Computers and Student Learning: Interpreting the Multivariate Analysis Of PISA 2000

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In November 2004, economists Thomas Fuchs and Ludger Woessmann published a statistical analysis of the relationship between technology and student achievement using year 2000 data from the Programme for International Student Assessment (PISA). The 2000 PISA was the first in a series of triennial assessments of 15-year-olds conducted by the Organisation for Economic Co-operation and Development (OECD). The assessment included problems in reading, math, and science, as well as questions about student background, school characteristics, and information on the use of computers and the Internet at home and at school. Fuchs and Woessmann analyzed data from 31 countries: 96,855 students tested in math and 174,227 students tested in reading. (In these same countries 96,785 students were tested in science, but Fuchs and Woessmann chose to concentrate on math because of its relation to future job performance and its relative comparability across countries, and on reading because it had special emphasis in the 2000 PISA.)

Initial analyses of PISA data in 2001 had indicated that there was a significant positive relationship between academic achievement and computer access. However, when Fuchs and Woessmann controlled for family-background characteristics using multivariate regressions, they found:

- no significant effect on math and reading for computer access in school.
- a negative effect on achievement for computer access at home.
- a positive effect for Internet use and educational software at home.
- a "conditional" positive effect for computer and Internet use at school (positive at moderate frequencies of use, but negative for low and high levels of use) [Fuchs & Woessmann, 2004].

These findings set off a flurry of headlines in both the popular and education press: "Too Much Computer Exposure May Hinder Learning" (USA Today [MacDonald, 2004]); "Doubts About School Computer Use" (BBC News [2004]); "Toxic Computers?" (NEA Today [2005]); "Do Computers Help with Children's Education?" (ZDNet Australia [Lemay, 2005]); "Effect of Computer Use on Student Achievement Unclear" (TechLearning [2004]). Given the implications of this kind of exposure for educational policy, it seems essential to ask certain questions—What exactly did the study examine? How were the data analyzed? What exactly did the analysis find?—before educational decision makers can respond to the news bites or consider how to use such a study to guide policy and practice.

WHAT EXACTLY DID THE STUDY EXAMINE?

The PISA database consisted of several types of information:

- Scores for 15-year old students in literacy, science, and math. As noted above, Fuchs and Woessmann concentrated on math and reading. They did not disaggregate scores by country. According to the OECD, the content of the PISA assessment is designed "to measure how far young adults… near the end of compulsory schooling are prepared to meet the challenges of today's knowledge societies. The assessment is forward-looking, focusing on young people's abilities to use their knowledge and skills to meet real-life challenges, and rather than on the extent to which they have mastered a particular school curriculum" (Organisation for Economic Co-operation and Development, 2002, p. 9).
- Survey questions of the students about their home and school environments. These included questions about the types of appliances (including computers) in the house, parents' occupations and education, the kinds of discussions children have with their parents, what classes the students are taking, students' attitudes toward teachers' instruction and classroom management, the frequency of use of various school resources (including computers and the Internet), and various other aspects of home and school life.
- Survey questions of the students' principals about their school environments. These included questions about the school's resources (including access to computers), the number of teachers in the school and their qualifications, characteristics of the student body, the relationship between the school and students, administrative structures, and teaching practices.
- Statistical data, such as the gross domestic product for the school's country.

The specific questions relating to technology that Fuchs and Woessman examined appear in Table 1, along with the source of the information.

For purposes of their analysis, Fuchs and Woessman considered *home computer access* to be indicated by two dichotomous dummy variables derived from the PISA survey. "One computer at home" or "More than one computer at home." *School computer access* was specified by a similar pair of dummy variables derived from the principals' responses: "Learning hindered a lot by lack of computers" or "Learning not hindered at all by lack of computers." School access was also elaborated by the two computer-density measures, overall numbers of computers and internetworked computers per student.

Home computer use was indicated by reported frequency of reading e-mail and Web pages (dichotomous dummies "Never or hardly ever" or "Several times a week"), Internet access at home, and having educational software at home. *School computer use* was indicated by frequency of computer use and of Internet use ("Never or hardly ever" or "Several times a week" for both variables).

Because their hypothesis was that school and family characteristics would

Table 1. Technology questions on the PISA 2000 Student and Principal Questionnaires.

Question text in English	Response options	Asked of:
In your home, do you have educational software? In your home, do you have a link to the Internet?	Yes/No	Students
How many of these do you have in your home: Computer?	None / 1 / 2 / 3 or more	Students
How often do you read these materials *because you want to*: E-mail, Web pages? At your school, how often do you use computers? At your school, how often do you use Internet?	Never or hardly ever A few times a year About once a month Several times a month Several times a week	Students
In your school, how much is the learning of 15-year-old students hindered by not enough computers for instruction?	Not at all Very little To some extent A lot	Principals
In your school, about how many computers are: in the school altogether? connected to the Internet/ World Wide Web?	(Enter number)	Principals

interact with the technology variables to predict outcomes, Fuchs and Woessmann generated several clusters of control variables based on demographics and other information. These included *student characteristics* (gender, age, and grade); *family background* (28 socioeconomic variables); *resource inputs* (a dozen variables including class size, teacher education, instruction time, etc.); and *institutional characteristics* (a dozen variables including the use of exit exams and standardized tests and various measures of school autonomy). Fuchs and Woessmann also created a *school composition* variable from the school means for gender and all of the family background variables and a set of *country* dummy variables. These last two sets of variables were intended to control for sources of statistical error attributable to relationships between socio-economic status and school and to systematic differences between countries. (This analysis did not otherwise make any distinction between countries.)

HOW WERE THE DATA ANALYZED?

Fuchs and Woessman proposed a "production function" model that described a student's test score as a function of computer access and use plus background data on school and family characteristics. The model also included a certain amount of measurement error caused by imputing values for surveys where the respondent had failed to answer some of the questions. (This is a common problem on a large survey where many respondents leave one or more questions blank. The cleanest solution is to simply drop the entire record, but that would have resulted in a loss of nearly 73% of the PISA data.) Finally, the model included a general error term for variance that could not be otherwise accounted for.

The analysis began by considering only part of the equation—scores as a function of computer access. Fuchs and Woessman repeated the regression analyses several times for both home and school access, each time accounting for the advantages of additional control variables until they had an estimate of the effect of computer access that was corrected for all the other effects in their model.

The analyses of computer use were somewhat different. Fuchs and Woessmann included all the control variables from the start. They also included the effects of computer access. That is, they attempted to account for the interaction of computer access at home on the three home computer-use variables, and for the interaction of computer access at school with the two school computer-use variables. Finally, Fuchs and Woessman calculated the effect on math and reading scores with all elements added into the model: home access and use; school access and use; and all the control variables.

WHAT EXACTLY DID THE STUDY FIND?

Fuchs and Woessman estimated that students with a computer at home would score about 23 points higher in math and 22 points higher in reading. That is without taking into account any other characteristics. The advantage was even greater (29 and 26 points respectively for math and reading) for students with more than one computer at home. These differences were significantly greater than 0 ($p>.01$). To give an idea of the magnitude of this effect, the PISA test mean is 500 and the standard deviation is 100. The advantage for computer access (uncorrected for any other effects) is thus about .22–.29 standard deviation units. According to Fuchs and Woessmann, it is almost as much as the difference in mean scores between grades 9 and 10, the school levels that include most of the 15-year-olds in the study.

Accounting for the effects of student characteristics (age, gender, grade) made only a small difference in results; however when family background variables were added to the model (essentially subtracting the advantages attributable to wealthy, stable, supportive parents), the unique advantage of home computer access fell dramatically. A similar pattern was found when the analyses were repeated for school computer access.

The computer-use regressions, which included all the control variables, showed mixed results, as detailed below. However, (with changes in magnitude on the order of a few points) the pattern of effects for home access and use remained stable when effects for school access and use were added into the model. That is, there were no apparent major interactions between these variables.

After removing effects of family background and school characteristics, Fuchs and Woessmann found these relationships in the PISA data on technology and test scores:

- Students who reported having educational software at home had an *advantage* of about two points in math ($p<.05$) and no significant difference in reading.

- Students who reported having a link to the Internet at home had an *advantage* of about five points in math and about four points in reading ($p<.01$).
- Students who reported having one computer at home had a *disadvantage* of about seven points in reading and about six points in math. Students who reported having more than one computer at home had a *disadvantage* of about 16 points in reading and about 14 points in math ($p<.01$).
- Students whose principals felt that instruction was hindered a lot by lack of computers had no significant advantage in math and reading. Nor did students whose principals felt that instruction was not hindered at all by lack of computers. There was no significant relationship between test scores and computer density.
- Students who reported never reading "e-mail and Web pages because (they) want to" had a *disadvantage* of seven points in math and about six points in reading. Students who reported reading email and web pages several times a week had an *advantage* of about six points in math and about nine points in reading ($p<.01$).
- Students who reported "never or hardly ever" using computers at school had about a two-point *disadvantage* in math ($p<.05$) and no significant difference in reading. Students who reported using computers several times a week had a *disadvantage* of about six points in math and five points in reading ($p<.01$).
- Students who reported never or hardly ever using the Internet at school had a *disadvantage* of about two points in math and reading ($p<.05$ in math and $p<.10$ in reading). Students who reported using the Internet at school several times a week reported a *disadvantage* of about nine points in math and 13 points in reading ($p<.01$).

The last two findings are conditional; that is, students who reported intermediate levels of use between "never" and "several times a week," actually had an advantage in math and reading.

WHAT DOES THE STUDY MEAN?

Finally, we get to the question of how to interpret these findings such that they can be used for policy or practice. This is how Fuchs & Woessmann state their central conclusions:

> . . . once family background and school characteristics are extensively controlled for, the mere availability of computers at home is negatively related to student performance in math and reading, and the availability of computers at school is unrelated to student performance. By contrast, student performance is positively related to the use of computers at home for accessing e-mails and Web pages and to the availability of educational software at home. Finally, student performance shows an inverted U-shaped relationship with the extent of computer and

> internet use at school, rising with some use but falling again with a use of several times a week (Fuchs & Woessmann, 2004, p. 17).

The key phrase in this statement is "extensively controlled for." The impetus for the reanalysis of PISA data was skepticism by Fuchs and Woessman toward the apparent dramatic effect of having access to computers. From the standpoint of the educational technology research, this skepticism is well founded.

Mixed findings for overall effects of technology use are the norm. This has been the case in other correlational analyses of large data sets, such as such as Wenglinsky's (1998) analysis of National Assessment of Educational Progress scores, and Goolsbee and Guryan's (2002) study of e-Rate subsidies in California. Research reviews have found the same issues in other types of studies, along with a deplorable lack of controls (Fouts, 2000; Waxman, 2002).

On the other hand, there is also ample evidence that the use of technology *can* have a significant positive effect on student learning. James Kulik's (2003) meta-analysis of controlled studies found effect sizes of .25-.36 standard deviation units for applications including integrated learning systems, writing, and tutorials. The U.S. Department of Education's What Works Clearinghouse, in a review of middle school mathematics programs, found only two studies that not only showed positive results but also met the very rigorous WWC standards for experimental design. However, both of those addressed interventions with substantial technology components (What Works Clearinghouse, 2004).

What makes the difference in findings? Fuchs and Woessmann have part of the answer: control of variables. Studies with significant positive effects for technology tend to be those with well-defined interventions that can specify the conditions of implementation (e.g., Boster, 2002, 2004; Morgan & Ritter, 2001). There are numerous variables affecting successful implementation, including where in a building computers are used, how they are scheduled, the breadth versus depth of the curriculum, the computer knowledge of teachers, and teachers' pedagogical approaches (Becker & Ravitz, 2001). In the United States, the National Educational Technology Standards specify a number of conditions and competencies that teachers in a Delphi-type consensus process have agreed are important for integrating technology in teaching and learning (International Society for Technology in Education, 2000, 2002). The instrumentation for assessment at this level of detail is well-established. Self-report surveys, observation protocols, and other approaches for assessing technology attitudes and use have been widely reported on in this and other journals (International Society for Technology in Education, 2003; Johnson & Barker, 2002; Knezek, 1998).

The point here is that, from the standpoint of educational technology research, the proxies (Fuchs and Woessman's term) for technology access and use are not adequate to define the constructs. Or, put another way, "school characteristics" were not "extensively controlled for," to the extent that those characteristics include the instructional context of technology use. It is interesting to note that there was an optional survey on students' computer interests administered in about two-thirds of the countries participating in PISA 2000 (Adams & Wu, 2002). This survey dealt with some of the issues covered in typical educational technology research (e.g., student use of particular types of applications). However, Fuchs and Woessman did not use those data in their analysis.

There are other critiques that might be made of the PISA data and the regression analysis of technology access and use. For instance, anyone who has worked with technology in schools will have encountered principals whose beliefs about technology use in the building vary widely from the expressed beliefs and observable behaviors of the teachers. Furthermore, even a well-informed and instructionally astute administrator might have a difficult time giving a reliable single rating for technology adequacy across all subjects and classrooms in a school.

Another caveat offered by Fuchs and Woessmann themselves is that their work is only correlational. They can propose explanations, but they cannot test them without an actual controlled experiment. Others have raised concerns about the PISA methodology itself: the difficulty of writing "real-life" items for students across multiple cultures and curricula and the problem that 15-year olds are at different stages of schooling in different countries (Prais, 2003).

However, the contention of this paper is that, even if the regression model were more complex, the sampling issues resolved, and the reliability established for all items, we are still left with no more than (1) the presence of technology is not, by itself, related to student achievement and (2) the use of technology may help or hinder academic learning, depending on the nature of the use. The quality of data in a survey such as PISA 2000 simply does not permit much more elaboration.

These two findings are not trivial. Similar issues have been debated among educators in the past, notably in the meta-analyses of James Kulik and Richard Clark (Clark, 2001). At this point, however, these assertions are to educational technology what "buy low, sell high" is to economics—fundamental principles. They are best expressed in the National Educational Technology Standards' "essential conditions" for technology integration, which include alignment of curriculum, instruction, assessment, technology resources, and teacher skills (International Society for Technology in Education, 2000).

Fuchs and Woessman were correct to question the simple conclusion that student achievement is positively related to computer access. And there will certainly be more opportunities to consider these relationships in databases coming out of other large-scale assessments. (The preliminary results from PISA 2003 were released at about the same time as Fuchs and Woessman published their re-analysis of the 2000 data.) The challenge for the technology-using educators is to make clear to the headline writers—and those who consume the headlines—that the predictable rediscovery that technology's effect depends on curriculum and instruction is not the revelation of a secret, but the affirmation of well-known principles of teaching and learning.

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