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ORIGINAL RESEARCH

The impact of digital distraction on lecture note taking and student learning

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Abstract

Laptop computers allow students to type lecture notes instead of relying on the traditional longhand (i.e. paper–pencil) method. The present research compared laptop and longhand note-taking methods by investigating how the quality (i.e. complete versus incomplete idea units) and quantity (i.e. total words and total idea units) of typed and handwritten notes differed when students did or did not reply to text messages during a simulated lecture. Accounting for the presence of text messaging while participants took notes situated the present study within the reality facing many students in today's digital age. Findings indicated that a considerable proportion of the idea units captured in participants' notes were incomplete, regardless of note-taking method or exposure to distraction during the simulated lecture. However, only the total number of complete idea units stored in student notes meaningfully predicted lecture learning. Furthermore, the presence of digital distraction was particularly disruptive to the quality and quantity of laptop users' lecture notes relative to longhand note takers. Finally, digital distraction emerged as a more meaningful predictor of lecture learning than note-taking method. Recommendations for improving the quality of student lecture notes are discussed and avenues for future research into note-taking completeness and the interplay between digital distraction and note-taking method are proposed.

Keywords Note-taking method · Digital distraction · Lectures · College students · Technology

Note taking is one of the primary strategies college students use to learn in the classroom (Hartley and Marshall 1974; Morehead et al. 2019b; Kiewra 2002). Although most college students are never formally trained to take lecture notes (Morehead et al. 2019b), nearly

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all of them spontaneously take notes during class (Morehead et al. 2019b; Palmatier and Bennett 1974; Williams and Eggert 2002). Students are wise to take notes, as those who take and review lecture notes tend to have higher achievement on quizzes and exams than those who do not take notes (Armbruster 2000; Kiewra 1985; Knight and McKelvie 1986; Kobayashi 2005). Contemporary mobile technology has expanded the modalities through which students take notes. Students have traditionally taken notes using a longhand (e.g. pencil-paper) method, but the proliferation of laptop computers has allowed college students to type their notes during class (Ragan et al. 2014; Ravizza et al. 2017). In fact, approximately half of all college students surveyed prefer typing their notes over writing their notes (e.g. Morehead et al. 2019b; Ragan et al. 2014). Widespread laptop use is fueled by the belief that laptops make it easier to take notes (Kay and Lauricella 2011) and to learn during class (Houle et al. 2013; Morehead et al. 2019b) than longhand note taking.

Unfortunately, lecture note taking is often disrupted as students use their mobile devices (e.g. smart phones, laptops) for off-task purposes—a phenomenon commonly referred to as digital distraction (e.g. McCoy 2013, 2016). Prominence of the digital distraction phenomenon has increased in recent years. For instance, Witherby and Tauber (2019) surveyed current and former undergraduates about their off-task device use during class. The former students included in the sample were approximately 10 years older than the current students. Survey results revealed that nearly 20% more of the current students reported succumbing to digital distraction during class than did former students.

College students succumb to digital distraction regularly. Upwards of 70–90% of college students regularly text on their mobile phones during class (Kornhauser et al. 2016; Parry and le Roux 2018). Students who text during class often send and receive between 15 and 20 text messages during typical class periods (Dietz and Henrich 2014; Pettijohn et al. 2015). Laptop users also spend considerable amounts of time off task during class. For instance, although only 10% of the current undergraduates surveyed by Witherby and Tauber (2019) self-reported frequently using their laptops for off-task purposes, about 26% reported getting distracted by their computers at least occasionally during class. Other self-report studies have found that nearly 60% of laptop users spend 40% of typical class periods using their computers for off-task purposes (Ragan et al. 2014). Furthermore, research using tracking software has revealed that laptop users spend 40–60% of typical class periods using their computers for off-task reasons (Ravizza et al. 2017).

Unsurprisingly, digital distraction has been linked to reductions in lecture note taking and learning when notes are taken using a longhand method (Kuznekoff et al. 2015; Waite et al. 2018). However, no known research has examined the extent to which digital distraction impedes note taking and lecture learning when students take notes on their laptops. The purpose of the present research was to extend the educational research community's understanding of how digital distraction and note-taking medium interact to influence the quality and quantity of students' notes, as well as their learning from a lesson.

Lecture note taking

Educational researchers have proposed that taking notes serves two potential functions: a behavior that helps encode incoming information to memory (i.e. the encoding function) or a behavior that generates an external record of lecture information that can be reviewed after a lecture has finished (i.e. the external storage function) (e.g. Di Vesta and Gray 1972; Kiewra 1985).

The encoding function proposes that the act of taking notes commits information to memory better than listening only (Di Vesta and Gray 1972). The encoding function is grounded in the generative hypothesis (Wittrock 1974)—the contention that taking notes provides students with an opportunity to write down their spontaneous insights during lectures. For instance, Di Vesta and Gray (1972) contend that taking notes allows students to record all subjective associations, inferences, connections to prior knowledge, or interpretations that occur to them while they listen to a lecture. Scholars propose that recording spontaneous insights alongside a lecture's main points in notes helps students encode information into memory (e.g. Di Vesta and Gray 1972). Research on the encoding function of note taking, however, has yielded mixed results. Studies have failed to consistently demonstrate that students who take notes learn more than students who only listen during lectures (e.g. Kiewra 1985; Kiewra et al. 1991; Knight and McKelvie 1986). Although the encoding function reflects the idea that note takers engage in generative processing (Di Vesta and Gray 1972), there is little evidence that note takers engage in generative activities (e.g. Kiewra et al. 1991). Instead, the cognitive demands placed on note takers to continuously listen, identify and interpret important information, and record that information into notes leave few cognitive resources available for generative processing of lecture information (Peters 1972), which appears to limit the encoding function of note taking.

The external storage function of note taking proposes that taking lecture notes benefits student learning because notes provide students with a document to review and commit to memory after the lecture is finished (Di Vesta and Gray 1972; Kiewra et al. 1991). The external storage function is grounded in the repetition effect—the more times information is reviewed, the more easily it is stored into and retrieved from memory (e.g. Bromage and Mayer 1986). Research on the external storage function has uncovered robust benefits of reviewing notes. Students who record and review their own lecture notes score higher on tests based on lecture information than their peers who record but do not review lecture notes (e.g. Carter and Van Matre 1975; Kiewra et al. 1991; Knight and McKelvie 1986; Rickards and Friedman 1978). Such trends indicate that the true value in taking lecture notes emerges only when students take time to review their notes.

Studies of the external storage function typically involve students taking and reviewing their own lecture notes before being tested on lecture information and having their test performance compared against students who did not have an opportunity to review their notes before being tested (Armbruster 2000; Robinson and Kiewra 1995; Knight and McKelvie 1986; Luo et al. 2018). Such studies typically report the total number of complete lecture ideas students record in their notes. For instance, Morehead, Dunlosky, and Rawson (2019a) had students record notes using either a laptop or longhand medium while attending a 17-min video lecture. Student notes were scored for the total number of complete lecture ideas recorded during the video lecture. According to Morehead et al. (2019a), "Each idea unit included in the notes that was correct based on information in the video was given one point" (p. 11). Such an approach to analyzing student notes only accounts for the complete ideas that students capture. However, students occasionally record incomplete ideas into their notes (Peverly et al. 2007; Reddington et al. 2015). According to Blohm and Colwell (1983), idea units represent propositional statements from a text or from spoken word that communicate meaning (e.g. cause-effect relationships; compare-contrast; example; state isolated facts). For instance, while learning about the planet Venus, a student might write a complete lecture idea of, "Venus is 67,000,000 miles away from the Sun" or, "Venus = 67 million miles from Sun" into her notes. Another student, however, might merely write, "Venus = 67,000,000 miles." Because this idea unit offers no context for what the distance refers to, this note would represent an incomplete idea unit because it does not complete the full propositional statement. Little is known about the extent to which students store incomplete idea units in their notes. Research into college students' incomplete note-taking tendencies has scored notes using a 4-point scoring system (e.g. Peverly et al. 2007; Reddington et al. 2015). Research using this system has analyzed student notes and assigned point values depending on whether a lecture idea was missing from notes (0 points), mentioned in notes but not explained at all (1 point), mentioned in notes but not fully explained (2 points), or mentioned in notes and fully explained (3 points). For instance, the student learning about planets who simply wrote, "Venus = 67,000,000" would receive 2 points for this piece of noted information—the idea unit was mentioned in student notes, but only partially explained. There is no information available to indicate if this refers to distance from the Sun, earth, or some other celestial body. It is plausible that a student studying this incomplete idea unit days or weeks after the lesson would not be able to recall what the idea unit refers to, thus eliminating any potential benefit of reviewing that piece of noted information. Given that most college students review their lecture notes to study for exams (e.g. Blasiman et al. 2017; Morehead et al. 2019b), studying notes replete with incomplete idea units could hinder the external storage function of lecture notes and diminish how well students do on quizzes or exams.

Although the 4-point scoring procedure used previously accounts for the presence of partial ideas in students' notes, the use of a cumulative score to index the quality of student notes provides no insight into how many incomplete idea units are present in students' notes. Participants are assigned a total score—higher scores are indicative of more information being contained in notes—which is then used to predict their performance on posttests following simulated lectures. The present study addresses this gap in the literature by examining the proportions of complete and incomplete lecture ideas stored in students' notes and how the magnitude of incomplete note taking relates to learning as assessed by a posttest of lecture content.

Laptop versus longhand note taking

Technological advances have led many college students to type lecture notes on their laptops rather than rely on the traditional longhand method (Morehead et al. 2019b), leading contemporary researchers to investigate how note-taking behaviors and learning differ whether students take notes using a laptop or longhand method.

Laptop note takers have an advantage over longhand note takers in terms of the volume of words and complete text-based lecture ideas they capture in their notes (Bui et al. 2012; Luo et al. 2018; Morehead et al. 2019a; Mueller and Oppenheimer 2014). Because most students type faster than they write (Brown 1988), taking notes on a laptop makes it easier to quickly record lecture ideas into their notes than the longhand method (Kay and Lauricella 2011). The speed advantage allows laptop note takers to store approximately 20% more complete text-based ideas in their notes than longhand note takers (Bui et al. 2012). The speed at which laptop users type their notes allows them to transcribe many lecture ideas in a verbatim, word-for-word style as ideas are communicated during class, while longhand note takers adapt to their speed disadvantage by paraphrasing lecture ideas into shorter sentences (Bui et al. 2012; Luo et al. 2018; Mueller and Oppenheimer 2014).

The speed advantage held by laptop users does not help them record more lecture-related images into their notes than longhand note takers (Fiorella and Mayer 2017; Luo et al. 2018). For instance, Luo et al. (2018) had undergraduate participants take notes using either a laptop or longhand method while viewing a simulated lecture on the topic of educational measurement that contained nine images (e.g. positively and negatively skewed distributions). As a group, the 30 laptop note takers failed to record even a single image in their notes. Although typing on a laptop makes it easier to record textual information into notes, the functionality of word processing programs makes it difficult to quickly and easily record images into notes (e.g. Mosleh et al. 2016; Reimer et al. 2009).

Despite differences in note-taking style and the quantity of complete text-based idea units and lecture-related images captured in their notes, laptop and longhand note takers have not consistently demonstrated meaningful achievement differences. Specifically, research has yielded mixed findings with respect to laptop and longhand note takers' performance on tests immediately following lectures. Separate studies have favored longhand (Mueller and Oppenheimer 2014) and laptop (Bui et al. 2012) note-taking methods. Other research found no advantage for either method when testing immediately followed a lecture (Luo et al. 2018). Similar inconsistencies have also emerged when students are given an opportunity to review their notes, as separate studies have identified higher performance for longhand note takers relative to laptop note takers on free recall and multiple-choice tests (Luo et al. 2018; Mueller and Oppenheimer 2014) and no advantages for either method (Morehead et al. 2019a) when notes are reviewed. Such inconsistencies in the laptop versus longhand literature led Morehead et al. (2019a) to conclude that there is not enough evidence to claim that either note-taking method is superior to the other for boosting student learning. Regarding the encoding and external storage functions of note taking, it appears that neither method has consistently emerged as possessing superior encoding benefits or as a more useful record of lecture ideas to study from and commit to memory.

When achievement differences for laptop and longhand note takers have emerged, researchers have typically pointed to differences in the tendencies of laptop and longhand note takers to transcribe lecture ideas verbatim as a contributing factor (e.g. Mueller and Oppenheimer 2014). However, research related to the outcomes stemming from transcribing or paraphrasing one's lecture notes has also been mixed. For instance, research has favored both laptop users' tendency to transcribe lecture ideas verbatim (Bui et al. 2012) and longhand note takers' tendency to paraphrase lecture ideas (Luo et al. 2018) when students review notes prior to testing and favored laptop note takers' verbatim tendency when students do not have an opportunity to review their notes before testing (Bui et al. 2012). Furthermore, despite uncovering large differences in the extent to which laptop and longhand note takers captured verbatim lecture ideas, Morehead et al. (2019a) uncovered small, non-significant achievement differences—leading these scholars to contend that qualitative differences in how laptop and longhand note takers capture lecture ideas do not appear to consistently produce different learning outcomes.

Differences in note-taking style (i.e. verbatim versus paraphrased) do not lead to consistent achievement differences (e.g. Morehead et al. 2019a). What remains unknown, however, is the extent to which laptop and longhand note takers record incomplete lecture ideas into their notes and whether any differences are subsequently predictive of achievement. As previously discussed, the existing research on lecture note-taking has focused almost exclusively on the extent to which students store complete lecture idea units into their notes and ignored the extent to which students capture incomplete lecture idea units (Bui et al. 2012; Kiewra et al. 1995; Mueller and Oppenheimer 2014; Morehead et al. 2019a). Given that the true benefit of lecture note taking appears to stem from the external storage function (Kiewra et al. 1991; Rickhards and Friedman 1978), it is plausible that the extent to which students record incomplete lecture idea units into their notes hinders the external storage function of lecture notes and diminishes learning and achievement. Furthermore, because of the documented differences in how quickly laptop and longhand note takers can record lecture ideas into their notes, it is also plausible that laptop and longhand users differ in the number of incomplete lecture ideas contained in their notes. The present study addressed these important literature gaps by comparing how laptop and longhand note takers differed in the extent to which they recorded complete and incomplete lecture ideas into their notes and whether these differences related to performance on a lecture posttest.

Digital distractions and note taking

Despite the importance of recording and reviewing lecture notes, the rise of digital technology has created a situation wherein mobile devices often pull students off-task during class (McCoy 2016; Pettijohn et al. 2015). Such regular off-task behavior indicates that an accurate depiction of college students' classroom learning experiences should account for digital distraction. Three known studies examined how sending and receiving lecture-irrelevant text messages during simulated lectures influenced lecture note taking and learning when notes were recorded using a longhand method (i.e. Kuznekoff and Titsworth 2013; Kuznekoff et al. 2015; Waite et al. 2018). Across all three studies, college students who sent and received text messages during simulated lectures recorded fewer lecture ideas in their handwritten notes than students who did not text during the lecture—texters recorded between 35 and 60% fewer complete lecture ideas than non-texters during the simulated lectures (Kuznekoff and Titsworth 2013; Kuznekoff et al. 2015; Waite et al. 2018). Moreover, texters recalled 30% fewer complete ideas on free recall tests (Kuznekoff and Titsworth 2013; Kuznekoff et al. 2015) and performed more poorly on multiple-choice tests following the lectures (Kuznekoff and Titsworth 2013; Kuznekoff et al. 2015; Waite et al. 2018) than non-texters. The superior performance of non-texters relative to texters on lecture posttests was present whether students reviewed (Kuznekoff and Titsworth 2013; Kuznekoff et al. 2015) or did not review (Waite et al. 2018) their lecture notes beforehand. However, because all three known studies examined how texting affected note taking when notes were written by hand, no known research has examined the impact that digital distraction has on lecture note taking and learning when notes are typed during lectures. Furthermore, it remains unknown how the presence of digital distractions impacts the proportion of incomplete idea units students capture in their notes when notes are typed or written. The present study addresses both important gaps in the existing literature base.

The present research

The primary purpose of the present study was to investigate the interplay among note-taking method, digital distraction, and learning. Specifically, we examined how distraction level (texting; no texting) interacted with note-taking medium (laptop; longhand) to affect lecture note-taking behaviors and learning. To do so, we had college students attend a video lecture and record notes using either a laptop or longhand medium. Half of the participants in both note-taking medium groups responded to text messages while taking notes during the video lecture.

The secondary purpose of the present study was to examine the extent to which students record incomplete lecture ideas into their notes. The existing research on student note taking has focused almost exclusively on the extent to which students record complete text-based lecture ideas (e.g. Bui et al. 2012; Mueller and Oppenheimer 2014) or images (e.g.

Fiorella and Mayer 2017) into their notes. Recently, Luo et al. (2018) investigated how students differentially recorded complete and incomplete images into their notes across laptop and longhand note-taking mediums. However, the extent to which students record incomplete text-based idea units into their notes remains understudied. Only a few studies have accounted for the presence of incomplete idea units in students' lecture notes (e.g. Peverly et al. 2007; Reddington et al. 2015), but these studies have not indexed the proportion of incomplete idea units present in students' lecture notes. Thus, the present research also examined (a) the extent to which students record incomplete idea units into their notes and (b) how the extent to which students capture complete and incomplete lecture ideas into their notes relates to lecture learning.

Based on the existing literature, two predominant hypotheses guided the present study:

H1: Digital distraction will be more consequential for the note-taking quantity and quality of longhand note takers due to their speed disadvantage relative to laptop note takers.
H2: The proportion of incomplete idea units stored in student notes will be negatively associated with posttest achievement due to the lower external storage value of those notes.

Method

Participants and design

Participants were 100 undergraduate students enrolled in communication studies and education courses at a large, public Midwestern university who participated in order to receive course credit. Participants were mostly underclassmen (55%) and female (60%) and 66% held cumulative grade-point averages (GPAs) of 3.0 or higher. Most participants were White (86%). See Table 1 for complete demographic information. Approval for the present study was granted by the Institutional Review Board at Ohio University.

The present study used a 2 (note-taking medium: laptop vs. longhand) X 2 (distraction level: texting vs. no-texting) factorial design. Data collection took place in a university classroom setting. Because data were collected during students' personal time outside of class, participants signed up for data collection sessions online by choosing from 26 available timeslots. All participants were required to bring a mobile phone with them to the data collection site. Prior to their arrival at the data collection site, half of the participants were randomly selected and instructed to bring a laptop computer with them. Upon arrival, participants were randomly assigned to either the no-distraction or distraction condition. This process ultimately resulted in the creation of four participant groups: a longhand (no texting) group ($n=25$), a longhand (texting) group ($n=25$), a laptop (no texting) group ($n=25$), or a laptop (texting) group ($n=25$). Data were collected from participants in groups ranging in size from two to eight participants at once. Such an approach has been utilized in past experimental research on student learning when researchers were unable to gather many participants at a single time point (e.g. Colliot and Jamet 2018a, b). Because students can become distracted when classmates use digital devices for off-task purposes during class (Sana et al. 2013), students in the no-distraction groups were seated in front of the participants in the distraction groups where they would be unaware of the off-task behavior.

Table 1 Participant demographic information

	Laptop (no-texting)	Laptop (tex-ting)	Longhand (no-tex-ting)	Long-hand (texting)
Gender				
Male	9	8	7	15
Female	16	17	18	10
Race/ethnicity				
White	22	21	22	21
Hispanic/Latino	1	0	1	0
Black	1	1	0	2
Asian/Pacific Islander	0	0	1	0
Mixed heritage	1	3	0	2
Other	0	0	1	0
Grade level				
Freshman	12	8	10	11
Sophomore	2	4	7	1
Junior	2	4	3	1
Senior	9	9	5	12
Preferred note-taking method				
Laptop	4	5	7	7
Longhand	16	18	16	18
Don't take notes	1	0	0	0
Other	4	2	2	0
Prior course on plate tectonics?				
Yes	5	3	0	0
No	20	22	25	25
Prior tectonic plate knowledge				
None	4	7	6	5
A little	13	9	12	13
Some of it	4	5	5	7
Most of it	2	4	2	0
All of it	2	0	0	0

Values refer to total numbers of participants

Materials

Participants viewed a 15-min video lecture on the topic of plate tectonics theory. The video was displayed on a projector screen in a classroom setting. The video lecture consisted of an instructor standing in front of a whiteboard that had 12 lecture-relevant images projected onto it throughout the lecture. The video lecture contained 2235 words presented at a rate of approximately 149 wpm. The rate of speech in the video lecture is consistent with previous recommendations regarding the relationship between rate of instructor speech and student learning (e.g. Simonds et al. 2006) and similar to the rate of speech used in video lectures in previous investigations of differences between laptop and longhand note taking (e.g. Morehead et al. 2019a; Mueller and Oppenheimer 2014). The first four minutes of the video lecture described the earth's layers (e.g. crust, upper and lower mantle). The next six minutes of the video lecture described the three types of plate boundaries (i.e. convergent, divergent and transform) and their related geological processes (e.g. subduction, seafloor spreading, rifting, earthquakes). The final five minutes discussed different types of fault planes (e.g. dip-slip and strike-slip). The content validity of the video lecture was confirmed by a doctoral-level geologist.

Longhand note takers received blank paper and pens for note taking. Laptop note takers took notes on their own laptops. All but two participants recorded their notes using the Microsoft Word program; the other two participants recorded their notes on the Google Docs application.

Participants in the longhand (texting) and laptop (texting) groups received and replied to text messages on their own mobile phones during the learning session. Participants in these groups were provided with a URL to enter into their mobile web browser. The URL took participants to a Qualtrics® survey that was programmed to send a new question to their mobile phone every 40 s. These questions were designed to simulate incoming text messages. Participants received and responded to 21 total questions. Example questions include, "What is your favorite local restaurant for dinner?" or "What movie do you recommend to see in the theater?" All the questions were irrelevant to the plate tectonics video lecture.

A distractor task was used to clear working memory between the learning phase and testing. The distractor task consisted of an 18-item word completion task. Participants were given two minutes to complete 18 fragmented words. For example, one item presented students with the following fragment: "B_x_r." Participants were tasked with completing the fragmented word. For instance, completing the "B_x_r" fragment by writing "Boxer."

The multiple-choice test consisted of 40 items and contained a mixture of fact-learning and concept-recognition questions (e.g. Kiewra 2009; Luo et al. 2018). Thirty questions assessed how well participants learned the factual information presented during the lecture. For example, "Seafloor spreading is the result of what kind of tectonic plate boundary?" Ten concept questions assessed students' ability to identify novel examples of lecture concepts. For example, "Which type of plate boundary does the image below represent?" The fact-learning and concept-recognition questions were interspersed together throughout the exam, so that students did not complete all fact-learning and then all concept-recognition questions together. Test items were presented in a fixed order for all participants. The test's overall internal consistency, as measured by Cronbach's Alpha, was 0.779.

A 10-item exit survey collected participants' demographic information, note-taking medium preference, and lecture topic knowledge. Demographic information included participants' gender, age, ethnicity, class standing, major, and cumulative GPA. Freshmen participants provided their cumulative high school GPA because the data were collected during their first collegiate semester. Note-taking medium preference was assessed by asking participants how they typically record notes during lectures (a. Pen/pencil and paper, b. laptop, c. I don't take notes, d. Other) and if the note-taking method they used during the video lecture aligned with how they typically record lecture notes (a. Yes, b. No). Lecture topic knowledge was assessed by asking participants if they had ever taken a college-level course on the theory of plate tectonics (a. Yes, b. No) and how much information contained in the video lecture on plate tectonics they knew before watching the video lecture (1. None, 2. A little, 3. Some of it, 4. Most of it, 5. All of it).

Procedure

Participants were provided with copies of the informed consent sheet and given time to read through the document and ask questions to the primary investigator. The primary investigator then read the research instructions aloud. Participants in the longhand (no texting) and longhand (texting) groups were provided with pens and paper to take notes; participants in the laptop (no texting) and laptop (texting) groups were instructed to turn on their laptops and open the Microsoft Word® program. Participants in the texting groups were provided with a link to access the Qualtrics® survey and instructed how to respond to the survey using their mobile phones. Participants then viewed the video lecture. Participants were given five minutes to review their notes after watching the lecture before completing the distractor task. Then, participants were given 40 min to complete the posttest. Questions on the final test were presented in a fixed order to all participants. Finally, participants completed the demographic survey before being debriefed and dismissed.

Pilot study

Six undergraduate students participated in a pilot study to test the research procedures. All six students arrived at a classroom setting and were assigned randomly to one of the study's four groups before being provided with the same research directions and procedures described above. Participants completed all stages of the research process, beginning with reading and signing of the informed consent sheet and ending with the demographic survey. During the pilot study, text messages were delivered via the Qualtrics® survey at a rate of once every 30 s to align with the procedures used in previous research (e.g. Kuznekoff and Titsworth 2013; Kuznekoff et al. 2015). The primary investigator orally questioned the group of pilot participants about their experience after the completion of the pilot study. Participants disagreed about how the frequency of the text messages received during the pilot study reflected their typical classroom experiences. Two participants suggested that text messages or other forms of social media messaging cause them to receive messages similar to the rate they received messages during the pilot study. All other participants indicated that they received more text messages during the pilot study than they would receive during a typical classroom lecture. Thus, it was decided that the delivery of the text messages would be slowed to a rate of once every 40 s, reducing the total number of text messages received during the video lecture from 30 to 21 messages. The decision to reduce the number of text messages allowed us to provide participants with an experience that is a closer approximation to most of our pilot study participants' typical classroom experiences while simultaneously keeping our data collection approach similar to that used by past researchers in this domain (e.g. Kuznekoff and Titsworth 2013; Kuznekoff et al. 2015).

Data analysis

The multiple-choice tests were scored by the researchers using an objective scoring sheet. Test achievement was measured by calculating the total number of questions participants answered correctly on the 40-item multiple-choice test.

All lecture notes were scored for total word count, total complete and incomplete main ideas, total complete and incomplete supporting details, and total complete and incomplete examples for each participant. An efficiency rating was also calculated to index the average number of words needed to capture complete idea units into notes (e.g. Kiewra 1985; Luo et al. 2018; Morehead et al. 2019a). The primary researcher and a trained rater each scored one-fourth of the lecture notes to establish reliability for the note scoring procedures. Total word counts for typed notes were scored by computer using the Microsoft Word® "word count" function. Total word counts for longhand notes were tabulated by summing the total number of stand-alone units (i.e. individual words, numbers, symbols) contained in students' notes—the same rules used by the Microsoft Word® "word count" function.

The video lecture contained a total of 143 lecture ideas. The number of lecture ideas relative to the length of the lecture was similar to that used in previous research (e.g. Luo et al. 2018). The video lecture consisted of 22 main topics, 105 supporting details, and 16 examples. Participants were awarded points based on whether they captured a complete or incomplete lecture idea. We followed Blohm and Colwell's (1983) approach for classifying idea units. As discussed by Blohm and Colwell (1983), propositions from a text or from spoken word are statements that communicate meaning (e.g. cause-effect relationships; compare-contrast; example; state isolated facts). Student lecture notes, then, were scored by identifying isolated idea units (e.g. propositions/statements) that convey unique pieces of information. A sample idea unit in the present study: the crust is 25 miles thick underneath the continental surface. Blohm and Colwell (1983) showed that lecture ideas can be divided into different categories based on their level of subordination to each other. In the present research, lecture ideas were divided into three categories: main topics, supporting details, and examples. Main topics are superordinate idea units that represent the main subjects that were discussed during the video lecture. Examples of main topics include the names of the different tectonic plate boundaries (i.e. convergent, divergent, and transform), faults (i.e. dip-slip and strike-slip faults), or layers of the earth (i.e. lithosphere, crust, lower mantle) discussed during the video lecture. Supporting details are subordinate ideas that provide supplemental information related to the characteristics and processes involved in main topics. An example of a supporting detail is, "The crust is 25 miles thick underneath the continental surface." Examples are real-world illustrations of the main topics or supporting details. For instance, "If a left-lateral fault occurred between you and a barn, then you would see the barn shift to your left." Participants were awarded one point for each complete lecture idea contained in their notes. For instance, participants who noted ideas such as, "The crust is 25 miles thick underneath the continental surface" or "Crust = 25 mi. thick under continental surface" were awarded one point for a complete lecture idea because the idea unit contains the complete proposition—it conveys the statement's full meaning.

Incomplete idea units were also scored by assigning participants one point for each incomplete idea contained in their notes. Because students often shorten and paraphrase their notes to keep up with the pace of lectures (e.g. Van Meter et al. 1994), lecture ideas were scored as incomplete only if they lacked details that could not be inferred from the noted information. For instance, participants who noted, "Crust = 25 miles thick" received one point for an incomplete lecture idea because this noted information contains no cues that a student studying the information later could use to infer that the distance refers to the depth underneath the continental surface. Moreover, because the depth of the crust differs underneath continental and seafloor surfaces, a student reviewing this incomplete idea unit might fail to recall the type of crust to which this depth is related.

Idea units present in participants' lecture notes that were deemed to be incomplete were further investigated using an "identification only" and "identification + incomplete description" framework similar to the approaches used by past researchers who accounted for the presence of partial idea units in student lecture notes (Peverly et al. 2007; Reddington et al.

2015). Incomplete idea units were classified as "identification only" if the idea unit simply named a lecture idea without providing any supplemental information about that idea unit. For instance, if a participant wrote, "Hanging Wall," then she received 1 point for identifying that lecture concept. However, this idea unit lacks the details necessary to complete the proposition—there is no description or definition of what the hanging wall is or the direction it moves in a fault plane. Or, a participant who wrote down, "Barn Example" without providing any information necessary to detail what was illustrated by this example, would be credited for only identifying that example. In line with past research (e.g. Peverly et al. 2007; Reddington et al. 2015), such idea units are considered incomplete because they only identify the concepts without providing the elaboration necessary to understand how the hanging wall functions or what was illustrated by the barn example. Incomplete ideas were classified as "identification + incomplete description" if the idea unit identified a lecture concept and attempted to complete the full proposition but failed to do so. For instance, the video lecture informed participants that, "The hanging wall moves downward in relation to the footwall during a normal dip-slip fault," but if a participant only wrote, "Hanging Wall = down" in an attempt to convey the full statement, then the idea unit was labeled as "identification + incomplete description" and assigned one point because it attempts to fully capture the proposition for this idea unit, but fails to do so completely. Cohen's kappa was 0.823 for scored lecture ideas, indicating a substantially high degree of agreement between the two raters (Cohen 1988). Disagreements were discussed and resolved.

Notes were also scored for the number of complete images contained (e.g. an image of subduction or a dip-slip fault). The video lecture contained a total of 12 images. Participants received one point for each complete image recorded into their notes. Cohen's kappa was 0.942 for scored images, indicating excellent agreement between the two raters (Cohen 1988). Disagreements were resolved by discussion. Three sample images have been included in the Appendix.

Results

Results pertain to preliminary analyses, note-taking behaviors, and achievement.

Preliminary analyses

Chi-squared tests and analysis of variance (ANOVA) were conducted for demographic variables, prior knowledge, and note-taking medium preference. Table 2 provides group

Table 2 Group differences across demographic variables

	Chi square tests		Analysis of variance	
	χ^2	p	F	p
Gender	5.191	0.213		
Typical note-taking method	8.41	0.493		
Alignment with typical note-taking method	13.051	0.005		
College-level course	9.783	0.021		
Prior plate tectonic knowledge			0.862	0.374

statistics for these analyses. The four groups (longhand no-texting, longhand texting, laptop no-texting, and laptop texting) differed significantly on the extent to which they had previously taken a college-level course on the theory of plate tectonics ($p=0.021$) and whether the note-taking method they were assigned to in the present study differed from how they typically take notes ($p=0.005$). Neither variable was included in our analyses as covariates. Eight of our participants had previously taken a college-level course on the theory of plate tectonics. Because all of these participants were randomly assigned to the laptop note-taking condition, variance in this demographic variable was not spread across all of our treatment groups, making it unsuitable as a covariate (Miller and Chapman 2001). Furthermore, alignment between typical note-taking methods and treatment group assignment significantly differed across treatment groups, which can obscure the treatment effect when controlled for in statistical analyses (Wildt and Ahtola 1978). As a result, neither variable was included as a covariate in our analyses. The four groups did not differ significantly on any other demographic or note-taking variables. Refer to Table 1 for an overview of participant demographic information across the four note-taking groups.

Note-taking outcomes

Participant notes were scored for (a) total word count, (b) complete and incomplete main topics, supporting details, and examples, (c) note-taking efficiency, and (d) images. See Table 3 for descriptive statistics and correlations among the note-taking outcomes, Table 4 for means across note-taking medium and distraction level, and Table 5 for means across note-taking groups. Although prior course enrollment was not included as a covariate in our analyses, separate analyses were run using prior course enrollment as a predictor variable to determine whether prior course enrollment biased our findings.

Total word count

The total number of words captured in participant lecture notes was dependent upon note-taking modality and distraction level. Laptop users tended to store more words in their notes than longhand note takers and non-texters tended to capture more total words than texters. However, this was not due to more laptop users having previously taken a course on plate tectonics, as there was no significant difference in word count between these individuals and individuals who had not previously taken such a course, $F(1, 98)=1.28$, $p=0.261$, partial $\eta^2=0.013$. A two-way ANOVA revealed significant main effects for medium, $F(1, 96)=47.09$, $p<0.001$, partial $\eta^2=0.329$, and distraction level, $F(1, 96)=24.26$, $p<0.001$, partial $\eta^2=0.202$, on total word count, and a significant interaction between medium and distraction level, $F(1, 96)=3.99$, $p=0.049$, partial $\eta^2=0.040$.

The interaction between note-taking medium and distraction level is depicted in Fig. 1. As can be seen in the figure, the note-taking capabilities of laptop users are particularly hindered when they succumb to digital distraction while taking lecture notes relative to longhand note takers. Follow-up tests of simple effects were conducted to probe the interaction. Simple main effects for distraction level emerged regardless of whether participants were taking notes using either a laptop, $p<0.001$, partial $\eta^2=0.200$, or longhand, $p=0.041$, partial $\eta^2=0.043$, method. Across both note-taking modalities, undistracted participants recorded more total words in their lecture notes than their distracted peers. Undistracted laptop note takers recorded more words than distracted laptop note takers and undistracted longhand note takers recorded more words than distracted longhand note takers ($p<0.05$

Table 3 Descriptive statistics and correlations for note-taking outcomes and posttest score

Variable	*M*	*SD*	1	2	3	4	5	6	7	8	9
1. Word count	175.46	74.80	_								
2. Efficiency	4.15	1.21	0.631**	_							
3. Main ideas complete	17.61	3.50	0.434**	−0.225*	_						
4. Main ideas incomplete	1.14	1.53	0.140	0.456**	−0.284**	_					
5. Supporting details complete	13.34	7.04	0.837**	0.359**	0.482**	0.109	_				
6. Supporting details incomplete	6.51	3.62	0.281**	−0.052	0.151	0.011	0.087	_			
7. Examples complete	2.90	2.12	0.558**	0.249**	0.329**	0.165*	0.651**	−0.022	_		
8. Examples incomplete	0.42	0.79	0.177*	0.109	0.081	0.117	−0.044	0.301**	−0.142	_	
9. Total posttest score	23.29	5.96	0.202*	0.631**	0.434**	0.140	0.837**	0.281**	0.558**	0.177*	_

n 100 for all reported variables

*$p < 0.05$

**$p < 0.001$

Table 4 Posttest and note taking differences across distraction level and note-taking medium

	Distracted	Undistracted	Laptop	Longhand
Total posttest score	22.00 (5.79)	24.58 (5.91)	23.36 (6.48)	23.22 (5.46)
Total words	147.46 (56.01)	203.46 (81.04)	214.48 (77.05)	136.44 (47.56)
Total complete ideas	29.16 (6.96)	38.54 (11.59)	37.24 (10.99)	30.46 (9.24)
Complete main topics	16.44 (2.57)	18.78 (3.92)	18.26 (3.16)	16.96 (3.73)
Complete details	10.56 (4.59)	16.12 (7.96)	15.78 (7.44)	10.90 (5.72)
Complete examples	2.16 (1.74)	3.64 (2.24)	3.20 (1.99)	2.60 (2.24)
Total incomplete ideas	7.74 (4.45)	8.52 (4.61)	8.10 (3.98)	8.16 (8.12)
Incomplete main ideas	1.10 (1.22)	1.30 (1.84)	1.22 (1.15)	1.18 (1.89)
Incomplete details	6.36 (3.77)	6.66 (3.51)	6.44 (3.59)	6.58 (3.69)
Incomplete examples	0.28 (0.64)	0.56 (0.91)	0.44 (0.79)	0.40 (0.81)
Total idea units	36.90 (9.34)	47.06 (12.61)	45.34 (12.01)	38.62 (11.18)
% of recorded notes complete	79%	82%	82%	79%
% of recorded notes incomplete	21%	18%	18%	21%

Values represent average total test scores and the average total number of each idea-type contained in participant notes. Standard deviations provided in parentheses

for all comparisons). Second, simple main effects for medium were detected when students were either texting, $p=0.001$, partial $\eta^2=0.110$, or not texting, $p<0.001$, partial $\eta^2=0.290$, as they took notes. Undistracted laptop note takers recorded more words than undistracted longhand note takers and distracted laptop note takers recorded more words than distracted longhand note takers ($p<0.01$ for all comparisons). However, a final planned comparison revealed no significant difference in the total word counts recorded by distracted laptop note takers and undistracted longhand note takers, $p=0.521$. The similar word counts for these two groups highlights the interaction between note-taking modality and distraction level—texting during the simulated lecture caused the speed advantage traditionally held by laptop users to dissipate to the point that their total word count was on par with undistracted participants who took handwritten notes.

Complete idea units

A two-way MANOVA—medium (laptop versus longhand) by distraction (texting versus no texting)—was conducted on total complete main idea units, total complete supporting details, and total complete examples recorded into notes. These three dependent variables were included in the MANOVA to index the extent to which students captured complete lecture ideas in their notes. Findings indicated that laptop users and non-texters

Table 5 Differences in posttest scores and note-taking outcomes across groups

	Distracted laptop	Distracted longhand	Undistracted laptop	Undistracted longhand
Total posttest score	22.12 (5.66)	21.88 (6.02)	24.32 (5.13)	24.84 (6.71)
Total words	175.12 (58.88)	119.80 (36.69)	253.84 (73.67)	153.08 (51.91)
Total complete ideas	31.32 (7.66)	27.00 (5.53)	43.12 (10.76)	33.92 (10.81)
Complete main topics	16.84 (2.75)	16.04 (2.37)	19.68 (2.94)	17.88 (4.58)
Complete details	12.08 (5.07)	9.04 (3.54)	19.48 (7.67)	12.76 (6.87)
Complete examples	2.40 (1.68)	1.92 (1.80)	4.00 (1.98)	3.28 (2.46)
Total incomplete ideas	7.56 (4.76)	7.92 (4.21)	8.64 (3.01)	8.84 (5.86)
Incomplete main ideas	1.28 (1.34)	0.92 (1.08)	1.16 (0.94)	1.44 (2.45)
Incomplete details	5.96 (3.96)	6.76 (3.59)	6.92 (3.17)	6.40 (3.86)
Incomplete examples	0.32 (0.69)	0.24 (0.59)	0.56 (0.96)	0.56 (0.87)
Total idea units	38.88 (10.21)	34.92 (8.11)	51.80 (10.17)	42.32 (12.91)
% Complete	81%	77%	83%	80%
% Incomplete	19%	23%	17%	20%

Values represent average total test scores and the average total number of each idea-type contained in participant notes. Standard deviations provided in parentheses

captured more complete idea units than longhand note takers and texters. The omnibus test revealed main effects for note-taking medium, $F(3, 94) = 5.911$, Pillai's Trace $= 0.159$, $p = 0.001$, partial $\eta^2 = 0.159$, and distraction level, $F(3, 94) = 8.840$, Pillai's Trace $= 0.220$, $p < 0.001$, partial $\eta^2 = 0.220$, but no interaction effect of note-taking medium and distraction level, $F(3, 94) = 0.969$, Pillai's Trace $= 0.030$, $p = 0.411$, partial $\eta^2 = 0.030$. There was not a significant effect for prior course enrollment, $F(1, 98) = 0.415$, Pillai's Trace $= 0.013$, $p = 0.742$, partial $\eta^2 = 0.013$.

Table 6 shows the proportions of the total lecture ideas students successfully captured in their notes. Participants were skilled at capturing main topics but showed less of a tendency to fully capture supporting details and examples. All four note-taking groups successfully captured more than 70% of the 22 main topics that were discussed in the video lecture. However, participants recorded a much smaller proportion of the supporting details. Both longhand groups and the distracted laptop users stored approximately 10% of the lecture's 105 supporting details in their notes, while undistracted laptop users captured nearly 20% of the complete details. Meanwhile, undistracted note takers recorded a greater proportion of the 16 examples that were discussed during the lecture than their distracted peers. Overall, undistracted note takers tended to store a greater proportion of each type of lecture idea

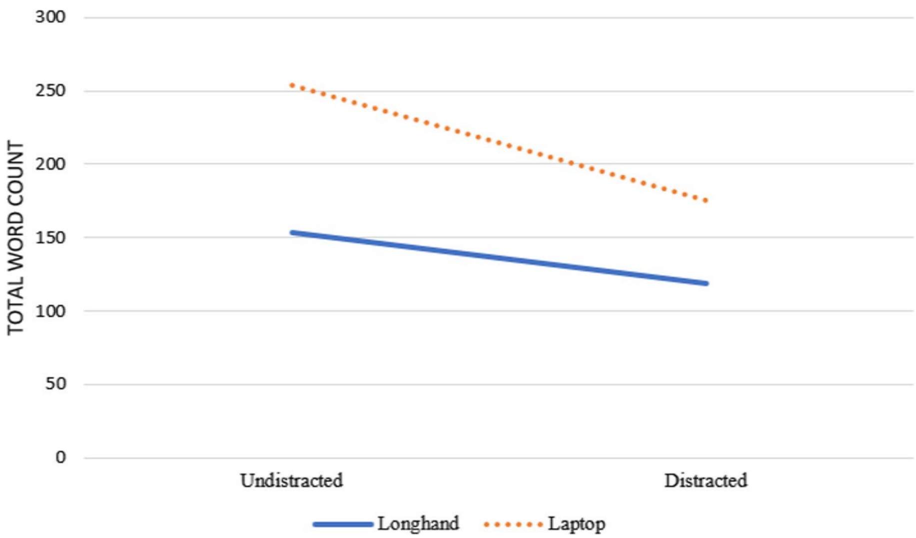

Fig. 1 Interaction between note-taking medium and distraction level for total word count

Table 6 Average proportions of total lecture ideas captured as complete and incomplete idea units by group

	Distracted laptop	Distracted longhand	Undistracted laptop	Undistracted longhand
Complete ideas				
Complete main topics	0.77	0.73	0.89	0.81
Complete details	0.12	0.09	0.19	0.12
Complete examples	0.15	0.12	0.25	0.21
Incomplete ideas				
Incomplete main ideas	0.06	0.04	0.05	0.09
Incomplete details	0.06	0.06	0.07	0.06
Incomplete examples	0.02	0.02	0.04	0.04

Proportions based on a total of 22 main topics, 105 supporting details, and 16 examples

into their notes, with the undistracted laptop users emerging as the most successful. The next three paragraphs further address complete main ideas, supporting details, and examples, respectively.

Distraction level emerged as the only variable that accounted for the number of complete main topics captured in lecture notes, $F(1, 96) = 12{,}779$, $p = 0.001$, partial $\eta^2 = 0.117$. Non-texters recorded more complete main topics into their notes than texters. Note-taking medium did not meaningfully differentiate the number of main topics participants stored into their notes, $F(1, 96) = 3.944$, $p = 0.050$, partial $\eta^2 = 0.039$, and there was not an interaction between note-taking medium and distraction level, $F(1, 96) = 0.583$, $p = 0.447$, partial $\eta^2 = 0.006$. Storage of main topics did not differ based on prior course enrollment, $F(1, 98) = 1.137$, $p = 0.289$, partial $\eta^2 = 0.011$.

The number of complete supporting details stored in participants' notes varied depending on their note-taking medium and distraction level. In general, laptop users and non-texters stored more complete supporting details into their notes than longhand note takers and texters. A significant main effect emerged for note-taking medium, $F(1, 96) = 16.511$, $p < 0.001$, partial $\eta^2 = 0.147$, with laptop users recording more complete supporting details into their notes than longhand note takers. However, this was not due to more laptop users having previously taken a course on plate tectonics, as there was no significant difference in the number of complete support details captured between these individuals and individuals who had not previously taken such a course, $F(1, 98) = 0.556$, $p = 0.458$, partial $\eta^2 = 0.006$. A significant main effect emerged for distraction level, $F(1, 96) = 21.433$, $p < 0.001$, partial $\eta^2 = 0.183$, with non-texters recording more complete supporting into their notes than texters, $p = 0.001$. There was not an interaction between note-taking medium and distraction level, $F(1, 96) = 2.347$, $p = 0.129$, partial $\eta^2 = 0.024$.

Distraction level emerged as the only variable that accounted for the number of complete examples captured in lecture notes, $F(1, 96) = 13.659$, $p < 0.001$, partial $\eta^2 = 0.128$. Non-texters recorded more complete examples into their notes than texters. There was not a main effect for note-taking medium, $F(1, 96) = 2.245$, $p = 0.137$, partial $\eta^2 = 0.023$, nor was there an interaction between note-taking medium and distraction level, $F(1, 96) = 0.90$, $p = 0.765$, partial $\eta^2 = 0.001$. The number of examples stored in lecture notes did not differ as a function of prior course enrollment, $F(1, 98) = 0.096$, $p = 0.757$, partial $\eta^2 = 0.001$.

Incomplete idea units

A two-way MANOVA—medium (laptop versus longhand) by distraction (texting versus no texting)—was conducted on total incomplete main idea units, total incomplete supporting details, and total incomplete examples recorded into notes. These three dependent variables were included in the MANOVA to index the extent to which students recorded incomplete lecture ideas into their notes. Findings indicate that the tendency to store incomplete idea units in lecture notes did not differ depending on note-taking medium or distraction level. The overall multivariate tested revealed no significant interaction effect, $F(3, 94) = 0.680$, Pillai's Trace $= 0.021$, $p = 0.567$, partial $\eta^2 = 0.021$, and no main effects for note-taking medium, $F(3, 94) = 0.050$, Pillai's Trace $= 0.002$, $p = 0.985$, partial $\eta^2 = 0.002$, or distraction level, $F(3, 94) = 1.093$, Pillai's Trace $= 0.034$, $p = 0.356$, partial $\eta^2 = 0.034$. There was not a significant effect for prior course enrollment, $F(3, 96) = 0.962$, Pillai's Trace $= 0.029$, $p = 0.414$, partial $\eta^2 = 0.029$.

As seen in Tables 4 and 5, the number of incomplete idea units recorded by the participants was consistent across groups. Regardless of distraction level or note-taking method, approximately 20% of the idea units students captured in their notes were incomplete. Participants were relatively skilled at capturing complete main ideas (e.g. the names of different faults or foundational principles of tectonic plate theory) and examples, but seemed to struggle to capture the supporting details (e.g. directions moved by hanging wall and footwall blocks in each type of fault) that were communicated during the lecture. Approximately one-third of all the supporting details captured in students' notes were incomplete idea units.

Amount of information captured in incomplete idea units

Incomplete idea units were examined further to investigate how the amount of information contained in each incomplete idea (i.e. identification-only and identification + incomplete description) differed across note-taking medium and distraction level.

Group means for the number of "identification-only" and "identification + incomplete description" idea units contained in participant notes can be found in Table 7. The next three paragraphs overview the amount of information contained in incomplete main topics, supporting details, and examples, respectively.

The number of "identification-only" and "identification + incomplete description" main topic idea units did not meaningfully differ across note-taking conditions. No significant main effects emerged for note-taking medium, $F(2, 95) = 0.174$, Pillai's Trace = 0.004, $p = 0.841$, partial $\eta^2 = 0.004$, or distraction level $F(2, 95) = 0.696$, Pillai's Trace = 0.014, $p = 0.501$, partial $\eta^2 = 0.014$, and no interaction existed, $F(2, 95) = 0.392$, Pillai's Trace = 0.008, $p = 0.677$, partial $\eta^2 = 0.008$. It appears that neither note-taking medium or distraction level differentially affects the amount of information contained in the incomplete main topics students store in their notes.

Undistracted note takers tended to include more information in the incomplete supporting details they captured in their notes than their peers who texted during the video lecture, $F(2, 95) = 0.246$, Pillai's Trace = 0.246, $p < 0.001$, partial $\eta^2 = 0.246$. Distracted note takers displayed more instances of "identification-only" supporting details in their notes than undistracted note takers, $F(1, 96) = 7.370$, $p < 0.001$, partial $\eta^2 = 0.071$. Undistracted note takers displayed more instances of "identification + incomplete description" supporting details in their notes than distracted note takers, $F(1, 96) = 18.977$, $p < 0.001$, partial $\eta^2 = 0.165$. Such findings indicate that distracted note takers are more likely to simply write down the name of a supporting detail without trying to capture a complete description or definition, while undistracted note takers display a greater tendency to at least attempt to capture full descriptions or definitions of supporting details, even though they might fail to do so completely. No main effect emerged for note-taking medium, $F(2, 95) = 0.044$, Pillai's Trace = 0.001, $p = 0.957$, partial $\eta^2 = 0.001$, and no interaction emerged between distraction level and note-taking medium, $F(2, 95) = 0.388$, Pillai's Trace = 0.008, $p = 0.679$, partial $\eta^2 = 0.008$.

The number of "identification-only" and "identification + incomplete description" examples contained in participants' notes did not meaningfully differ across note-taking conditions. No significant main effects emerged for note-taking medium, $F(2, 95) = 0.043$, Pillai's Trace = 0.001, $p = 0.958$, partial $\eta^2 = 0.001$, or distraction level $F(2, 95) = 0.2.097$, Pillai's Trace = 0.042, $p = 0.129$, partial $\eta^2 = 0.042$, and no interaction existed, $F(2, 95) = 0.359$, Pillai's Trace = 0.008, $p = 0.699$, partial $\eta^2 = 0.008$. It appears that neither note-taking medium nor distraction level differentially interferes with the

Table 7 Group means for number of incomplete idea units contained in notes by idea type

	Distracted laptop	Distracted longhand	Undistracted laptop	Undistracted longhand
Identification-only				
Main topics	1.28	0.88	1.36	1.44
Supporting details	3.92	4.36	2.76	2.60
Examples	0.24	0.20	0.52	0.48
Identification + incomplete description				
Main topics	0.04	0.04	0.04	0.04
Supporting details	2.04	2.32	4.16	3.80
Examples	0.08	0.04	0.04	0.08

amount of information students capture when they store incomplete examples in their notes.

Note-taking efficiency

An efficiency rating was calculated for each participant by dividing the total word count used to capture complete idea units by the total number of complete idea units recorded (e.g. Kiewra 1985; Morehead et al. 2019a), which provides an index of the average number of words each participant used to capture complete idea units into his or her notes. Two-way ANOVA analysis—medium (laptop versus longhand) by distraction (texting versus no texting)—revealed significant main effects for note-taking medium, $F(1, 96)=21.685$, $p<0.001$, partial $\eta^2=0.184$, and distraction level, $F(1, 96)=4.026$, $p=0.048$, partial $\eta^2=0.040$, but no interaction between note-taking medium and distraction level, $F(1, 96)=0.034$, $p=0.854$, partial $\eta^2=0.000$. Distracted participants ($M=3.92$, SD = 0.89) were more efficient than undistracted participants ($M=4.37$, SD = 1.54) and longhand note takers ($M=3.63$, SD = 1.31) were more efficient than laptop users ($M=4.66$, SD = 0.86). There was not a significant effect for prior course enrollment, $F(1, 98)=0.130$, $p=0.720$, partial $\eta^2=0.001$.

Total images

A two-way ANOVA—medium (laptop versus longhand) by distraction (texting versus no texting)—was conducted on the total number of images participants recorded into their notes. The omnibus test revealed no significant interaction between note-taking medium and distraction level, $F(1, 96)=0.130$, $p=0.931$, partial $\eta^2=0.000$, and no main effect for distraction level, $F(1, 98)=0.007$, $p=0.931$, partial $\eta^2=0.000$. A main effect for note-taking medium emerged, $F(1, 98)=34.411$, $p<0.001$, partial $\eta^2=0.264$. Longhand note takers recorded more images into their notes than laptop note takers. No laptop users recorded any images into their notes. None of the images stored into students' notes were incomplete. There was not a significant effect for prior course enrollment, $F(1, 98)=2.301$, $p=0.132$, partial $\eta^2=0.023$.

Achievement

A two-way ANOVA—medium (laptop versus longhand) by distraction (texting versus no texting)—was conducted on the total posttest score. The omnibus test revealed no significant interaction between note-taking medium and distraction level, $F(1, 96)=0.103$, $p=0.748$, partial $\eta^2=0.001$, and no main effect for note-taking medium, $F(1, 98)=0.103$, $p=0.906$, partial $\eta^2=0.000$. A main effect for distraction level emerged, $F(1, 98)=4.769$, $p=0.031$, partial $\eta^2=0.047$. Non-texters scored more highly on the posttest than texters, $p=0.044$. There was not a significant effect for prior course enrollment, $F(1, 98)=1.811$, $p=0.182$, partial $\eta^2=0.018$.

Correlations shown in Table 3 revealed that posttest achievement was positively associated with measures of note-taking quantity. Three separate regression analyses were conducted to investigate the relationship between note-taking outcomes and posttest achievement. All Regression statistics can be found in Table 8.

A multiple regression was run to predict total test score from the total number of complete and incomplete idea units students captured in their notes. The multiple regression

Table 8 Relationships between note-taking outcomes and test performance

	B	*t*	*p*	R^2	Adj. R^2
Model 1				0.137	0.119
Total complete idea units	0.196	3.688	< 0.001		
Total incomplete idea units	0.128	1.033	0.304		
Model 2				0.136	0.109
Complete main ideas	0.167	0.907	0.367		
Complete supporting details	0.296	2.596	0.011		
Complete examples	−0.180	−0.514	0.609		
Model 3				0.000	−0.010
Note-taking efficiency rating	−0.083	−0.017	0.868		

model accounted for a significant proportion of the variation in participants' total test scores, $F(2, 97) = 7.709$, $p = 0.001$, adj. $R^2 = 0.119$. Only the total number of complete idea units captured in notes added significantly to the prediction of total test score, $p < 0.001$.

Because the number of complete idea units emerged as a significant predictor of total test score in our initial model, a second model was run using complete main topics, supporting details, and examples as predictor variables. The multiple regression model accounted for a significant proportion of the variation in participants' total test scores, $F(3, 96) = 5.024$, $p = 0.003$, adj. $R^2 = 0.109$. Only the total number of complete supporting details captured in notes added significantly to the prediction of total test score, $p = 0.011$.

Finally, a simple linear regression including only note-taking efficiency as a predictor variable did not account for a significant proportion of variation in participants' total test scores, $F(1, 98) = 0.028$, $p = 0.868$, adj. $R^2 = -0.010$.

Discussion

The present study contributes to literature on lecture note taking in three important ways. First, although scholars have investigated the impact digital distractions have on the quality and quantity of lecture notes and lecture learning when notes are taken using a longhand method (e.g. Kuznekoff and Titsworth 2013; Kuznekoff et al. 2015; Waite et al. 2018), the present study is the first to extend these investigations to include laptop note taking. Second, the present study is the first investigation of laptop versus longhand note taking to incorporate the presence of digital distractions, thereby situating this investigation in an environment that is a closer approximation to students' lived experiences in today's contemporary classrooms where the presence of digital distraction is often ubiquitous. Third, studies of lecture note taking have usually focused on the number of complete lecture ideas students capture in their notes (e.g. Bui et al. 2012; Kiewra et al. 1995; Mueller and Oppenheimer 2014), while the relatively small number of studies that have accounted for the presence of incomplete ideas in student notes did not index the proportion of incomplete ideas relative to complete idea units (Reddington et al. 2015). The present study investigated the extent to which college students store incomplete idea units in their notes to provide a more comprehensive analysis of student note-taking behaviors.

The present study's main objective was investigating how the interplay between distraction level and note-taking medium affected lecture note taking and learning. Consistent with prior research, undistracted laptop users captured more total words and complete lecture ideas in their notes than longhand note takers. Such findings align with the unanimous conclusion reached thus far by existing studies regarding the advantage held by undistracted laptop users for storing text-based lecture ideas into their notes (e.g. Bui et al. 2012; Luo et al. 2018; Morehead et al. 2019a; Mueller and Oppenheimer 2014). Furthermore, longhand note-takers appeared to try and overcome their speed deficit by being more efficient (i.e. use fewer words) when storing complete idea units into their notes. This tendency has been uncovered previously (e.g. Luo et al. 2018; Morehead et al. 2019a). Thus, our study adds to the growing consensus that laptop and longhand note takers differ in the style with which they capture incoming idea units during classroom lectures. Longhand note takers seem to adapt to their speed disadvantage by trying to be more efficient note takers than laptop users.

Despite their attempts to be more efficient, longhand note takers still captured fewer lecture ideas into their notes than laptop users. However, longhand note takers—whether distracted or undistracted—held the advantage over laptop users when storing lecture-related images into their notes. Consistent with Luo et al. (2018), no laptop users captured a single lecture-related image into their notes. Such findings reinforce the notion that although undistracted laptop users are more successful at storing complete text-based lecture ideas into their notes, the functionality of popular word processing programs makes it hard for laptop users to capture lecture-related images into their notes (e.g. Fiorella and Mayer 2017; Mosleh et al. 2016; Reimer et al. 2009). Despite the speed advantage held by laptop users to record text-based information into their notes, the apparent inability of laptop users to capture lecture-relevant images into their notes could potentially place laptop users as a disadvantage during image-heavy lectures. Future research will need to examine how taking notes using a laptop or longhand method relates to learning when images are the primary mode of instruction during lectures. Additionally, various tablet apps allow note takers to use pen-like stylus technology to digitally capture both hand-written notes and images. Research should explore whether such technology is more similar to paper-pen handwritten notes where the capture of images is more likely.

The note-taking advantages traditionally held by laptop users over undistracted longhand note takers essentially disappeared when laptop users sent and received text messages during the simulated lecture. The interaction between note-taking method and distraction level for the total word count in participant notes revealed that laptop users were particularly disrupted by texting during the lecture—contradicting our first hypothesis that digital distraction would be more consequential for longhand note takers because of their speed disadvantage relative to laptop users. Furthermore, although distracted laptop users still stored more total words in their notes, the total was not significantly different from undistracted longhand note takers. Moreover, undistracted longhand note takers recorded more complete main topics, details, examples, and lecture-related images into their notes than their peers who texted while taking notes on a laptop. Taken altogether, these findings indicate that digital distraction negates many of the benefits afforded to students who take notes on their laptops.

The more pronounced consequences experienced by laptop users for several of our note-taking outcomes is a curious finding considering the speed advantage held by laptop users, but a potential explanation exists. Longhand note takers try to paraphrase lecture ideas they store into their notes into shorter sentences to accommodate for the slower speed with which they capture ideas into their notes, while laptop users try to store lecture ideas in a verbatim, word-for-word style as they hear it (Bui et al. 2012; Luo et al. 2018). However, replying to text messages seemed to influence how students stored information into their notes. Specifically, analysis of note-taking efficiency revealed that texters used fewer words to store idea units into their notes than non-texters. It appears that texters tried to become more efficient with the time that they had to capture lecture ideas in-between incoming text messages. Given that laptop users typically try and store lecture ideas in a verbatim fashion, it is plausible that trying to become more efficient in the face of distraction disrupted their note-taking abilities, causing them to store fewer—and less meaningful—words and idea units into their notes than normal. Future research should explore whether the tendency to become more efficient in the face of distraction is commonplace for students using digital devices for off-task purposes during class and to identify the contexts under which note-taking efficiency relates to learning and achievement outcomes for students who multitask with their digital devices while taking notes during class.

Our findings hold potentially serious ramifications for the quality and quantity of lecture note taking in live classrooms. The number of students who prefer taking lecture notes on a laptop has increased in the past several years because many students believe that taking notes on a laptop makes it easier to take notes (Kay and Lauricella 2011) and learn (Morehead et al. 2019b). However, many laptop users spend considerable class time using their devices for off-task purposes (Ragan et al. 2014; Ravizza et al. 2017). Our findings indicate that the tendency of laptop users to succumb to digital distraction during class creates a situation wherein the quality and quantity of their lecture notes becomes on par with, or worse than, undistracted longhand note takers. By continuing to account for digital distraction during note taking, perhaps future research could achieve a more definitive conclusion to whether taking notes on a laptop is truly beneficial for learning in today's digital age. As it stands, findings from the present research support Morehead et al.'s (2019a) contention that it is too early to declare one note-taking method superior to the other.

Succumbing to digital distractions hinders student learning. Regardless of note-taking medium, distracted note takers consistently recorded fewer words and lecture ideas into their notes and scored lower on the posttest than undistracted note takers. The main effect for distraction level on posttest achievement suggests that neither note-taking modality insulates students from the pitfalls of digital distraction. Such findings were consistent with past research regarding the downsides of digital distraction during classroom lectures (Kuznekoff and Titsworth 2013; Kuznekoff et al. 2015; Waite et al. 2018). As discussed by Flanigan and Kiewra (2018), classroom instructors must identify strategies to curb student digital distraction during class if they hope to protect the integrity of the classroom learning environment. Fortunately, instructors can refer to a growing literature base that advocates practical instructional techniques instructors can use to minimize student digital distraction in their courses (e.g. Flanigan and Kiewra 2018; Jorgensen et al. 2018; Wood et al. 2018).

The secondary objective of the present research was to examine college students' tendencies to record incomplete lecture ideas into their notes. Past research has focused almost exclusively on how well students capture complete lecture ideas into their notes (e.g. Bui et al. 2012; Kiewra et al. 1995; Morehead et al. 2019a). The minimal research that has investigated the presence of incomplete idea units in student notes has not reported on the proportionality of incomplete idea units relative to complete idea units in college student lecture notes (Peverly et al. 2007; Reddington et al. 2015). The present study was the first to address this literature gap. Our findings indicate that many of the lecture ideas students capture in their notes are incomplete ideas. Regardless of distraction level or note-taking medium, approximately 20% of all idea units participants stored in their notes were incomplete. Although participants were skilled at storing superordinate main topics and corresponding examples in their notes, they were less successful at capturing subordinate supporting details. Approximately one-third of all the supporting details recorded into notes were incomplete.

Contrary to our second hypothesis, the proportion of incomplete idea units stored in participant lecture notes was not meaningfully predictive of posttest achievement. In fact, the number of incomplete idea units stored into notes showed a positive correlation with total posttest score. However, this relationship appears to have been driven by the fact that, as the number of incomplete idea units captured in notes increased, the number of complete idea units captured in notes increased in greater magnitude. Indeed, regression analyses revealed that only the number of complete idea units captured in notes predicted total posttest score. We predicted that storing incomplete idea units would hinder the external storage benefits of lecture notes. However, this largely was not the case. Storing and studying incomplete idea units did not appear to hinder learning in the present study. Perhaps incomplete idea units serve a retrieval cue function that aids students as they study their notes. Based on McDougall's (1904) threshold hypothesis, it is possible that incomplete idea units are adequate to overcome the recognition threshold and aid recall of the complete idea. Going forward, additional research will be needed to more fully understand if—and to what extent—storage of incomplete idea units boosts student learning and to identify any possible contexts in which storage of incomplete idea units harms learning.

One aspect that might impact the value of studying an incomplete idea unit is the amount of information contained within that idea unit. In the present study, the amount of information contained within incomplete details often differed for participants who did and did not text during the simulated lecture. On one hand, distracted students were more likely to only write down the name of a supporting detail (i.e. identification-only) while not trying to capture any additional information to elaborate on that detail. On the other hand, undistracted students were more likely to capture the name of a supporting detail and try to fully convey the idea unit, but do so incompletely (i.e. identification + incomplete description). And, undistracted students did better on the posttest than distracted participants. By including more information into their incomplete idea units, it is plausible that undistracted students might have benefitted more from reviewing their notes than distracted students who had less information to use as a memory retrieval cue while studying. Clearly, more research is necessary to understand how the amount of information contained in an incomplete idea unit impacts the external storage benefits of that piece of noted information.

Given the benefits of storing complete idea units, it appears that well-intentioned classroom instructors could aid their students by providing them with opportunities to produce a more complete set of lecture notes. For instance, Luo et al. (2016) demonstrated how deliberately embedding pauses into lectures and providing students with opportunities to compare their notes with classmates boosts the number of complete lecture ideas that students record into their notes. Such strategies could be useful for helping students finish the incomplete idea units they capture during lectures. Because Luo et al. (2016) did not investigate whether students finished incomplete idea units during pauses in the lecture or while comparing notes with a partner, future research should investigate how such a strategy could be used to help students finish the incomplete idea units they record during lectures. One practical strategy might be to provide students with opportunities, or encouragement, to use supplemental information sources to add missing information to their notes. The present study was aligned with past research that examined the external storage function of note taking by allowing participants to take and review their own lecture notes (Kiewra et al. 1991; Luo et al. 2018; Morehead et al. 2019a). However, students take notes on more sources than classroom lectures. Textbook readings, online PowerPoint slides, and videos have all been identified by students as other informational sources that they take notes on during and outside of class (Morehead et al. 2019b). To date, no known studies have examined—either in a laboratory or naturalistic setting—the extent to which students add information from supplemental sources to their lecture notes. Providing students with opportunities, or encouraging them, to use such an approach could be a way to help students finish the incomplete idea units they store during lectures and create a more detailed set of notes to study from as they prepare for tests and exams.

Regardless of the strategy used to create a more complete set of lecture notes, such strategies would be wise to focus on helping students finish any incomplete supporting details that are present in their notes. Most of the incomplete idea units contained in student notes were supporting details. Our regression analyses indicated that the presence of incomplete supporting details in students' lecture notes is particularly problematic because the number of complete supporting details captured in students' notes was the only note-taking outcome meaningfully associated with increasing posttest scores. Helping students finish any incomplete supporting details that are present in their notes might be a viable way for instructors to help students build a more robust set of notes to study, which may ultimately boost learning and achievement.

Limitations and future research

There are a few potential limitations to the present research to discuss. First, although the proportion of incomplete idea units recorded into notes did not account for a significant proportion of variance in total test scores in the present study, there are a couple potential causes. First, the posttest was difficult. The average posttest score was 58% and nearly two-thirds of the participants scored within the range from 45–75%. The consistently low student test scores—paired with the uniformity with which the different note-taking groups recorded incomplete idea units—hindered the predictive ability of our (M)ANOVA analyses and regression models.

Second, the nature of the review period could have impacted the external storage benefit of participants' notes. Participants were provided with a five-minute review period before completing the distractor task. However, the review period took place just a few minutes after the simulated lecture ended, so it is possible that the lecture was still relatively fresh in participants' minds and they were able to recall information that had not been completely stored in their notes. Information presented during lectures in live classrooms is often quizzed or tested over days or weeks after that lecture was given—which gives students time to forget information that was not completely captured in their lecture notes and reviewed later. Future research should employ delayed testing procedures to examine how the extent to which students capture—and then subsequently review—incomplete lecture ideas impacts learning and achievement. Such an approach would be aligned with the realities of classroom assessments.

A third potential limitation relates to the content of the simulated lecture. The theory of plate tectonics was selected as the lecture topic because it was correctly believed most of our participants would have little prior knowledge in the topic (see Table 1). However, because this topic was not related to a course in which the participants were currently enrolled, it is possible that participants were less motivated to learn during the video lecture than during typical lectures in the courses in which they are enrolled. Indeed, student perceptions of the instrumentality of to-be-learned content influences task motivation and use of learning strategies (Husman et al. 2000; Malka and Covington 2005; Kover and

Worrell 2010). Future research could address this potential limitation by assessing student interest in, and motivation to learn, the lecture topic or by providing participants with lectures consisting of information relevant to their major(s) or to courses in which they are currently enrolled.

A fourth potential limitation relates to the use of intermittent text messages as the distraction manipulation. College students have self-reported (Flanigan and Babchuk 2015) and research using tracking software on laptop computers (Ravizza et al. 2017) has revealed that digital distraction in the classroom often manifests itself in the form of spending several minutes at a time scrolling through social media accounts or instant messaging with friends before returning their attention to lectures. Future research into the effects of digital distraction on laptop and longhand note-taking methods might benefit from comparing the effects of multiple distraction manipulations (e.g. intermittent text messages, sustained social networking) on the quality and quantity of typed and handwritten lecture notes. Furthermore, the platform used to deliver the intermittent text messages in the present study—Qualtrics®—did not allow us to track how quickly students responded to text messages once they received them or track how long it took participants to reply to the messages. Although our observations during data collection suggested that all participants replied to the messages almost immediately and spent about 5–10 s replying to each message, it is plausible that the amount of time spent replying to messages would influence note-taking outcomes and lecture learning. Future research could address this limitation by delivering the text messaging distraction using a platform that would allow for such data to be gathered and analyzed.

A fifth potential limitation relates to our sample size. Each of our balanced experimental groups consisted of 25 participants. Our recruitment efforts were restricted to departmental participant pools, which constrained our ability to obtain a robust sample size and led to several of our analyses being underpowered (Keppel and Wickens 2004). Future studies would benefit from obtaining larger sample sizes to conduct more well-powered analyses. Such an approach would aid the generalizability of the findings.

Conclusion

Findings from the present study suggest that digital distraction is consequential for the quality and quantity of college students' lecture notes and learning. Regardless of note-taking medium, students who texted during the simulated lecture recorded fewer lecture ideas and performed more poorly on the posttest than their peers who did not text during the lecture. Furthermore, the effects of digital distraction appear to be more impactful for laptop users. Although laptop users typically enjoy the benefit of capturing more words and lecture ideas into their notes than their peers who take handwritten notes (Bui et al. 2012; Luo et al. 2018; Mueller and Oppenheimer 2014), this benefit dissolved for laptop users who texted during the simulated lecture. And, laptop users stored just as many incomplete lecture ideas into their notes as longhand note takers, regardless of distraction level. Questions surrounding whether laptop or longhand note-taking methods are more beneficial for learning will undoubtedly continue to swirl, and our findings suggest that it would be wise for scholars to continue to account for digital distraction so that research studies can be situated within contexts aligned with students' lived experiences in today's college classrooms.

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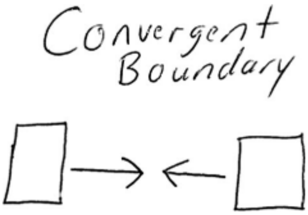
Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interests.

Appendix

See Schemes 1, 2, 3.



Scheme 1. Sample image of convergent boundary from participant lecture notes

Scheme 2. Sample image of rifting process from participant lecture notes

Scheme 3 Sample image of a normal dip-slip fault from participant lecture notes

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