Mindwandering While Reading Not Only Reduces Science Learning But Also Increases Content Misunderstandings

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More frequent mindwandering has been shown to reduce overall text comprehension. However, are mindwanders also more likely to generate incorrect associations based on what they have read? This question is especially critical for science learning, as errors in understanding can resonate through future learning efforts. Across 2 experiments, participants read a science text and were asked to generate a causal essay response related to the text, in addition to completing a sentence recognition test. Participants who reported more mindwandering not only demonstrated lower levels of correct understanding overall, but also included more misunderstandings in their essay responses. Mediation analyses suggest that the production of misunderstandings was tied to less available correct knowledge, and not demand characteristics at time of test. The results from these experiments suggest that mindwandering does not just prohibit correct memory for text, but also produces a negative learning effect in the form of textual misunderstanding.

General Audience Summary

Perhaps unsurprisingly, research has shown that when people mindwander away from the task at hand, they remember less correct information about what they were supposed to be learning. However, does mindwandering also cause people to instead learn more incorrect information, or perhaps connect what they were learning in wrong ways? In other words, are they not only learning less correct information, but simultaneously learning more of the incorrect information they should be trying to avoid? To explore this question, in two experiments participants read a science text and were evaluated on how much they mindwandered during reading. Both of the current studies found that when readers mindwander, they not only remember fewer correct concepts, but also demonstrate more misunderstandings of the material. Thus, not only are they less able to tell you correct information, but what little they do know is incorrect. This represents a double impact of mindwandering, which ultimately results in poorer overall understanding of the material. The findings of this study are broadly applicable to all settings that require people to learn information from text, whether in the classroom or on-the-job. Finally, this also suggests that it is especially important to design teaching materials that discourage mindwandering, so as not to put individuals at a huge disadvantage moving forward.

Keywords: Mindwandering, Misunderstanding

Recent research has identified a stable and ubiquitous phenomenon known as mindwandering (also referred to as mindless reading or perceptual decoupling), in which individuals mentally drift away from the task-at-hand and instead focus on internal task-unrelated information. Most agree that this type of behavior is not uncommon, and may even occur as frequently as on-task thought (Killingsworth & Gilbert, 2010). The frequency of mindwandering is also sensitive to individual variation or

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differences across numerous dimensions. For example, more dysphoric individuals tend to mindwander more (Smallwood, O’Connor, Sudbery, & Obonsawin, 2007), and those individuals higher in working memory capacity also seem to mindwander less (Rummel & Boywitt, 2014; Unsworth, McMillan, Brewer, & Spillers, 2012). Similarly, older adults also seem to mindwander less, perhaps suggesting a role of prior knowledge or experience on the likelihood of exhibiting such behavior (Giambra, 1989).

However frequent, the occurrence of this behavior can be detrimental to performance, especially in tasks that require the management and focusing of consciousness. Declines in performance due to increased mindwandering have been observed in multiple contexts, including simple attentional tasks (McVay & Kane, 2009; Smallwood, McSpadden, & Schooler, 2007), and also more complex tasks like driving (He, Becic, Lee, & McCarley, 2011), standardized test performance (Mrazek et al., 2012), and even mood regulation (Killingsworth & Gilbert, 2010; Smallwood, Fishman, & Schooler, 2007; Smallwood, McSpadden, et al., 2007; Smallwood, O’Connor, et al., 2007). Relevant for the current study, mindwandering has also been implicated in the processing and comprehension of textual information (McVay & Kane, 2012; Naylor & Sanchez, 2018; Smallwood, McSpadden, & Schooler, 2008), and as such could have significant implications for learning in educational settings, and specifically in the STEM domains (Smallwood, Fishman, et al., 2007). For example, if one accepts the suggestion that off-task thought occurs nearly as frequently as on-task thought (e.g., Killingsworth & Gilbert, 2010), reducing this behavior in an educational setting to just half of this expected amount (i.e., from 50% to 25%) would be equivalent to adding nearly 45 full school days of additional learning opportunity for students (estimate drawn for data obtained from NCES, 2018). In an age of constant cuts to educational funding and enrichment opportunities for students, acknowledging the potential impact of mindwandering (and more importantly, how to address it) could produce immediate and lasting impacts on the quality of education.

Text Comprehension, Errors in Learning, and Mindwandering

More so than a simple memory exercise in which a participant is asked to remember static pieces of information (e.g., list learning), expository text comprehension represents a distinct cognitive activity where the successful usage and integration of information is valued above rote memorization (Kintsch, 1994). In other words, the goal of reading (especially in science) is not only to remember correct information, but also integrate this knowledge to build an appropriate mental model of instructional material. This process of understanding expository text requires readers to simultaneously manage multiple factors in addition to the representation of the text itself. For example, the degree of domain prior knowledge, text expectations, and even superficial characteristics of how the text is presented can all influence what a reader takes away from a given reading (Kintsch & Yarborough, 1982; Mayer, 1984; Ozuru, Dempsey, & McNamara, 2009; Zwaan, 1994).

While developing understanding is the primary goal when reading in science, an important consideration is how to best measure whether or not this understanding has taken place. Typically, readers are asked to demonstrate their knowledge by completing some kind of summative assessment in one of several traditional forms. These assessments range from somewhat simple recognition tasks (i.e., multiple-choice tests, true-false tests) to more complex free recall tasks (i.e., essay responses, short answers), and these measures are often used in concert. However, across nearly all types of assessments, positive evidence of understanding is explicitly prioritized. For example, multiple-choice tests are scored for how many correct responses are provided, and essay or short answer responses are often evaluated only on how many correct ideas or concepts are contained within a given response. However, this positive-focused approach neglects a critical aspect of evaluating mental models formed while learning science from text: namely, the negative or erroneous information that might also exist within learner’s representations. By considering these misunderstandings, in addition to the amount of correct information in the response, it should be possible to more accurately diagnose readers’ true understanding of the text and target scientific phenomenon. This represents a shift in focus away from considering the mere quantity of correct information in a given response, to instead evaluating the overall quality of knowledge demonstrated, which includes aspects of both correct and incorrect information (Kendeou & van den Broek, 2005).

Especially in science learning, these incorrect connections of knowledge represent a critical problem for all learners (Perkins & Simmons, 1988). It is important to note that these erroneous connections or concepts, are not simply mistakes or slips in understanding (e.g., I meant to select answer A, but accidentally circled B), but instead represent systematic and identifiable misunderstandings of information (Moore et al., 1997). For example, after reading a text about global warming, the idea that the different seasons of the year are produced by variations in Earth’s distance from the sun is a conceptual misunderstanding relating learned relevant information (i.e., the sun’s rays, how they strike Earth, and the seasons) in a fundamentally inappropriate way. Note that this is not a simple error in response, but instead a pervasive and robust misconception of knowledge, and a misunderstanding of how this scientific process works. Not only do such misunderstandings demonstrate that learners do not grasp the target information as well as they perhaps should, but the presence of these misunderstandings can lead to the formation of more pervasive and deeply held misconceptions about the content area (Feltevich, Coulson, & Spiro, 2001; Graham, Berry, & Rowlands, 2013; Smith, Disesa, & Roschelle, 1994). Learners often hold on to such incorrect frameworks staunchly (Guzzetti, Snyder, Glass, & Gamas, 1993), and as such these misunderstandings potentially resonate through multiple learning opportunities by promoting future maladaptive processing based on this erroneous information (Kendeou & van den Broek, 2005; van den Broek & Kendeou, 2008).
The importance of considering how often misunderstandings are made during learning is especially pronounced in studies of mindwandering or mindless reading. As participants are explicitly shifting their focus away from understanding the text, it is often the case that they would likely remember less correct information in text comprehension and the formation of understanding. It is entirely possible, and argued here, that mindwanderers not only remember less correct information, but also are more likely to generate failures of understanding as a result of these breakdowns in attentional focus. This would demonstrate an exponentially increasing negative effect on learners, as not only are readers learning more poorly in the moment, but as discussed above, if this information is carried over to future learning settings, the learner could find themselves even farther behind than normal. Further, as expository text is used in nearly all contexts of adult education, whether academic or on-the-job, it is possible that this phenomenon might have additional costs (both capital and human) outside of just lower grades in a classroom setting.

More misunderstandings might be expected in mindwanderers for several reasons, resulting from efforts during or after reading. First, as mindwandering is often framed as a breakdown in attentional control processes (McVay & Kane, 2012), such breakdowns potentially provide multiple opportunities for failures in understanding during reading. Not only is more irrelevant information permitted to remain active in short-term memory (i.e., the content of what one is mindwandering about pollutes the comprehension process), but as executive control processes are unavailable or distracted, this might also cause the erroneous connection of available relevant information (McVay & Kane, 2010; Trabasso & Suh, 1993). Thus, not only is correct knowledge less likely to be available to those who mindwander, but the limited information that is correct and accessible to mindwanderers is also more likely to be misused and confused. These online consequences could account for both the lower levels of positive learning previously observed in mindwanderers and also the potential development of scientific misunderstandings of information related to a given text.

Further, post-reading processes might also contribute to the formation of erroneous connections in mindwanderers. As individuals are often aware of their mindwandering (McVay, Kane, & Kwapil, 2009), they might attempt to fill the gaps in their knowledge by making connections between what they did actually read to what they glossed over while mindwandering. In other words, as readers know they have missed critical information (but also know they must try to demonstrate that they did learn), they attempt to bring concepts together in inappropriate or disjointed ways at the time-of-test. As reading in most academic settings is completed with the expectation of later evaluation or assessment (McDaniel, Blischak, & Challis, 1994), it would not be surprising to see such post hoc behavior produced as a consequence of mindwandering, perhaps as a compensatory strategy to attempt to make up for overt lapses in processing.

To examine whether erroneous connections of knowledge are more likely to be formed while mindwandering, two studies were conducted in which participants read an expository science text and were asked to demonstrate their knowledge of what they read in both a free recall and recognition task. Participants were also evaluated for mindwandering, and the relationship between the incidence of mindwandering and science learning was then explored. As suggested above, it was expected that those who mindwandered more, while certainly learning less correct scientific information, would also be more likely to demonstrate incorrect associations of the material due to these attentional lapses.

**Experiment 1**

**Methods**

**Participants.** Given that previous investigations have found a medium-to-large effect size for mindwandering on reading comprehension ($f^2 = .21$; McVay & Kane, 2012), results of an a priori power analysis recommended approximately 40 individuals be recruited for the current study. To this end, 47 native English speaking undergraduates (72% female; average age = 19.36 ($SD = 1.69$) years) were recruited from a large public university in the United States. All participants were compensated with course credit for their participation.

**Materials**

**Prior knowledge test and prior earth science coursework.** To ensure that results were not driven by participants’ prior knowledge of the content domain, all participants completed a Volcano Concept Pretest (VCP) before reading. This measure has been used previously to evaluate domain knowledge of plate tectonics (Sanchez & Wiley, 2014; Wiley et al., 2009). The VCP contains 30 inferences related to plate tectonics and volcanic eruptions. 20 of these inferences are factually incorrect, while the remaining 10 are correct. Thus, in this task participants were asked to correctly identify the correct and incorrect inferences, and were awarded one point for every correct answer, with a maximum score of 30. Within this sample, the VCP demonstrated an acceptable level of reliability ($KR_{20} = .71$). The average score on the VCP in this sample was 18.60 ($SD = 2.15$), indicating a low level of prior knowledge, consistent with previous research and usage of the VCP (Wiley et al., 2009).

As an additional means of ensuring participants were low in prior knowledge of the science content area, participants were also asked to self-report how many Earth science courses they had taken previously, both in high school and at the university level. On average, participants reported taking less than one course previously in Earth Science ($M = 0.47$, $SD = 0.93$), consistent with the low prior knowledge levels observed on the VCP above.

**Reading material and comprehension measures.** Participants read an expository Earth science text about plate tectonics
that contained ~3500 words and no illustrations. The text was based on information from the USGS “This Dynamic Planet” unit and the NASA Classrooms of the Future “Volcanoes” unit, originally developed by Wiley (2001). This text includes eight a priori concepts from a causal model of volcanic eruptions. In order to develop a full understanding of the text, participants must integrate these eight causal concepts within their mental model of the text (Sanchez & Wiley, 2014). For example, participants must not only understand that plates move, but appreciate that these plates interact, converge, and subduct within the plate tectonic cycle.

Essay task. After reading, participants were asked to write an argumentative essay responding to the prompt “What caused Mt. St. Helens to erupt?” As the text never explicitly mentions the eruption of Mt. St. Helens, this measure requires participants to appropriately apply their knowledge from the text to this novel situation. Participants were not allowed to access the text during this time, and were asked to write at least one page in response. Essay responses were then examined for the presence of the eight correct concepts, length of response (in words), and any misunderstandings or incorrect concepts. These correct and incorrect concepts, with examples, are available in Table 1.

Two scorers blind to participants’ reports of mind wandering independently coded these essay responses for the presence of correct and incorrect concepts and produced a high level of interrater agreement for both measures (ICCs > .92; ps < .001; Shrout & Fleiss, 1979). Any observed scoring differences were resolved through discussion for the final analysis.

Sentence verification task. A long history of text processing research has provided clear evidence that memory for the textbase and for more deep text comprehension are indeed separable (Fletcher & Chrysler, 1990; Kintsch, 1994). To evaluate these differing levels of text representation, participants also completed a 20-item Sentence Verification Task (SVT; Sanchez & Wiley, 2010) that included 10 sentences that had appeared verbatim in the text and an additional 10 that had not. Participants were asked to identify whether each of these 20 sentences had in fact appeared in the text they just read, and higher scores are indicative of a better textbase representation of the material. Within this sample, this measure also demonstrated an acceptable level of reliability (KR20 = .74).

Mindwandering assessments. Participants completed a series of questionnaires to assess both their task-specific mindwandering, as well as general experiences of lapses of attention and mindwandering. These questionnaires were completed after reading. Post-reading assessments were used for two critical reasons. First, prior research has shown that post-assessments and real-time probing measures of mindwandering are significantly and positively correlated (e.g., McVay & Kane, 2009; Mrazek, Phillips, Franklin, Broadway, & Schooler, 2013; Smallwood, Baracca, Lowe, & Obonsawin, 2003; Smallwood & Schooler, 2006). While it is true that other studies have identified several biases that may result in inaccurate self-reports of mindwandering (e.g., Selig, Carriere, & Smilek, 2015; Vinski & Watter, 2012; Zedelius, Broadway & Schooler, 2015), in all of the above studies, post-assessments of mindwandering produced results that were directly in-line (and consistent) with the results obtained from real-time probing methodologies that instead probed individuals during task completion. Thus, despite mindwandering post-assessments taking place after the mindwandering episodes have actually occurred, learners appear to have a very good sense of the magnitude of their mindwandering, with a degree of accuracy that is highly consistent with those results obtained from real-time probing. Based on these prior results, one would be hard-pressed to dismiss post-assessments as an ineffective means of measuring mindwandering occurrence, as they appear to be valid and reliable metrics of this phenomenon. It is also possible that these metrics are in fact better suited to examining mindwandering in the context of reading comprehension, as these measures are less likely to influence the target behavior itself (see below).

Second, there is also a realistic concern that explicit probing methodology can potentially disrupt reading processes. Such explicit probing is used overwhelmingly in studies of mindwandering and requires the reader to physically stop reading and respond to a question prompt about whether they were mindwandering or not. Numerous studies have found that forcing readers to stop mid-reading to answer questions (regardless of the nature of the questions) can actually reduce text comprehension (e.g., Britton, Piha, Davis, & Wehausen, 1978; Foroughi, Werner, Barragán, & Boehm-Davis, 2015; Hakala & O’Brien, 1995).

Table 1
Correct Causal Concepts and Misunderstandings, With Examples of Each

<table>
<thead>
<tr>
<th>Essay variable</th>
<th>Example response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct causal concepts</td>
<td>Plate move…plates move because of convection currents in the asthenosphere. Commonsense concept of the volcanic activity.</td>
</tr>
<tr>
<td>Plates move</td>
<td>...plates move based on the force exerted by the underlying mantle...</td>
</tr>
<tr>
<td>Plates converge/subduct</td>
<td>Oceanic plate crust subducted under the continental plate...</td>
</tr>
<tr>
<td>Friction</td>
<td>North American continental plate...</td>
</tr>
<tr>
<td>Viscous magma forms</td>
<td>...the magma they form is very sticky and traps gases...</td>
</tr>
<tr>
<td>More buoyant magma rises</td>
<td>...the buoyant magma rises up through the Earth’s crust...</td>
</tr>
<tr>
<td>Magma chambers fill</td>
<td>...magma accumulated in the chambers...</td>
</tr>
<tr>
<td>Cracks/weakness in crust form</td>
<td>Earthquake cause a massive landslide...</td>
</tr>
<tr>
<td>Pressure builds and must be</td>
<td>...once the pressure became too much, the crust...</td>
</tr>
<tr>
<td>released</td>
<td>Explosion or eruption occurred...</td>
</tr>
<tr>
<td>Misunderstandings</td>
<td>Wrong tectonic phenomenon...</td>
</tr>
<tr>
<td>Temperature of Earth’s core</td>
<td>A rise in the Earth’s core temperature below...</td>
</tr>
<tr>
<td>Autonomous magma</td>
<td>Molten rock took such an opportunity...</td>
</tr>
<tr>
<td>External causes</td>
<td>People were drilling oil, they could have caused some pressure to be released or added pressure...</td>
</tr>
<tr>
<td>Abrupt collision</td>
<td>The plate movement had to have been very fast...</td>
</tr>
</tbody>
</table>
These results suggest that there is a potential for a large negative reaction to explicit probing methodologies while reading, which is especially problematic when the goal of the investigation is to measure reading comprehension itself. At the very least, it opens the possibility that reactivity to online probing could affect, or at least interact with, estimations of the relationship between mindwandering and reading comprehension. To provide a more controlled examination of this relationship it seems imperative to utilize measures of mindwandering that do not themselves impact the formation of mental models of text. Given that post-assessments occur after this formative process, and as discussed above provide accurate estimations of mindwandering, these types of post-assessments seem ideal for the study of mindwandering and text comprehension, at least more-so than other explicit probing methodologies.

**Task-specific mindwandering questionnaire (TSWQ).** In order to assess task-specific mindwandering, a post-task survey was developed to measure the frequency of mindwandering experiences during the reading task. This measure consisted of 5 questions loosely adapted from the Mind Wandering Questionnaire (MWQ, see below; Mrazek et al., 2013) and the Memory and Attention Lapses subset of the Cognitive Failures Questionnaire (CFQ-MAL; McVay & Kane, 2009). These five questions were modified to specifically reference mindwandering in the reading task they had just completed (1. While reading the text, how often did you notice your mind wandering to thoughts other than the text?; 2. My full attention was on the text; 3. While reading the text, I found that I hadn’t been thinking about the text and had to re-read a section; 4. While reading the text I caught myself running on “automatic” without much awareness of the content; 5. When I noticed that my mind had wandered I easily refocused my attention) Participants rated each of these questions on a 6 point scale from 1 (almost never) to 6 (almost always), and within this sample this measure demonstrated a high degree of reliability (Cronbach’s α = .80).

**Mindwandering questionnaire.** The Mind Wandering Questionnaire (Mrazek et al., 2013) is a validated five-item scale that assesses the prevalence of mindwandering experiences in a more broad sense, and not necessarily specific to the task at hand. Example statements from this measure include “I do things without paying full attention” and “I mindwander during lectures and presentations” on a 6 point scale from 1 (almost never) to 6 (almost always). Within this sample, this survey produced a high degree of reliability (Cronbach’s α = .76).

**Procedure.** After providing informed consent, participants first completed the VCP. They were then given 15 min to read the volcano text. Participants were warned about the time remaining at both 7 min and 2 min remaining, so they could better manage their reading efforts. Participants were instructed to read the entire text and that they would be tested on it at a later time. After reading, participants were then given 15 min to first complete the comprehension measures and then the mindwandering assessments. The website was unavailable to participants while completing the comprehension measures. When all tasks were completed, participants were thanked and debriefed. The entire study took no longer than 1 h.

**Results and Discussion**

Descriptive statistics and correlations between all measures are available in Table 2. As is visible in Table 2, there are several interesting patterns worth noting. First, all learning measures were significantly correlated in appropriate ways. For example, the number of correct causal concepts in the essay response was positively correlated with SVT performance, and both were negatively correlated with the number of misunderstandings observed in the essay response. Further, both measures of mindwandering were significantly correlated with all comprehension measures, replicating prior research on text comprehension and mindwandering. Finally, both mindwandering questionnaires were significantly correlated with each other. To more closely examine this complex pattern of interrelationships, a second set of analyses were then conducted.

To simultaneously consider the effect of mindwandering on learning while controlling for other factors like prior knowledge, separate linear regressions were performed for each learning variable (i.e., correct causal concepts, misunderstandings, and SVT). As both the TSWQ and MWQ were significantly correlated (r = .59, p = .000), these 2 scores were standardized and then averaged together to form a mindwandering composite (MWC) score. VCP, essay length, and MWC score were then used to predict performance on the essay variables, while VCP and MWC were used to predict performance on the SVT.

**Correct causal concepts in essay responses.** Results indicated that although the number of correct causes was predicted by the model (R² = .21, F(3, 43) = 3.86, p = .02), only MWC was a reliable predictor of how much correct information participants learned (β = −.44, p = .002). VCP (β = −.02) and essay length (β = .12) did not predict the amount of correct causal information in the essay response (ps > .39). This suggests that those who reported more mindwandering learned less correct information than those who reported lower levels of mindwandering behavior, consistent with prior research that has found such effects in narrative texts (Franklin et al., 2011; McVay & Kane, 2012; Smallwood et al., 2008).

**Misunderstandings in essay responses.** In terms of the amount of incorrect concepts or misunderstandings within the essay responses, the model was also able to predict a significant portion of variance, R² = .26, F(3, 43) = 5.01, p = .01. However, only essay length (β = .37) and MWC (β = .32) were reliable predictors of the number of misunderstandings in the essay responses (ps < .02). VCP performance was once again unrelated to this aspect of essay performance (β = .09, p = .52). Those that wrote longer essays were more likely to include erroneous concepts. Also, as was the case with the number of correct causes, those that reported more mindwandering learned less well, evidenced by more incorrect concepts in their essay responses. This suggests that participants who mindwandered were more likely to demonstrate misunderstandings of the material, and these incorrect pieces of information were included in their attempt to apply their knowledge to the essay task.

**Sentence verification task.** Finally, in terms of the ability to simply recognize information that had been read previously, the model was once again able to predict a significant portion
Means of subsequent post-wandered the mentioned also sensitive multiple function the this more via relevant appeared significantly that predict this successful recognition behavior (β = −.35; p = .01), and overall VCP performance also appeared to be related to this task performance (β = .29; p = .04). Those that mindwandered more were able to recognize fewer sentences, and those that had higher levels of prior knowledge also appeared to score better on the SVT.

An additional set of analyses (also controlling for VCP) was conducted by examining the two subsets of items that make up the total SVT score: the 10 items that were drawn verbatim from the text, and 10 items that were not contained in the text. These subsequent analyses indicated that those who mindwandered more (β = −.32; p = .02) were less likely to recognize sentences that were actually in the text ($R^2 = .25, F(2, 44) = 7.25, p = .002$), although there was apparently no difference in recognizing information that was not presented, $R^2 = .05, F(2, 44) = 1.20, p = .31$. Taken together, these results suggest that participants who mindwandered more had a less accurate representation of the text itself, and this less accurate textbase representation was not a function of increased false-alarming to information that was not presented, but instead less of a sense of what was actually in the text.

These findings thus corroborate the above results found in the essay response, suggesting that more mindwandering does in fact produce lower learning, in this case in the form of recognizing information that has been previously read. These results also suggest that the recognition measures are perhaps more sensitive to prior knowledge of the individuals (e.g., Lipson, 1982; Long & Prat, 2002) than the free recall measures used above.

**Multiple mediation analyses of misunderstandings.** As mentioned above, it is possible that the demonstration of misunderstandings could be a result of either a failure to gather relevant information while learning (e.g., missing information whilst reading and not suppressing irrelevant thought), or instead post hoc efforts at time-of-test to compensate for mindwandering via the inappropriate homogenization of available information. In a final effort to distinguish between these potential causes, a multiple mediation analysis was conducted using the bootstrapping procedure (5000 samples) of Preacher and Hayes (2008). In this model, it was evaluated whether the actual relevant knowledge learners possessed (evidenced by a composite score of the standardized values for correct causes mentioned in the essay response and their score on the SVT), or instead a testing demand characteristic (evidenced by length of essay response) mediated the observed relationship between MWC and the production of misunderstandings. It is important to note that while these two potential mediators were uncorrelated in this sample ($r = .04, p = .81$) indicating they are separable factors, simple correlations also indicated that both factors were both positively correlated to the occurrence of misunderstandings. Prior knowledge was also controlled for in this analysis by using VCP as a covariate.

Results are summarized in Figure 1. Analyses indicated that only overall correct knowledge was predicted by increased mindwandering, $F(2, 44) = 6.80, MSE = .59, p = .01$, whereas length of essay response was not ($F < 1$). The amount of overall correct knowledge learners possessed also exerted a significant indirect effect (.23; 95% CI [.10, .43]) on misunderstandings, but the indirect effect of essay length was not significant (.01; 95% CI [−.10, .15]). Finally, the direct effect of MWC on misunderstanding (.31; 95% CI [.03, .59]) became non-significant (.08; 95% CI [−.16, .34]) when testing the mediated model, suggesting a fully mediated relationship between MWC and misunderstanding by correct knowledge. This mediation analysis suggests that the relationship between mindwandering and the occurrence of misunderstanding can be fully accounted for by reductions in the amount of correct information present in the learners’ mental model, and not reaction to the need to demonstrate a response at the time of test.
Experiment 2

To ensure that the observed effects in Experiment 1 were not merely an artifact of the post-reading evaluation of mindwandering, a second experiment was conducted in which participants were probed explicitly while reading. Participants also completed a pre-reading essay to assess the likelihood that they possessed the identified misunderstandings prior to reading. All other aspects of the experiment were identical.

Methods

Participants. Seventy-four (70% female, Mean age = 20.04 years, SD = 5.19) native English speaking undergraduates who had not participated in Experiment 1 were solicited for participation in this second experiment. All participants were compensated with course credit.

Materials and procedure. All materials and procedures were identical to that of Experiment 1, with three changes. First, participants were now probed for mindwandering while reading, consistent with the procedure of McVay and Kane (2012). In this probing procedure, participants were explicitly interrupted while reading, and asked to respond to the following probe: “What were you just thinking about? Please be honest. Press the # that corresponds with your choice.” Participants were asked to select among seven different alternatives in response to the above probe: (1) the text, (2) how well I’m learning the material, (3) everyday stuff, (4) personal worries, (5) current state of being, (6) daydreams, (7) other. Responses 1 and 2 were classified as on-task thoughts, while all remaining options were classified as task unrelated thoughts (TUTs), indicative of mindwandering. Participants were probed every 2 min for as long as the participants read. Thus, participants who read longer also received more probes. In order to provide an estimate of mindwandering behavior that takes into account the overall amount of probing respective to each individual, a proportion of TUT responses was calculated (number of TUT responses divided by number of total probes). The TSMWQ was still completed by participants after reading; however, the general MWQ was also eliminated from this study due to the fact that it did not appear to significantly diverge from the TSMWQ in both this sample and others, in addition to new pragmatic concerns about time constraints resulting from the addition of the probing methodology and additional pre-essay (see below).

The second major difference involved the inclusion of an additional pretest that required students to write a causal essay about volcanic eruptions, in a context that while superficially dissimilar to the target essay about Mt. St. Helens, is conceptually identical to the target essay. In this new pre-essay, participants were informed that it has been speculated that Mt. Rainier, located in Washington, might erupt sometime soon, and participants were asked to generate a causal essay about what might produce an eruption of Mt. Rainier? Importantly, Mt. Rainier is also located in the Cascade range (just as Mt. St. Helens is), but has not erupted. It was hoped that if participants possessed any of the identified misunderstandings prior to reading, they would demonstrate them in this pre-essay. This pre-essay was completed before the VCP. Two independent coders scored these pre (and post) essays for both the correct causal concepts and misunderstandings identified in Experiment 1, and produced a high degree of inter-rater reliability for both pre-essay measures (ICCs > .91, p < .001), and for both measures on the subsequent target essay about Mt. St. Helens (ICCs > .92, p < .001). To provide a more accurate holistic understanding of participants’ knowledge and mental model, a difference score was then calculated (target essay minus pre-essay) for both correct causal concepts and misunderstandings in the final essay response (Mt. St. Helens). Higher scores for either change score are indicative of attainment of more correct causal concepts, or conversely, more misunderstandings.

All other measures and procedures were identical to Experiment 1.

Results and Discussion

Descriptive statistics are available in Table 3. Consistent with Experiment 1, measures of understanding were significantly correlated in anticipated ways, such that the attainment of more correct causal concepts coincided with less misunderstandings (r = −.29, p < .01), and more correct causal understanding was positively correlated with SVT performance (r = .25, p < .03), while more misunderstanding negatively correlated with SVT performance (r = −.24, p < .04). Similarly, both measures of mindwandering were also positively correlated. Higher proportion of TUTs corresponded with significantly higher scores on the TSMWQ (r = .63, p < .001). This correlation confirms the assertion made in Experiment 1 (and in numerous other studies) that online probing of mindwandering appears to be nearly synonymous with post-task evaluation when it comes to evaluating the occurrence of mindwandering.

As in Experiment 1, these simple patterns of interrelation were then further examined using linear regression analysis. As both the TSMWQ and proportion TUT measures were significantly correlated, these two scores were standardized and averaged together to form a mindwandering composite (MWC) score as in Experiment 1. VCP, target essay length, and MWC score were then used to predict performance on both target essay variables, and VCP and MWC were also used to predict SVT performance.

Correct causal concepts and misunderstandings in essay responses. Identical to the pattern of results in Experiment 1, the change in number of correct causes was predicted by the model (R² = .17, F[3, 70] = 4.68, p = .005), and only MWC was a reliable predictor of correct information learned (β = −.34, p = .004). VCP (β = .11) and essay length (β = .12) did not predict the amount of correct causal information in the essay response (ps > .30).

Similarly, the change in the amount of misunderstandings was also significantly predicted by the model (R² = .14, F[3, 70] = 3.72, p = .02), and was only predicted by MWC (β = .35). Both essay length (β = .09) and VCP (β = −.08, ps > .44) were once again unrelated to misunderstandings in the essay response. Thus, the results of this second experiment directly replicate the critical essay findings of Experiment 1, even with the incorporation of an online probing measure.
Means (SDs) and Inter-correlations for All Measures for Experiment 2

<table>
<thead>
<tr>
<th>Measure</th>
<th>Mean (SD)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. VCP</td>
<td>20.14 (2.96)</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Pre-essay causal concepts</td>
<td>0.78 (0.73)</td>
<td>-10</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Pre-essay misunderstandings</td>
<td>0.39 (0.54)</td>
<td>.04</td>
<td>-.06</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Target essay length (words)</td>
<td>57.28 (23.51)</td>
<td>-.04</td>
<td>.13</td>
<td>-.08</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Target causal concepts</td>
<td>2.05 (0.92)</td>
<td>.11</td>
<td>-.33</td>
<td>-.07</td>
<td>.28</td>
<td>-.37</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Target misunderstandings</td>
<td>1.12 (0.70)</td>
<td>-.15</td>
<td>-.00</td>
<td>.20</td>
<td>-.03</td>
<td>-.37</td>
<td>-.37</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Causal concepts Δ</td>
<td>1.27 (0.97)</td>
<td>.18</td>
<td>-.44</td>
<td>-.02</td>
<td>.17</td>
<td>.71</td>
<td>-.35</td>
<td>-.35</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Misunderstandings Δ</td>
<td>0.73 (0.80)</td>
<td>-.16</td>
<td>.04</td>
<td>-.51</td>
<td>-.03</td>
<td>-.28</td>
<td>.74</td>
<td>-.29</td>
<td>-.29</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. SVT</td>
<td>12.18 (2.49)</td>
<td>.20</td>
<td>.12</td>
<td>-.07</td>
<td>.09</td>
<td>.36</td>
<td>-.33</td>
<td>.25</td>
<td>-.24</td>
<td>-.24</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>10. TSMWQ</td>
<td>15.24 (5.18)</td>
<td>-.31</td>
<td>-.06</td>
<td>-.03</td>
<td>-.15</td>
<td>-.36</td>
<td>.32</td>
<td>-.39</td>
<td>.30</td>
<td>-.30</td>
<td>-.30</td>
<td>-</td>
</tr>
<tr>
<td>11. TUT proportion</td>
<td>0.17 (0.22)</td>
<td>-.07</td>
<td>-.05</td>
<td>.00</td>
<td>-.18</td>
<td>-.36</td>
<td>.39</td>
<td>-.30</td>
<td>.34</td>
<td>-.30</td>
<td>-.63</td>
<td>.63</td>
</tr>
</tbody>
</table>

*a p < .05.
** p < .01.

**Sentence verification task.** Finally, when it comes to the ability to simply recognize information that had been read previously, the model was again able to predict a significant portion of variance, \( R^2 = .13, F(2, 71) = 5.26, p = .01 \). MWC did significantly predict this successful recognition behavior (\( \beta = -.31; p = .01 \)); however, VCP performance did not appear to be related to SVT performance (\( \beta = .14; p = .23 \)). This is once again largely consistent with the results of Experiment 1, such that those who mindwandered more also appear to have a less correct surface-level representation of the science text.

**General Discussion**

Prior research has confirmed that mindwandering negatively impacts how much correct information individuals learn when reading a text. The current set of studies sought to extend these results and investigate whether these mindwandering episodes also cause the formation of more incorrect misunderstandings when reading, specifically in science or expository text. Higher reported instances of mindwandering produced lower reading comprehension in both experiments, consistent with previous findings (Franklin et al., 2011; McVay & Kane, 2012; Smallwood et al., 2008). Those that mindwandered not only recognized less verbatim information drawn from the text (e.g., SVT), but also recalled less correct factual information in their essay response. Thus, mindwandering produced lower levels of understanding at multiple levels of text comprehension, consistent with previous speculation (Smallwood, 2011).

Importantly, higher incidences of mindwandering also produced more frequent misunderstandings in readers’ essay responses. Controlling for prior knowledge and response length, across two experiments that included online and offline probing, those that mindwandered more produced significantly more misunderstandings of the material. This novel finding suggests that the negative repercussions of mindwandering are twofold: not only does mindwandering produce lower levels of recall for correct information, but this maladaptive behavior also increases the production of scientific misunderstandings related to the material. This represents the first verification of such a negative learning effect and identifies an additional means by which mindwandering can impact the comprehension of text.

The higher incidence of incorrect concepts for those that mindwandered could be a result of numerous factors. For example, more failures to pay attention and learn material while reading would simply result in less correct (and more incorrect) material being included in learners’ representation of the text. It is also possible that post hoc compensatory attempts to demonstrate understanding at the time of test could result in inappropriate connections of knowledge by the reader. A multiple-mediation analysis was conducted in an attempt to distinguish between these different potential causes, and results indicated that lack of correct knowledge (and not post hoc efforts at test) fully mediated the production of misunderstandings. This finding suggests that the production of misunderstandings is not a compensatory effort by learners to cover up failures in their attentional processes, but instead a probabilistic function of not having enough relevant information in their representation of the text. Future research should continue to explore the mechanisms of how misunderstandings are formed while mindwandering, perhaps exploring how mindwandering impacts physical reading processes (e.g., eye movements), as they might provide additional theoretical insight into how specific breaks in task focus resonate through the comprehension process and what participants know or do not know.

In closing, variations in mindwandering represent a novel and consistent predictor of learning performance. As demonstrated here, the occurrence of this phenomenon can have several repercussions for science learning, both by reducing learning of relevant materials and also increasing the likelihood that individuals develop misunderstandings of information. This twofold decrement is especially problematic when one considers the potential downstream consequences of this phenomenon. For example, learners are not only remembering significantly less than if they were not mindwandering (by approximately 20%, as estimated in this study), but they also move farther from correct understanding by instead remembering incorrect information that must now be explicitly remedied. As such, this likely mandates the need for further instruction to catch up and allow learners to reach criterion levels of performance. However, it
cannot be overlooked that having this incorrect information (for however long it takes to re-educate via future instruction), could produce significant issues for performance. For example, it could take days, weeks, or even months before such misunderstanding is addressed, depending on curriculum or opportunity. Obviously, this could produce not only lower grades on educational assessments and achievement (similar to the context explored here), but in the case of on-the-job or otherwise dangerous workplace training that also uses similar types of texts, the occurrence of both lower learning and more misunderstanding could serve as a recipe for disaster with extreme costs to both employees and employers.

Future research should continue to focus on better understanding the mechanisms and specific consequences mindwandering behavior has on complex performance such as expository text comprehension. Again, as expository writing is used for nearly all forms of adult education, regardless of field or occupation, it becomes imperative to also explore how this relationship is likewise impacted by context or the to-be-learned material. Such investigations will provide additional opportunities to refine theoretical understandings of this broad phenomenon, and more importantly allow for the development of more effective interventions that can be used to maximize learning performance within (and outside of) academic settings. Thus, by understanding how the to-be-learned material or method of delivery may produce or exacerbate mindwandering, more appropriate educational materials can be developed that not only enhance positive learning, but also further minimize this maladaptive behavior and its consequences.

**Conflict of Interest Statement**

The authors declare no conflict of interest.

**Author Contributions**

C.A. Sanchez was responsible for study conceptualization, experimental design, statistical analyses, and manuscript preparation/revision. J.S. Naylor was also involved in study conceptualization, in addition to data collection and manuscript preparation.

**References**


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