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Taking notes in the digital age: Evidence from classroom random control trials

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ABSTRACT

Taking good notes is linked to success in college. However, increased use of computers to take notes necessitates reconsideration of the linkages between note-taking and learning. One difficulty is disentangling the latent student characteristics that may correlate with computer use from the actual effect of computer note-taking on information retention. The authors employ a within-subject, random control experiment to distinguish whether the commonly perceived negative correlation between digital note-taking and performance is due to the note-taking process itself, or is instead due to the characteristics of students who choose to use computers. Their findings suggest that digital note-taking does not have a statistically meaningful impact on student performance; rather, the problem likely lies in the students' choice to use the computer.

KEYWORDS
classrooms; computers; experiment; note-taking

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Many have documented the link between note-taking skills and success in college courses (Kobayashi 2006; Peverly and Wolf 2019; Morehead et al. 2019). The importance of taking good notes underpins both first-year study-skills courses and more targeted student-learning interventions. Instructors regularly admonish their students to "write this down." However, the increased use of laptops and tablets by students in the classroom has necessitated that educators reconsider the link between note-taking and learning. Some see the use of computers in the classroom as a way to improve student engagement, to allow for more active learning, and to foster collaboration (Efaw et al. 2004; Fried 2008; Trimmel and Bachmann 2004; Wurst, Smarkola, and Gaffney 2008). Others argue that computers provide too many opportunities for distraction and, consequently, their use has a deleterious effect on student course performance (Aguilar-Roca, Williams, and O'Dowd 2012; Hembrooke and Gay 2003; Kraushaar and Novak 2010; Patterson and Patterson 2017; Sana, Weston, and Cepeda 2013). Despite the differing perspectives of faculty, Morehead et al. (2019) report that students highly value the ability to use computers to take notes.

One difficulty of studying digital note-taking is disentangling the latent student characteristics that may influence choices about computer use from the actual effect of computer note-taking on studying and retention. For example, Kirschner and Karpinski (2010) speculate that students who are more susceptible to distraction, as well as students with lower impulse control, may be more likely to choose to take notes on the computer; the same students are also more likely to do poorly in the course, even when controlling for other factors. In other words, the relationship may not be causal, but correlative.

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We deconstructed this problem by narrowly focusing on pencil-and-paper versus computer note-taking, employing a within-subject, random control experimental design in the classroom. We did not consider how students use their notes nor what they include in them. Instead, we examined how the same student performs when forced to take notes on paper versus on a computer in a real classroom setting with real grades at stake. We found that, for a typical student, having to take notes on the computer does not lead to poorer performance on quizzes or exams. This suggests that the source of the negative outcomes associated with computer note-taking identified by previous studies may originate with the student rather than the method. If this is the case, instructors can mitigate these negative effects through strategic classroom choices.

Background and literature

Computers' increasingly ubiquitous presence in classrooms is largely due to their use by students for taking notes. The educational psychology literature suggests note-taking affects academic performance through an "encoding function," the process of generating personalized, nonverbatim notes (Igo, Bruning, and McCrudden 2005). Encoding requires inference, integration, and structuring of material being presented. Learning occurs because students engage in the process of selecting important information and summarizing it, all while still actively listening to the lecture (Beck 2014). The type of note-taking that translates to encoding is considered more efficient than verbatim note-taking when used for future studying (Di Vesta and Gray 1972).[1] In particular, the process of writing notes by hand is thought to be closely associated with encoding, and thus, handwritten notes are generally believed to be associated with better recall than notes taken on a computer or other device (Olive and Barbier 2017; Patterson and Patterson 2017).

Many studies that observe how note-taking behavior relates to information recall take place in laboratory environments, often testing students on the same day the material was presented (Beck 2014; Bui, Myerson, and Hale 2013; Morehead, Dunlosky, and Rawson 2019; Mueller and Oppenheimer 2014; Olive and Barbier 2017; Sana, Weston, and Cepeda 2013; Wei, Wang, and Fass 2014). Such studies have yielded important information about how note-taking translates into retention by strictly controlling the environment and student choices. Yet, these studies have reached little consensus as to whether computer note-taking is causally associated with poorer recall. Mueller and Oppenheimer (2014) find paper note-takers performed statistically significantly better on conceptual questions, although there was no difference when comparing results on factual questions. Morehead, Dunlosky, and Rawson (2019) essentially draw the opposite conclusion in their replication study. Bui, Myerson, and Hale (2013) find taking notes on a laptop was superior to taking notes on paper in laboratory experiments examining the link between different note-taking strategies and recall. Luo et al. (2018) could identify no significant difference in outcomes when examining students in a laboratory setting, paying specific attention to student recording of images versus verbal content.

Inevitably, there is some artificiality and selection bias inherent in laboratory studies that, for example, test volunteers' recall on TED talks (Morehead, Dunlosky, and Rawson 2019; Mueller and Oppenheimer 2014) or lectures on nonfiction books (Bui, Myerson, and Hale 2013). This means they cannot fully capture the reality of student life in the classroom. One missing element relates to student motivation. While some laboratory-based studies do offer course extra credit (Beck 2014) or some nominal amount of course participation points (Bui, Myerson, and Hale 2013; Igo, Bruning, and McCrudden 2005; Sana, Weston, and Cepeda 2013), others rely on volunteers (Kiewra et al. 1991; Olive and Barbier 2017; Wei, Wang, and Fass 2014; Wurst, Smarkola, and Gaffney 2008) or cash payments (Mueller and Oppenheimer 2014).

Studies conducted in a classroom setting—field experiments—can overcome some of the issues that bedevil laboratory experiments (Harrison and List 2004). First, student recognition and understanding are tested on a timeframe more consistent with a typical course schedule for giving quizzes and exams. Second, the stakes become much more realistic in the classroom, as students' grades—and hence their ability to move forward with their university education—depend on recall and understanding of lecture content. Patterson and Patterson (2017) leverage an institutional policy change for a natural experiment at a private liberal arts college. They find that optional computer use in the classroom is negatively associated with grade outcomes across disciplines, measured as grade point average (GPA). In two additional field experiments, Fried (2008) and Aguilar-Roca, Williams, and O'Dowd (2012) allow students to self-select computer usage in the classroom. Both studies conclude that a student's choice to use computers to take notes during lectures is associated with lower course performance. Carter, Greenberg, and Walker (2017) study students at the U.S. Military Academy, West Point. They find that introductory economics students who were enrolled in sections that allowed for optional digital note-taking exhibited poorer performance on the course's common final exam (of about 1.7 points on a 100-point scale). However, by allowing students to choose their method of note-taking, these field experiments can still suffer from a variation of the self-selection problem—this happens if the characteristics that lead students to choose to take notes on the computer are also the characteristics that are associated with poorer class performance (e.g., high distractibility).

One feature of introductory economics that tends to be unusual as compared to other disciplines, and which deserves specific mention, is the mixing of conceptual, theoretical, practical, and quantitative information in lectures (Allgood, Walstad, and Siegfried 2015). This has important implications for student note-taking. For example, Patterson and Patterson (2017) suggest that students in courses with a high degree of quantitative, mathematical, or graphical content may experience a greater penalty from taking notes on computers than students in more verbally-oriented courses. This is because the word processing programs commonly used by students for note-taking are cumbersome and slow when it comes to incorporating detailed equations or graphs. Fiorella and Mayer (2017) document that students who take notes on paper tend to use more spatial note-taking strategies such as mapping or drawing images. These students also had better learning outcomes. Luo et al. (2018) discuss how laptop use does not lend itself to recording images presented in lectures. In their study, students report that drawing pictures, charts, and graphs was slower and more difficult on laptops than it was for handwritten notes.

Experiment design

Context and participants

We employed a within-subject, random control trial experiment design, a variation of what Harrison and List (2004) call a "framed field experiment." The experiment was administered during the fall 2016 semester at a regional comprehensive university located in the U.S. Midwest. During this semester, all five of the scheduled principles of microeconomics sections participated in the study; approximately 45 students were enrolled in each section. Three sections met for 60 minutes on Mondays, Wednesdays and Fridays; the remaining two sections met for 90 minutes on Tuesdays and Thursdays. Three of the five sections met during the morning; the remaining sections met during the early afternoon. The sections were taught by three different tenured professors. They all used a whiteboard for primary instruction and Microsoft PowerPoint slides as supplements. All exams and quizzes were multiple choice. Principles of microeconomics is a required course for entrance into our College of Business. Students must achieve a minimum grade of 2.0 in the course, with an average grade of 2.5 across all introductory business courses. Thus, student performance in microeconomics has implications for their ability to choose a business major.

All 230 students enrolled in the principles of microeconomics sections agreed to participate in the experiment.[2] Students in each section were randomly assigned to one of two groups based on

Trial	Must Take Notes on a Laptop Computer	Must Take Notes on Paper
Trial 1 (Topic = Consumer Theory)	ODDS (N = 127)	EVENS (N = 103)
Trial 2 (Topic = Economic Inequality)	EVENS (N = 103)	ODDS (N = 127)

Figure 1. Experimental design.

whether the last digit of their student ID number was odd or even. The university assigns IDs on an increasing integer basis such that $\mathrm{ID}_{i+1} = \mathrm{ID}_i + 1$ for each subsequent person, $i + 1$. Insofar as students did not attempt to be strategically matriculated at the university in such a way to be assigned a specific ID number (highly improbable), our selection mechanism is random.

Experimental procedure

A fourth tenured professor met with each section on two separate, rigorously scheduled occasions for our experimental trials. For each trial, the fourth instructor lectured for the first 30 minutes of class on a topic that, although common to introductory economics courses, could be taught as a small, independent and stand-alone unit. These topics were not covered by the primary instructors.[3] Primary instructors could answer specific questions about the topics and remind the students that the topics would be covered on quizzes and exams. Instructors were otherwise cautious to not elaborate on this material in lectures.

In Trial 1, students whose ID ended with an odd digit (ODDS) were instructed to use laptop computers to take notes. The second group (EVENS) was instructed to use paper (figure 1). Students could choose to use their own paper notebooks or laptop computers/tablets. Paper, pencils, and university laptops were supplied to any student upon request, as well as to students who were unprepared to participate in the experiment on a given day. ODDS could take notes using whatever computer program they preferred, although most used Microsoft Word.

In the second trial, which occurred approximately one month later, the ODDS and EVENS reversed their note-taking restrictions. This within-subject, random control trial experimental design provided a distinct advantage over studies that rely on either self-choice of computer use or studies that assign each student a single option. First, because we randomly assigned a note-taking method to each group of students, sample selection bias was negated. Second, because each student had to take notes using both paper and a computer, we were able to capture the within-subject effect of switching note-taking tools on assessment scores.

Instructor 4 taught the same material to all five sections, following a highly structured lecture outline and using only the classroom whiteboard. Students were notified by their primary instructor that they would be quizzed on their knowledge of the lecture material during the next class period (in two days' time). Students were also told the material would be covered on the next course exam (2–3 weeks later). Thus, the students were acutely aware that their knowledge of the lecture material could affect their course grade.

Identical ten-question, multiple choice quizzes were deployed in each section two days after the special lecture to test student recognition. The questions were representative of typical introductory economics questions and were much like what would be found in a standard textbook question bank (available upon request). Students faced an additional two multiple choice questions on the same topic seeded into instructor-specific exams. Cognizant of the challenges of recording mathematical and graphical information digitally, and because such content is standard in the introductory economics course, we identified a subset of three to four quiz questions in each trial that required more sophisticated analysis of graphically represented information.

Table 1. Summary Statistics; means and standard deviations in parentheses.

Variable description	Observations	Mean (SD)
Computer 1: assigned to use computer in trial 1	230	0.552 (0.498)
Computer 2: assigned to use computer in trial 2	230	0.448 (0.498)
Attendance 1: attended lecture in trial 1	230	0.930 (0.255)
Attendance 2: attended lecture in trial 2	230	0.913 (0.282)
Quiz 1: score on trial 1 quiz (out of 10)	220	8.018 (1.627)
Quiz 2: score on trial 2 quiz (out of 10)	215	7.972 (1.694)
Conceptual Subset 1: score on trial 1 quiz subset Questions (2), (4), (7) and (8)	220	2.808 (1.018)
Conceptual Subset 2: score on trial 2 quiz subset Questions (4), (7) and (10)	215	2.340 (0.756)
Exam 1: score on trial 1 exam questions (out of 2)	223	0.767 (0.722)
Exam 2: score on trial 2 exam questions (out of 2)	219	1.329 (0.761)
Total 1: sum of trial 1 quiz and exam scores (out of 12)	217	8.806 (1.903)
Total 2: sum of trial 2 quiz and exam scores (out of 12)	212	9.311 (2.028)
Female: = 1 if student is a woman and 0 otherwise	228	0.360 (0.481)
Nonwhite: = 1 if student's race is not white and 0 otherwise	228	0.105 (0.308)
Age: age of student in years	227	20.251 (2.936)
GPA: cumulative college grade point average at start of the semester (out of 4)	225	3.145 (1.727)
ACT: student composite collegiate entrance exam score (out of 36)	213	22.732 (3.140)
Hours: number of hours per week student works for pay	226	11.280 (11.703)

While each primary instructor set their own grading scheme, course schedule and assigned their own choice of textbook, everything related to the experiment was highly controlled, including the dates of the lectures and quizzes and the relative value of experimental points in the total course grade. Because we are interested only in how students performed on the quiz and exam questions related to the special lectures (trials) material, other variations in class organization are irrelevant to our study.

Data and methodology

Students completed pre-experiment and post-experiment surveys that provided demographic information along with knowledge of students' note-taking and studying preferences. (Surveys are available upon request.) The pre-experiment survey was completed on the first day of class when the experiment was explained. The post-experiment survey was completed on the same day as the last quiz. Whole sample summary statistics are presented in table 1. The random selection mechanism placed roughly 55 percent of the students in one group (ODDS) and 45 percent in the other (EVENS). While one might suppose that each group should be essentially the same size, a random selection process need not guarantee this. More than 90 percent of students attended the special lectures. Women made up 36 percent of the sample (typical of pre-business courses at our university). Most students were sophomores, and the average student age was slightly over 20 years old. The average student self-reported GPA was 3.145 out of 4. The responses provided by the students in our sample were highly consistent with the known population information of pre-business students at our university.

Mean quiz grades were approximately 80 percent for each trial of the experiment; mean scores for exam questions exhibited more variation, with an average of less than one question correct in Trial 1 and 1.3 questions correct in Trial 2 (out of two total questions). Summary statistics are provided in table 1; student performance on the relevant questions are also summed into a combined "total" score (73.3% for Trial 1 and 77.5% for Trial 2). In addition, table 1 reports the average number correct from a subset of questions that we identified as "conceptual" as opposed to "definitional." Conceptual questions involved either the use or interpretation of mathematical equations or graphs. Students scored slightly lower on conceptual questions overall, but the difference was not statistically significant.

Table 2. Summary Statistics by Group; means and standard deviations in parentheses.

	Trial 1		Trial 2	
Variable	Computer Group (ODDS)	Paper Group (EVENS)	Computer Group (EVENS)	Paper Group (ODDS)
Attendance	0.929 (0.259)	0.932 (0.253)	0.883 (0.322)	0.937 (0.244)
Quiz score (out of 10)	7.924 (1.688)	8.129 (1.553)	7.916 (1.760)	8.017 (1.645)
Conceptual subset score (out of 4; out of 3)	2.831 (1.032)	2.782 (1.006)	2.295 (0.770)	2.375 (0.745)
Exam score (out of 2)	0.754 (0.742)	0.782 (0.701)	1.323 (0.740)	1.333 (0.781)
Total score (Quiz + Exam, out of 12)	8.675 (1.995)	8.960 (1.786)	9.213 (2.047)	9.390 (2.017)
	Computer Group in Trial 1		Computer Group in Trial 2	
Female	0.376 (0.486)		0.340 (0.476)	
Nonwhite	0.128 (0.335)		0.078 (0.269)	
Age	20.097 (1.985)		20.437 (3.780)	
GPA	3.289 (2.293)		2.970 (0.452)	
ACT	22.839 (3.323)		22.600 (2.908)	
Hours	10.538 (12.400)		12.181 (10.788)	

Table 2 separates the sample by group and provides the mean values. This allows us to make simple comparisons between the groups. The similarity in characteristics between the ODD and EVEN groups is indicative of the randomness of our sorting. The groups are statistically insignificantly different from each other in terms of gender, race, age, and scholastic ability as measured by self-reported GPA and self-reported score on the ACT collegiate entrance exam. Attendance at Trial 2 decreased slightly in the group scheduled to take notes using a computer. There is no clear reason for this other than normal midterm attrition; the difference is not statistically significant.

Discussion of findings

Outcomes from t-tests

Because the treatment and control groups were randomly assigned, unconditional means comparisons offer a meaningful and statistically relevant way to begin to examine how note-taking influences recognition. In table 3, we present the results of the unpaired, two-sample *t*-tests for equivalence between the mean score of paper note-taking students with the mean score of computer note-taking students. The columns successively offer group means for each assessment. The first two rows of table 3 feature effect sizes and test statistics that assume equal variances in the groups' scores. Although a simple *F*-test fails to reject the null hypothesis of equal variances between the groups' scores, we also include *t*-test means comparisons that assume unequal variances in the third row. Insofar as we are measuring how note-taking behavior affects assessment scores, it is also prudent to provide means comparisons between groups consisting only of students that attended each lecture. These results are presented in rows 5 and 6.

We are unable to discern any statistically significant difference between paper and computer note-taking assessment scores in any of the group comparisons. The *t*-tests indicate that when students are randomly assigned to take notes by computer, students perform only insignificantly worse, and by a small practical effect. These findings suggest that it may be the choice to take notes by computer that is driving the negative results in previous studies, and not the process of taking notes on the computer, per se.

OLS fixed effects and cross-section regression results

While indicative, mean comparisons offer few insights as to why no difference between the groups is found. For example, it might be useful to understand what is driving the magnitude of

Table 3. Group comparison *t*-tests.

	Unpaired Two-sample *t*-tests. Ho: mean (handwritten) − mean (computer) = 0							
	(*t*-statistic in parentheses); {*p*-value in brackets}							
	Trial 1 Assessments				Trial 2 Assessments			
	Quiz 1	Exam 1	Total 1	Conceptual Subset 1	Quiz 2	Exam 2	Total 2	Conceptual Subset 2
Whole sample effect size	0.204	0.028	0.285	−0.048	0.101	0.010	0.177	0.080
Equal variances	(0.928)	(0.288)	(1.100)	(−0.350)	(0.433)	(0.098)	(0.631)	(0.773)
	{0.355}	{0.773}	{0.273}	{0.727}	{0.666}	{0.922}	{0.529}	{0.441}
Unequal variances	(0.934)	(0.290)	(1.109)	(−0.350)	(0.430)	(0.098)	(0.630)	(0.770)
	{0.351}	{0.772}	{0.269}	{0.727}	{0.668}	{0.922}	{0.530}	{0.442}
Observations	220	223	217	219	215	219	212	215
Attendance in each lecture sub-sample effect size	0.230	0.026	0.261	−0.017	0.144	0.080	0.275	0.131
Equal variances	(1.030)	(0.259)	(0.986)	(−0.119)	(0.619)	(0.741)	(0.984)	(1.245)
	{0.304}	{0.796}	{0.325}	{0.906}	{0.537}	{0.460}	{0.326}	{0.214}
Observations	208	209	207	207	203	202	200	203

the difference in scores between the groups of note-takers. In addition, other explanatory factors besides note-taking method likely play a significant role in determining assessment scores; *t*-tests cannot identify these. To better identify effect magnitudes as well as other covariates that may determine assessment scores, we employ regression analysis.

The experiment's design allows us to measure assessment scores after switching between note-taking methods. The within-subject design randomly assigned a student to take notes by one method for one lecture-assessment pair (Trial 1) and then assigned the same student to switch methods for a second lecture-assessment pair (Trial 2). This unique feature allows the isolation of the effect of taking notes by computer within an individual student, abrogating the influence of choice. If taking notes by computer negatively affects student scores in actual classroom settings, then within-students (fixed effects) OLS estimations should result in statistically significant negative coefficients on the computer note-taking indicator variable.[4] Random assignment of groups means that other covariates should be unnecessary to assess performance.

We proceed by first standardizing assessment scores, done by fitting them to the standard normal distribution using all observations, where

$$z \text{ score } = \frac{\text{Individual student score } - \text{ Mean assessment score}}{\text{Standard deviation of the assessment score}}.$$

Student scores are thus measured in terms of standard deviations from the mean of each assessment. Using fixed effects OLS estimations to control for unmeasurable and unobservable individual student characteristics that influence assessment scores, the change in a standardized assessment score when a student switches between note-taking methods is identified. Table 4 presents the results for our four assessment measures (quiz scores, exam scores, combined total score, and score for the subset of conceptual questions). This is done for the whole sample, and then once more including a control identifying students who attended a lecture and completed the quiz versus those who did not attend the lecture but still completed the quiz.

The estimated coefficients for computer use are uniformly negative. They suggest that students who took notes on computers scored between 0.03 and 0.12 of a standard deviation lower than their peers who took notes on paper (roughly equivalent to 0.2 of a quiz question or 0.02 of an

Table 4. Fixed effects OLS.

	Fixed Effects OLS Regressions of Standardized Scores (*z* scores)							
	All Students				Controlling for Lecture Attendance			
	Quiz (1)	Exam (2)	Total (3)	Subset (4)	Quiz (5)	Exam (6)	Total (7)	Subset (8)
Computer notes#	−0.123	−0.027	−0.119	−0.056	−0.123	−0.025	−0.119	−0.055
	(−1.47)	(−0.37)	(−1.53)	(−0.61)	(−1.49)	(−0.34)	(−1.54)	(−0.59)
Attended class	–	–	–	–	0.688***	0.067	0.491**	0.314
	(3.12)	(0.25)	(2.25)	(1.16)				
Constant	0.061	0.013	0.059	0.278	−0.590***	−0.050	−0.406**	−0.270
	(1.47)	(0.37)	(1.53)	(0.61)	(−2.82)	(−0.20)	(−1.98)	(−1.06)
Observations	435	442	431	437	435	442	431	437
R-squared	0.002	0.000	0.003	0.000	0.029	0.002	0.023	0.007
F-stat	2.16	0.13	2.34	0.37	5.62***	0.10	3.36**	0.79

Notes: t-statistics are in parentheses; heteroskedasticity robust standard errors are clustered at the individual level.
#Coefficient estimates are the effect, in terms of standard deviations, of taking notes by computer on each assessment relative to taking notes by hand (column 1 estimate implies students taking notes on computers scored a statistically insignificant 0.123 standard deviation worse than students taking notes by hand).
***Indicates statistical significance at better than the 1% level ($p < 0.01$); **Indicates statistical significance at better than the 5% level ($p < 0.05$)

exam question worse). The results are remarkably robust, even when controlling for attendance. However, none of the results is statistically significant, meaning we cannot conclude that the estimated coefficients are meaningfully different from zero. Additionally, none of the results is of a magnitude that is practically significant in determining final grades. In other words, a typical student taking notes by a computer performs in a statistically equivalent way to when the same student takes notes on paper.[5] What is of interest is that students perform substantially better on quiz assessments after attending the lecture. However, this advantage wears off by the time students take an exam.

Although note-taking method seems to play a positive but insignificant role in determining assessment scores, our dataset does identify the conventional student characteristics that correlate strongly with performance. Women and nonwhite students perform worse, other factors held equal; GPA and ACT scores are positively and significantly related to performance. That our findings are largely consistent with the broader literature examining the determinants of student performance in economics suggests we are accurately capturing student-performance correlates in our data. In table 5, we provide the outcomes of OLS cross-section estimates of student assessments. While these cross-section estimations abandon the random control trial nature of our experiment, they do provide far better explanatory power, as evidenced by the models' R-squared measures. Moreover, they increase our confidence that our data are representative. Thus, after controlling for a variety of factors known to influence student success in introductory economics courses, we find that computer note-taking remains uncorrelated with assessment outcomes at practical levels of statistical significance.

Explaining our finding

When we eliminate the choice in note-taking method, we find no statistically significant difference in performance between those who employed a computer and those who used paper. However, we do confirm the literature's common result: computer note-taking is negatively related to assessment scores. Like Kirschner and Karpinski (2010), we speculate that students who choose to take notes on computers may harbor characteristics correlated with lower assessment scores than students who opt to take notes on paper. In order to test this hypothesis, we use our pre-experiment survey to identify the students who primarily use laptop or tablet computers to take notes when given a choice. Our small sample of only 18 digital note-takers constrains our

Table 5. OLS estimates of standardized scores (z scores).

	Trial 1 Assessments				Trial 2 Assessments			
	Quiz 1 (1)	Conceptual Subset 1 (2)	Exam 1 (3)	Total 1 (4)	Quiz 2 (5)	Conceptual Subset 2 (6)	Exam 2 (7)	Total 2 (8)
Computer[#]	−0.220	0.014	−0.095	−0.380	−0.040	−0.099	0.048	−0.066
	(−1.037)	(0.106)	(−0.976)	(−1.514)	(−0.175)	(−0.971)	(0.499)	(−0.252)
Attendance	1.025	0.468	−0.077	0.312	1.557**	0.450*	0.130	1.747**
	(1.583)	(0.989)	(−0.336)	(0.478)	(2.480)	(1.663)	(0.603)	(2.396)
Female	−0.466*	−0.282*	0.297***	−0.093	−0.113	0.027	0.004	−0.124
	(−1.884)	(−1.793)	(2.647)	(−0.320)	(−0.406)	(0.211)	(0.039)	(−0.399)
Nonwhite	−0.372	−0.513**	0.082	−0.338	−0.058	0.175	−0.101	−0.190
	(−0.940)	(−2.429)	(0.423)	(−0.673)	(−0.142)	(1.339)	(−0.543)	(−0.402)
Age	−0.078	−0.017	−0.021	−0.102*	−0.158**	−0.063**	−0.060**	−0.223***
	(−1.590)	(−0.515)	(−0.782)	(−1.719)	(−2.347)	(−2.121)	(−2.477)	(−2.884)
ACT	0.109**	0.077***	0.065***	0.182***	0.176***	0.075***	0.054***	0.235***
	(2.232)	(3.098)	(4.147)	(3.688)	(4.839)	(4.737)	(3.743)	(5.755)
GPA	0.173***	0.090***	−0.004	0.173***	−0.011	0.008	−0.006	−0.019
	(4.050)	(4.611)	(−0.212)	(3.069)	(−0.243)	(0.489)	(−0.458)	(−0.347)
Hours	0.007	0.004	−0.000	0.009	−0.002	−0.003	0.002	0.000
	(0.566)	(0.569)	(−0.061)	(0.689)	(−0.161)	(−0.479)	(0.377)	(0.031)
Section 2	0.000	0.092	−0.437***	−0.425	0.378	0.187	0.639***	1.036**
	(0.002)	(0.445)	(−2.957)	(−1.171)	(1.026)	(1.190)	(3.881)	(2.513)
Section 3	−0.094	−0.118	−0.137	−0.075	−0.075	0.061	0.636***	0.527
	(−0.345)	(−0.607)	(−0.908)	(−0.229)	(−0.205)	(0.379)	(4.177)	(1.233)
Section 4	−0.406	0.002	−0.170	−0.581	0.384	0.213	0.807***	1.191***
	(−1.059)	(0.009)	(−1.039)	(−1.344)	(1.001)	(1.299)	(5.758)	(2.733)
Section 5	0.280	0.150	−0.063	0.261	−0.099	0.004	−0.069	−0.229
	(0.931)	(0.772)	(−0.385)	(0.680)	(−0.274)	(0.025)	(−0.408)	(−0.531)
Constant	5.522***	0.216	−0.031	5.876***	5.623***	1.594*	0.676	6.272***
	(2.786)	(0.196)	(−0.040)	(2.769)	(2.877)	(1.849)	(0.856)	(2.771)
Observations	202	201	204	199	198	198	202	196
R squared	0.152	0.141	0.158	0.170	0.175	0.153	0.301	0.266
F-stat	3.02***	3.21***	3.62***	3.4***	3.28***	2.94***	9.83***	6.28***

Notes: *t*-statistics are in parentheses; heteroskedasticity robust standard errors are clustered at the individual level.
[#]Coefficient estimates are the effect, in terms of standard deviations, of taking notes by computer on each assessment relative to taking notes by hand (column 1 estimate implies students taking notes on computers scored a statistically insignificant 0.220 standard deviation worse than students taking notes by hand).
***Indicates statistical significance at better than the 1% level ($p < 0.01$); **Indicates statistical significance at better than the 5% level ($p < 0.05$); *Indicates statistical significance at better than the 10% level ($p < 0.10$)

ability to draw statistically strong conclusions regarding these students' characteristics relative to the remaining students. Nevertheless, table 6 offers some suggestive evidence that students who choose computers are somewhat different than students who choose paper, and these differences may correlate with lower assessment scores. In particular, students preferring computers are less likely to categorize their own note-taking skills as "very good," are more likely to categorize their note-taking skills as "poor," and are less likely to think that notes are "very useful" for performing well in courses.

Additionally, we might presume that the students who would normally choose to take notes on a computer would perform worse on assessments, regardless of the note-taking tool required by our trials. Table 7 presents estimates of simple OLS regressions controlling for students' choice of primary note-taking tool. Like in previous studies, we allow characteristics that correlate with performance—gender, GPA, ACT score—as well as those indicating the likelihood to choose computers for note-taking to vary among students. By doing so, we are able to replicate the common negative association found in the literature between choosing to take notes on the computer and course performance. However, we emphasize that this often statistically significant negative coefficient on digital note-taking in regressions cannot isolate whether it is the student's individual-specific characteristics that cause lower assessment scores or if the note-taking method is, itself, inherently at fault.

Table 6. Select descriptive statistics by note-taking preferences: mean (SD in parentheses).

	Computer preference ($n = 18$)		Paper preference ($n = 212$)	
Attendance: = 1 if student attended both trial lectures and 0 otherwise	0.722	(0.461)	0.882	(0.324)
Note-taking skills: = 1 if "very good" (best chosen category) and 0 otherwise	0.000***	(0.000)	0.118***	(0.323)
Note-taking skills: = 1 if "good" and 0 otherwise	0.722	(0.461)	0.811	(0.392)
Note-taking skills: = 1 if "poor" (lowest chosen category) and 0 otherwise	0.278*	(0.461)	0.061*	(0.240)
Study habits: =1 if student studies notes several times before every assessment (best chosen category) and 0 otherwise	0.500	(0.514)	0.656	(0.476)
Useful notes: = 1 if student thinks notes are typically "very useful" for performing well in courses and 0 otherwise	0.333*	(0.485)	0.580*	(0.495)

Notes: We test for statistical significance in the characteristics' differences between groups using unpaired two-sample *t*-tests, assuming unequal variances when necessary, and the null hypothesis: Ho: mean (paper preference) – mean (computer preference) = 0.

***Indicates statistical significance at better than the 1% level ($p < 0.01$); *Indicates statistical significance at better than the 10% level ($p < 0.10$)

Table 7. Simple OLS assessment scores controlling only for preferred note-taking tool.

	Trial 1 Assessments				Trial 2 Assessments			
	Quiz 1 (1)	Conceptual Subset 1 (2)	Exam 1 (3)	Total 1 (4)	Quiz 2 (5)	Conceptual Subset 2 (6)	Exam 2 (7)	Total 2 (8)
Computer preference#	−0.721*	−0.063	−0.230	−0.939**	−0.645	−0.367**	−0.152	−0.810**
	(−1.807)	(−0.264)	(−1.354)	(−2.200)	(−1.636)	(−1.978)	(−0.670)	(−2.108)
Constant	8.074***	2.813***	0.785***	8.880***	8.020***	2.367***	1.340***	9.372***
	(70.877)	(38.956)	(15.527)	(65.831)	(66.426)	(44.254)	(25.409)	(63.622)
Observations	220	219	223	217	215	215	219	212
R-squared	0.014	0.000	0.008	0.018	0.010	0.016	0.003	0.011
F-statistic	3.26*	0.07	1.83	4.84**	2.68	3.91**	0.45	4.44**

Notes: *t*-statistics are in parentheses; heteroskedasticity robust standard errors are clustered at the individual level.

#Coefficient estimates are the effect, in terms of points on each assessment, of preferring to take notes by computer vs. preferring to take notes by hand (column 1 estimate implies students who prefer to take notes on computers scored a statistically significant 0.721 points worse than students who prefer to take notes by hand).

***Indicates statistical significance at better than the 1% level ($p < 0.01$); **Indicates statistical significance at better than the 5% level ($p < 0.05$); *Indicates statistical significance at better than the 10% level ($p < 0.10$)

Student opinions on note-taking

In their sample, Aguilar-Roca, Williams, and O'Dowd (2012) find that about 50 percent of students prefer to take notes consistently on paper; about 22 percent preferred laptops. We find even greater homogeneity of opinion across students regarding computer use. At the beginning of the semester, 92.1 percent of our students reported that they preferred to take notes on paper; one student took notes on a tablet with an attached keypad; 17 students (7.5%) reported that they usually take notes on their laptop.[6]

Although 89.2 percent of students in our sample agreed with the statement that handwritten notes are associated with better quiz and exam performance, not one student who primarily used computers to take notes planned to switch to paper and pencil after completing our experiment. Among primary paper and pencil note-takers, though, 2.7 percent decided to switch to using computers.[7] Some of the student responses were driven by the content of the course: 88.7 percent of students believed they "wrote down" less mathematical or graphical content when using the computer. Overall, 41.9 percent of students agreed with the statement that some methods of note-taking are better for some classes than for others (7.4% of students reported that they felt computer and paper note-taking are equivalent; 49.3% agreed with the statement that taking notes by hand is superior; 1.5% believed taking notes on the computer is superior).

Limitations

This study makes a contribution to the literature by separating a student's choice to take notes on a computer from the process or effect of taking notes on a computer. However, several limitations should be addressed. First, the sample size is relatively small, reducing the statistical power through increased standard errors. Second, the number of items we measure (10 quiz questions and 2 exam questions in each trial) are somewhat small. Although the results were consistent across the quiz and exam questions, the small number of assessment items remains a weakness. Third, multiple, rather than single, lectures requiring students to take either paper or computer notes would have added to the robustness of the results. Fourth, the results speak to the experience of second-year, sophomore students in a lecture-oriented class, and as such, may not be widely generalizable. Finally, while the random assignment of student note-taking processes in the experiment should eliminate the need to examine the actual notes taken because note-taking proficiency would also be random, such information could have provided insights into student opinions and preferences regarding note-taking strategy. These limitations mostly stemmed from pedagogical constraints (three different professors across five different course sections) that limited our ability to frame an experiment entirely to our liking.

Conclusions and future study

Several classroom-based studies have demonstrated that students who choose to take notes digitally do worse than their paper note-taking peers (Aguilar-Roca, Williams, and O'Dowd 2012; Carter, Greenberg, and Walker 2017; Fried 2008; Patterson and Patterson 2017). Whether this result is due to the process of taking notes on a computer or the inherent characteristics of the student who chooses to do so have been difficult to disentangle. By requiring each student in our sample to participate in both types of note-taking, our experiment allows us to separate the effects of taking notes on a computer from the choice to take notes on the computer. In doing so, we conclude that for an introductory economics course, computer note-taking does not have a statistically significant impact on student recognition, as measured by performance on multiple choice quizzes and exams.

Our results highlight important avenues for future research. There is little conclusive agreement about why the choice to use laptops may correlate with negative assessment outcomes. Patterson and Patterson (2017) show some differential performance based on gender, race, and ability level. We find that students who choose to take notes on the computer may be poorer students overall. Morehead et al. (2019) report that students like the flexibility of choosing which method of note-taking to employ in different circumstances and are unlikely to relinquish the option voluntarily. Thus, given the ever-increasing use of digital devices in the classroom and the widely acknowledged importance of note-taking's contribution to learning, educators should perhaps consider how students can maximize their chance of success (Fried 2008). For example, instructors can suggest software applications that allow students to transform a tablet computer into computerized paper, or alternatively suggest using a digital pen on a tablet in courses with high visual content. Future research on note-taking media should consider such new technologies.[8] These technologies may allow students to benefit from the cognitive process of handwriting while still being able to take advantage of a computer for lecture-engagement or sharing notes.

Where does this leave the typical introductory economics instructor? We suggest, given the mixed results in the literature, that instructors should not presume that students will perform better if compelled to take notes on paper. Granberg and Witte (2005), for example, find little statistical evidence to support a classroom ban on laptops despite the widespread evidence that computers pose significant potential for distraction. Further, students are strongly opposed to such laptop bans (Brady 2009; Young 2006) and view computers in the classroom positively

(Zhuang and Xiao 2018), although simultaneously recognizing the potential for distraction (Wurst, Smarkola, and Gaffney 2008). Students' high preference for computer-associated course support and online courses further suggests that computers will become increasingly important in classrooms (Nemetz, Eager, and Limpaphayom 2017). Palmatier and Bennet (1974) raised concerns about the advent of spiral notebooks for note-taking (Morehead et al. 2019), and yet today spiral notebooks are the norm. Knowing how the medium of note-taking affects learning outcomes will continue to be an important area for further research as technology continues to change, and students adapt.

Notes

1. Some research suggests the encoding benefit of note-taking, on its own, is modest (Kiewra et al. 1991; Kobayashi 2005). In addition to encoding, the educational psychology literature identifies a storage function with note-taking. This is the process by which students improve retention of information by reviewing their notes prior to assessment. While this is obviously an important process, we do not address the storage function in this study, assuming that it remains constant for each individual student across their note-taking method.
2. There was some mild attrition over the course of the semester—11 students total across all five sections. This rate was statistically equivalent to the attrition rate for introductory microeconomics at our university for all sections over the previous two years.
3. The first topic was consumer theory and involved a short lecture on indifference curves and budget constraints as an extension of demand analysis. The second topic was income inequality as measured by Lorenz curves and Gini coefficients. All topics are discussed in brief chapters in the recommended textbooks (Hubbard and O'Brien 2013; Miller 2018; McEachern 2017).
4. A fixed effects model controls for any unobserved, time-invariant factors (fixed effects) associated with an individual such as gender, race, ACT score, etc. In doing so, the variation related to those factors is removed, which then allows us to observe within-individual variation explained by the computer note-taking.
5. Despite the effect's statistical insignificance, it is important to highlight our persistent results of a positive effect of taking notes by paper and pencil. The noisy environment of framed field experiments such as ours necessitates this note.
6. Despite anecdotal evidence to the contrary, zero students reported that "I do not regularly take notes" on the pre-experiment survey, and only 7.9 percent rated their note-taking skills as poor (0 rated their note-taking skills as "very poor").
7. When asked "for the class in general," rather than specifically about themselves, 89.7 percent of students in our sample believed that handwritten notes were associated with better quiz and exam scores.
8. Morehead, Dunlosky, and Rawson (2019) report preliminary results of using eWriters for note-taking; they find these are a viable substitute for handwritten notes on paper.

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