Paper vs. Screen: Effects on Reading Comprehension, Metacognition, and Reader Behavior

Dar-Wei Chen and Richard Catrambone
Georgia Institute of Technology

Students are increasingly learning through online environments that deliver different experiences from traditional classrooms. In this study, participants' learning environments were manipulated using two independent variables, each with two levels for a total of four conditions: study medium, which is the focus of this paper (text was presented either on paper or a screen), and in-text prompts (metacognitive or non-metacognitive in nature). Ninety-two participants were randomly assigned to one of the conditions in a between-subject design; during the study, they each read three expository texts, completed a comprehension test after each text, and responded to a survey at the end of the study. Participants who read text on paper tended to take more notes and spend more time studying than those who read from a screen, but comprehension differences were negligible. Results from this study can inform dialogue about the effects of technology in classrooms.

INTRODUCTION

Technology is now ubiquitous in many fundamental tasks of everyday life, including the presentation of text for reading. According to The Council for Research Excellence (2009), American adults spend an average of 8.5 hours a day looking at a screen. On any given day, Americans are more likely to have read news online (39%) than in a newspaper (23%), despite a robust 47% of Americans reading newspapers as recently as 2000 (Pew Research, 2012). These and other statistics all point in the same direction: the electronic screen is quickly surpassing other forms of text presentation.

Since computers started making their way into workplaces and homes in the late twentieth century, researchers have been studying the various cognitive effects of reading text on screens as opposed to traditional paper sources, and many of the findings have implications for learning. Current research suggests that paper presentation of text still has some advantages, even as people have become increasingly familiar with the backlight of a glowing screen. For example, people are slower when reading from a screen than from paper (Muter et al., 1982; Mayes, Sims, & Koonce, 2001). Skimming also takes more time on a screen than on paper (Muter & Maurutto, 1991). Even proofreading tasks are found to take longer for people using screens, and with less accurate performance (Creed, Dennis, & Newstead, 1987; Oliver, 1994; Wilkinson & Robinshaw, 1987).

Other measures indicate further advantages for paper texts. In a study by Wastlund et al. (2005), comprehension was found to be higher when reading paper. Noyes, Garland, and Robbins (2004) found in their study that although overall comprehension was not significantly different between screen and paper conditions, people reading screens endured higher cognitive workload to achieve that level of comprehension. This conclusion was corroborated by a related finding that screens caused people to report feeling more tired and stressed than paper readers performing the same activities (Wastlund et al., 2005). On a subjective level, online learners and students still prefer print materials "for reasons of portability, dependability, flexibility, and ergonomics" (Spencer, 2006, p. 33) and people also prefer them when they need to study thoroughly (Jamali, Nicholas, & Rowlands, 2009; Buzzetto-More, Sweat-Guy, & Elobaid, 2007). These findings seem to indicate that for all of the advances made in screen technology, paper reading still "feels" better to most people.

However, the performance gap between screens and paper has generally been narrowing in recent years as new technologies address weaknesses in electronic reading or as people generally become more familiar with technology. Therefore, few broad conclusions can be drawn regarding the advantages of one medium over the other because many articles in the body of research contain findings that clash with each other, likely because of variations in methodology such as participant pools, task demands, experimental design, reading material, technology used, etc. Discrepancies can be large, even for similar teams running similar studies: Gould and colleagues (1987a) found that people read more slowly from screens than on paper, but discovered a short time later that screen readers could actually read just as quickly provided particular image quality thresholds (Gould et al., 1987b).

The conclusions by Gould's teams are not anomalous; Oborne and Holton (1988) claim that "when all variables remain constant there is no difference in reading speed or comprehension between screen and paper" (p. 7), and that many other studies failed to hold all variables constant, thus introducing variability that could account for the performance differences. Ackerman and Goldsmith (2011) agreed that comprehension differences are negligible between the mediums, but only when study time is fixed; the differences become significant in self-regulated study (i.e. unlimited study time), as paper readers generally perform better and choose to spend more time with the text.

Differences between reading from screens and paper could be a product of the respective induced reading behaviors, implying that the gap between the two media could be narrowed if people took the same attitudes toward reading in all forms. A survey by Liu (2005) found that "screen-based reading behavior is characterized by more time spent on browsing and scanning, keyword spotting, one-time reading, non-linear reading, and reading more selectively" (p. 700), acts that are not as common in print reading. Morineau et al. (2005) concluded similarly that people put forth less cognitive

effort when using computerized environments. Perhaps as screens and other electronic media become more commonplace, people will read from them increasingly like they do paper texts, thus narrowing any existing performance differences between users of the two study mediums.

There has been a great deal of research examining comprehension differences between screen readers and paper readers, but not as much has been done regarding differences in metacognition ("one's knowledge concerning one's own cognitive processes"; Flavell, 1976) between the mediums. One recent study by Ackerman and Lauterman (2012) demonstrated that, when placed under restrictive time limits, only participants reading from paper were able to become more efficient in learning, scoring as well as they would have in conditions with no time pressure. Paper learners were also found to exhibit less overconfidence and comprehend better than screen learners, suggesting that "the primary differences between the two study media are not cognitive but rather metacognitive – less accurate prediction of performance (POP) and more erratic study-time regulation on screen than on paper" (Ackerman & Goldsmith, 2011, p. 18).

In this experiment, participants read text either from a screen or on paper, and the texts contained either metacognition-inducing prompts or non-metacognitive prompts, creating a 2x2 experimental design and four conditions. In the interest of space, this paper will discuss only the results related to study medium.

METHODS

Participants

Participants were 92 students from Georgia Tech, all of whom received course credit for participation and were at least 18 years in age. They were randomly assigned to conditions.

Materials

All students electing to participate in the study were given a demographics questionnaire to complete, which inquired about gender, age, college major, year in school, college grade point average, SAT scores, reading habits, screen usage, native language, and previous experience with the reading passage topics. Participants also received a stopwatch and instruction on how to use it to track the time they needed to read the passages.

During the study, all participants read three expository text passages, each of which was about 1,000 words in length (the order of the texts was completely counter-balanced between participants and conditions to ensure that any order effects were distributed across conditions). Below is an excerpt from one of the texts:

"According to some estimates, if we could compile the amount of food, land, water, and energy used to raise the 10 billion animals slaughtered each year for meat, we could use those resources to feed every single starving person on earth. The majority of these resources are depleted by concentrated animal feeding operations (CAFOs)."

Participants read either from a standard computer monitor or from printed pages (depending on the condition), and their texts contained either metacognitive prompts or non-metacognitive prompts, to which the participants responded while reading. Text was presented, for both paper and screen conditions, in 12 type size and Times New Roman font with black letters appearing on a white background.

When responding to prompts, participants in all conditions wrote their answers on sheets of paper designated for prompt responses and note-taking. Prompt responses were compared across the two study mediums as well as tested for comprehension predictive power. Any notes were also scored for thoroughness and inference-making.

After a participant finished reading a particular passage, he or she was provided with two example questions at the end of the text: one multiple-choice question for declarative fact knowledge and one short-response question for inference-making and/or information integration. Examples of these questions are below:

- Multiple-choice: Based on information in the passage, it can be inferred that animals raised on CAFOs live indoors because _____
- Short-answer: Fast food plays a sizable role in driving health care costs. Do you think the author would be in favor of raising the minimum wage, which would necessarily cause an increase in fast food prices?

Participants were also asked to use those questions as guidelines to predict their performance on the ensuing comprehension test questions – this dependent measure is called "prediction of performance," or POP. This step was conducted after each passage and entirely on paper, regardless of the study medium used by the participant.

Comprehension tests took place after a participant finished a particular passage and completed the associated POP. The tests consisted of multiple-choice questions and short answer questions. The materials for this step were also entirely on paper for all conditions.

Procedure

All participants read the informed consent form and signed it before participating. They were then given the demographics form to fill out.

The materials given to each participant were from one of four conditions: "paper with metacognitive prompts," "paper with non-metacognitive prompts," "screen with metacognitive prompts," or "screen with non-metacognitive prompts." In all conditions, participants received a sheet of paper to write down responses to their prompts. They also received electronic timers to track the following:

- Time required to answer each prompt – time was used as a proxy for the amount of effort expended
- Time from the start of a passage to the point at which they were ready for POP – this measure represents the time required by the participant to achieve the comprehension level displayed on the test.

Before reading began, participants were told that they had unlimited study time for each of the articles and tests, although nine participants had reading passages waived because they could not stay for the entire study. The nature of the prompts was also explained at this time. During the reading periods, participants were allowed to take notes at any time, but were instructed to perform these tasks in order:

1. Start the timer for the passage
2. Respond to the first prompt (preceding the passage), then record time showing on timer
3. Read the passage until reaching the intermediate thought prompt in the middle of the passage, then record time showing on timer
4. Respond to second prompt, then record time
5. Read the rest of the passage until reaching the third prompt (at end of passage), then record time
6. Respond to third prompt, then record time
7. Read example questions
8. Stop the timer when ready to proceed to the comprehension test, then record time

When ready for the comprehension test, the participants alerted the researcher, who provided the POP materials. After POP was complete, the researcher collected it and distributed the comprehension test, which the participant then completed. This step concluded the procedure for the first passage, and this procedure was repeated for each of the passages until all three were completed. At the end of the last comprehension test, the participants filled out a short survey about their actions during the experiment.

RESULTS AND DISCUSSION

Reading comprehension

The comprehension difference between participants reading from paper ($M = 0.70$, $SD = 0.13$) and those reading from screens ($M = 0.69$, $SD = 0.17$), in terms of performance on multiple-choice questions, was not statistically significant, $t(90) = 0.33$, $p > 0.05$ (maximum comprehension of 1, as in 100%). A similar pattern of insignificant differences held for performance on short-answer questions as well, $t(90) = 0.595$, $p > 0.05$ (Note: Short-answer responses were scored by two raters and analyzed for inter-rater reliability; the intra-class correlation coefficient of absolute agreement for reading comprehension scores was 0.96). These results indicate that participants comprehended as much when reading text from screens as they did when reading text printed on paper.

Although it was hypothesized that those reading from a screen would comprehend less than those reading from paper, the results did not support that hypothesis. The results are in line, however, with recent trends in the "paper vs. screen" literature, which demonstrate that differences in how people read on screen and on paper are diminishing as technology becomes more commonplace. For example, Noyes and Garland (2008) concluded in their meta-analysis that although equivalence between the two mediums is inherently difficult to achieve, greater equivalence is happening more now than in past generations. This trend toward equivalence is not necessarily a surprising one; after all, technology has become a larger presence in the lives of most people, enabling them to become almost as familiar with computer screens as they are with paper. For the population examined in this study (college students), equivalence is even more likely because computers likely played significant roles in their formative years.

Research has shown that younger people are indeed more comfortable with computers and generally have more feelings of control than older people (Czaja & Sharit, 1998). In fact, students are more likely to use e-books than faculty (Anuradha & Usha, 2006). In this study, that comfort level manifested itself in the fact that both study mediums produced statistically equal comprehension. The effects of technology familiarity also seemed to extend into areas that could indirectly affect comprehension, such as mental demand; as measured by NASA TLX responses, participants reported statistically-similar amounts of mental demand in the screen conditions ($M = 0.55$, $SD = 0.18$) as in the paper conditions ($M = 0.50$, $SD = 0.19$), $t(89) = 1.27$, $p > 0.05$. The deleterious effects of extraneous cognitive load are well-documented (e.g. Paas, Renkl, & Sweller, 2003), and it was thought that perhaps computer screens would produce some extraneous load that could decrease comprehension, but the difference in mental demand between the conditions appears to be negligible.

Some of the directions of future work related to these findings are fairly easy to envision. For example, a study similar to this one can be carried out using older populations to determine whether their relative unfamiliarity with technology makes a difference in reading comprehension. Another potential direction is to vary the genres of texts read by the participants. In this study, participants read human interest articles and the results demonstrated that study medium had no significant effect on comprehension, but perhaps other genres of texts could yield different results. Previous research has found that people usually prefer paper when deep processing is needed (Wu & Chen, 2011). Short stories or popular culture articles might be examples of text genres that elicit shallower processing than academic articles, and this processing could interact with the study medium used.

Prediction of performance

To calculate POP accuracy, the participant's actual test scores were subtracted from the participant's predicted scores to create a measure called the "POP-actual differential". When the two study mediums were compared on this measure of prediction accuracy, the differences were statistically insignificant; for multiple-choice questions, participants using screens ($M = 0.09$, $SD = 0.18$) were about as accurate in predicting their test performances as those reading from paper ($M = 0.08$, $SD = 0.18$), $t(90) = 0.21$, $p > 0.05$ (a similar pattern of statistical insignificance was also observed in the short-answer realm). A correlation analysis (predicted performance was correlated with actual performance) added that, for multiple-choice questions, neither those reading screens ($r = 0.23$, $p > 0.05$) or those reading paper ($r = -0.22$, $p > 0.05$) could reliably predict future test performance, with short-answer performance prediction again exhibiting similar correlation patterns with performance. In short, neither study

medium distinguished itself in terms of eliciting accurate predictions, and the participants in general were not especially accurate with predictions; therefore, at least by this measure, metacognition was about equal between the mediums.

These findings were again contrary to the expected results. Because of the relative difficulty of reading text from screens as opposed to paper, participants in the screen-reading conditions were originally hypothesized to have problems with overconfidence because of the "hard-easy" effect (e.g. Lichtenstein, Fischhoff, & Phillips, 1982), the tendency for people to be overconfident when studying difficult materials. A possible explanation for this effect is that working harder to understand material lends itself to feelings of more accomplishment, and therefore, superior understanding. Ackerman and Goldsmith (2011) concluded that the hard-easy effect was at work in their study comparing POP between paper and screen conditions. However, as alluded to earlier with the TLX results, the difficulties inherent in reading from screens are diminishing still (particularly those who have grown up with technology for most of their lives), leading to relative paper-screen equivalence in POP for this study.

To further investigate the effects of study medium on POP, future studies could vary the image qualities of screens to induce hard-easy effects. Although the hard-easy effect did not seem to be at work in the present study, only one particular computer setup was used, hardly a representative sample of all computers and screens. Perhaps with screens of lower image quality, people would be working harder to read the text and thus become overconfident about their understanding of the material (leading to worse POP). Image quality of text on paper is also a possible future manipulation, although perhaps of less interest because printing quality is not usually a limiting factor in most learning environments.

Study behaviors and preferences

Although the study medium manipulation appeared to have little effect on how readers comprehended text or assessed their own learning, some behavioral differences did emerge. The participants reading text on paper ($M = 0.54$, $SD = 0.64$) tended to take more notes while reading than those in the screen conditions ($M = 0.28$, $SD = 0.49$), $t\ (90) = 2.12$, $p < 0.05$ (participants' notes were scored as 0 for writing no notes, 1 for writing general concepts, and 2 for writing detailed ideas). On average, those in the paper conditions ($M = 19.14$ min., $SD = 6.58$) also spent more time studying (reading and answering prompts) than screen condition participants ($M = 16.87$ min., $SD = 4.41$), $t\ (90) = 1.96$, $p = 0.05$.

Taken together, these findings could suggest that when using paper to read text, participants were perhaps more deliberate and conscientious than when using screens (a participant's study time can be interpreted as a metacognitive control decision that he or she is ready for the test). Morineau et al.'s (2005) research suggests that people are inclined to work harder to understand text when it is presented on paper. The reverse also seems to be true – when people want to read in greater depth, they prefer to print out the text rather than read it on a screen (Wu & Chen, 2011). Jabr (2013) adds that electronic text is more ephemeral in nature than printed text, possibly leading readers to feel that words in print are to be lent more credence than words on a screen.

On the other hand, with screen participants achieving comparable comprehension to paper participants while spending less time and taking fewer notes, perhaps technology comfort levels have reached a point in which people are possibly more efficient when learning on screens. That is, as people read more often on screens, whether by choice or necessity, they have adapted to modern circumstances and overcome some of the inherent screen-related difficulties. Maybe screens have "caught up" in this sense.

One area in which screens have not caught up to paper is subjective preference. Data from this study show that the subjective experience of reading on screens is, although familiar, still not preferred to reading paper. In the surveys administered after participants finished the study, 46 % of those in the screen conditions reported that they would have preferred using the other study medium to read the articles, as opposed to just 9% in paper conditions, $t\ (90) = 4.24$, $p < 0.001$. That is, screen learners wanted to switch to paper significantly more often than paper learners wanted to switch to screens. If the screen experience is less pleasant on a subjective level, it makes sense that those using screens would want to end the experience more quickly.

An interesting direction for future studies on reading behavior involves the tablet (or e-books), a relatively new reading form that, in many ways, bridges the gap between screens and paper. The tablet presents text on a screen, but readers can use it to replicate some of the experiences of reading from paper such as associating information with its location on a page, flipping discrete pages, or physically holding the text in the hands (as opposed to looking at a screen from a distance). The points about locating information and flipping discrete pages are important for comprehension: People often recall information by remembering where they saw it on a page (Rothkopf, 1971), which is more difficult to do when reading text that has to be scrolled through in a continuous stream. Scrolling is an interesting area of study because according to Dyson and Haselgrove (2000), the more time someone spends in between scrolling movements, the higher his or her comprehension tends to be. Scrolling text is also likely more mentally taxing than flipping pages because scrolling requires some focus on how the text is moving (Wastlund, 2007). However, tablets still fall short in some areas when compared to paper. Gerlach and Buxmann (2011) propose that digital books produce "haptic dissonance" because they do not feel the way books are expected to feel, and this dissonance can cause discomfort in readers, although this dissonance is likely being negotiated more easily by younger generations and as technology becomes more ubiquitous. For example, a digital book weighs the same regardless of the length of the book, while the weight of a printed book tends to have some relation to its length.

The tablet, as an intermediate medium, could facilitate future research that can be more discerning about the particular characteristics of screens and paper that produce certain outcomes. That is, by using tablets, researchers would be better able to account for variation in comprehension, study behavior, etc. by pinpointing the characteristics that create the

variation. For example, the present study found that participants spent more time studying when reading paper than when reading from a screen. If participants also spend more time when using tablets than when using screens, then it can be inferred that screens themselves are not a deterrent to spending more time, and that perhaps discrete pagination is a feature that promotes increased study time.

CONCLUSIONS

Ackerman and Goldsmith (2011) have posited that performance differences between learners using paper and those using screens are primarily metacognitive, citing decreased POP accuracy, among other measures. More specifically, they found that screens induce less metacognition in readers than paper. Although the study medium manipulation in this study did not produce significant differences on comprehension or metacognition-related measures such as POP, the results did suggest that screen participants performed more efficiently by achieving comparable comprehension and POP accuracy while doing less work than paper participants. Nevertheless, at least in this study, participants still subjectively preferred text on paper.

The prevalence of technology-centered learning is nothing new to those paying attention – in 2011, almost one-third of US college students had taken at least one online course (Online Learning Consortium, 2012). Research regarding the effects of various text delivery mechanisms (and other classroom technologies) is therefore important, as is research concerning instructional design that can help students regulate their own learning when a teacher is not present.

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