1	−2.4	27.3	37.8	−10.5	59.7	29.0	30.7[a]
Science software	11.2	15.8	−4.6	18.2	27.0	−8.8	32.3	12.9	19.4
Text book[b]	62.7	82.9	−20.2[c]	72.7	78.4	−5.7	69.4	45.2	24.2
Wiki	42.5	26.3	16.2[d]	28.6	13.5	15.1	41.9	12.9	29.0[a]
Blogs	3.0	9.2	−6.2	0.0	8.1	−8.1	14.5	0.0	14.5
Internet research	83.6	89.5	−5.9	85.7	81.1	4.6	85.5	71.0	14.5
LMS[e]	63.4	57.9	5.5	51.9	56.8	−4.9	46.8	19.4	27.4
Video editing	30.6	13.2	17.4	9.1	0.0	9.1	29.0	9.7	19.3
Podcasting	6.0	1.3	4.7	10.4	5.4	5.0	12.9	6.5	6.4
Databases	5.2	3.9	1.3	3.9	0.0	3.9	8.1	0.0	8.1
Email	56.0	31.6	24.4	44.2	37.8	6.4	41.9	25.8	16.1
Datalogging	9.7	5.3	4.4	7.8	2.7	5.1	14.5	0.0	14.5

[a]top three most sizeable differences.
[b]electronic text book.
[c]dark gray represents differences $\Delta < -20$, $\Delta > 20$.
[d]light gray represents differences $-20 < \Delta < -10$, $10 < \Delta < 20$.
[e]LMS = Learning Management System: MyClasses®.

consistent with the effect sizes calculated from the natural data where physics has a far greater effect size, with biology slightly larger than chemistry. As mentioned earlier, finding differences between subjects is to be expected from the extant literature.

An obvious prediction might be that students with laptops would engage in much more computer-based activities than those without. However, upon inspection, this is not always the case; the students without laptops were still able to participate in a variety of computer-based activities, sometimes more, particularly in Biology and Chemistry, using school and/or home computers. Considering that the largest differences and the largest effect size were for physics, it is necessary to explore why physics is advantaged. The 3 largest differences in physics are particularly interesting: spreadsheets (38.7), simulations (30.7) and wikis (29.0). These are considered high-order activities (Crook & Sharma, 2013). Importantly, given that the access to computers for students without laptops is not as diminished as one might first think, the major differences would therefore appear to be related to classroom pedagogy (Hennessy, Deaney, & Ruthven, 2006). The use of spreadsheets and simulations in particular would be considered activities associated with higher order thinking skills, beneficial to the study of science (Huppert, Lomask, & Lazarowitz, 2002; Khan, 2010; Lindgren & Schwartz, 2009; Smetana & Bell, 2012). This is particularly the case with physics (Tambade, 2011; Wieman, Adams, & Perkins, 2008; Zucker & Hug, 2007, 2008). Within the 1:1 laptop physics classes, it would appear that there were greater opportunities for students to experience phenomena and perform experiments individually through simulations, represent and analyze data through spreadsheets, and collaborate and co-construct knowledge through wikis (Ruth & Houghton, 2009). We must also consider that the physics teachers may have had greater readiness and stronger belief systems around using the laptops with their students (Campbell, Zuwallack, Longhurst, Shelton, & Wolf, 2014; Howard, Chan, & Caputi, 2014).

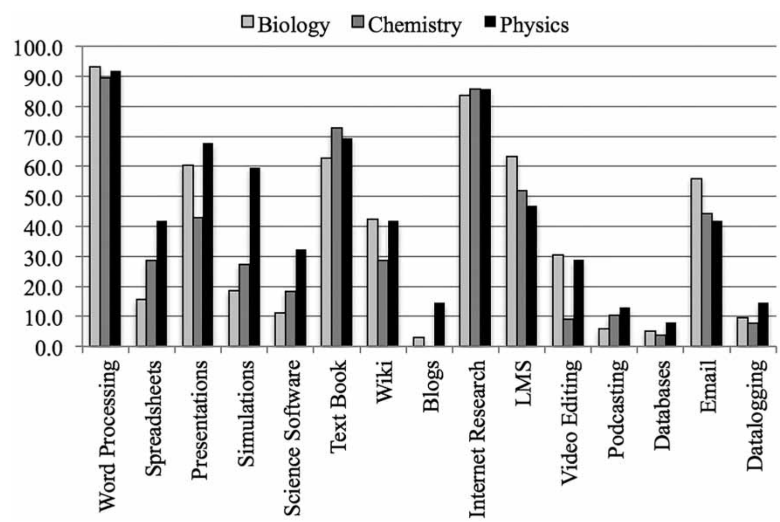

Figure 1. Student-reported percentage use of applications for students with laptops by subject

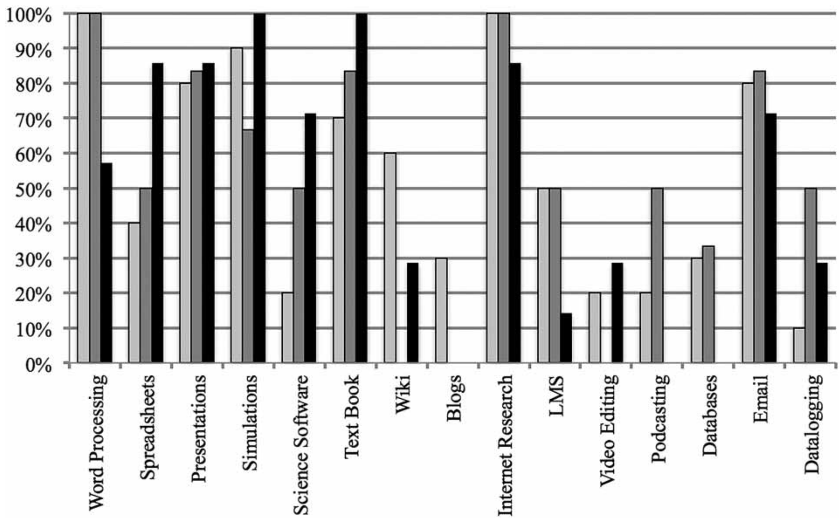

Figure 2. Teacher-reported percentage use of applications with classes with laptops by subject

Similarly, examining Figure 1, we can see that in terms of percentage use of applications for all students with laptops compared by subject that students in physics greatly out-report students in biology and chemistry in the use spreadsheets and simulations.

In terms of teachers' self-reported practices, in Figure 2 far more physics teachers of 1:1 laptop classes report using spreadsheets than biology or chemistry teachers, and 100% of physics teachers report using simulations with their 1:1 laptop classes. Importantly, but not surprisingly, these results concur with the students' self-reported uses.

Given the evidence from student and teacher responses regarding the activities engaged in by students (and teachers) on laptops, the substantially larger use of simulations and spreadsheets in 1:1 laptop classes in physics would appear to explain the far greater effect size of 1:1 laptops in physics.

Conclusion

Responding to the albeit blunt question at inception from school principals and district administrators, we have found that the roll out of the 1:1 laptops by CEO Sydney was certainly not detrimental to student attainment in the science subjects. In fact, there was a positive impact on student attainment in each of physics, biology and chemistry. As part of a $2.1 billion national DER initiative, the statistically significant and substantial standardized regression coefficients and effect sizes present policy-makers with some positive findings. Questions have also been asked regarding the cost-effectiveness of the DER. For the sample within this study, considering that most students already had access to computers at home and all had some level access to computers within their schools, one could argue that the DER was not cost-effective at AU$1,000 per student. However, regarding the impact of 1:1 laptops on student attainment in the sciences, even though the effect sizes were small to medium, the average net increase in examination score of three to five marks may have had considerable impact on the futures of the students. In NSW, although the examination marks are out of 100, they are more effectively out of 50–100, with students achieving ‘bands’ covering 10-mark ranges, that is, Band 2 (the minimum standard expected) corresponds to 50–59 marks, Band 3 corresponds to 60–69 marks; continuing in this fashion to Band 6: 90–100 marks (Board of Studies NSW, 2013). Therefore, an average increase of three to five marks could easily shift a student’s band, thus increasing their employment and university entry prospects.

We are not suggesting that by simply issuing students with a laptop they will perform better (Fullan, 2011). However, we would argue that associated with this particular laptop initiative, the 1:1 laptop environment provided the catalyst for a paradigm shift (Kroksmark, 2014; Weston & Bain, 2010), providing students with the opportunities for more student-centered and personalized learning (Granger et al., 2012; Odom, Marszalek, Stoddard, & Wrobel, 2011). Specifically in this study, it would appear that the more substantial effect size for laptops in physics is due to new pedagogies capitalizing on the affordances of the 1:1 laptop environment for student-centered, personalized learning, particularly in the use of simulations and spreadsheets. This raises the need for alignment of the use of new pedagogies with curriculum and assessment to ensure that their use is valued and there is payoff in terms of student attainment (Silvernail et al., 2011) for the sizeable cost of investment (Zucker & Light, 2009). The cost of professional development in this area would also need to be factored into any assessment of cost-effectiveness.

Additional research is required to further investigate *how* students use laptops and how these different factors affect student attainment (Crook et al., 2013; Crook & Sharma, 2013; Howard & Rennie, 2013). Within Australia, it would be beneficial to perform both statewide and national quantitative studies of the DER, on top of those performed at a system level such as this paper. Equally, the extant literature and the findings in this study pertain primarily to physics. Further research is required to look at the similarities and differences between integrating technology in biology, chemistry and physics and how best to leverage technology in biology and chemistry as well as physics.

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Supplemental data

Supplemental data for this article can be accessed at http://dx.doi.org/10.1080/09500693.2014.982229.

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