An Evidence-Centered Design Approach to Mind Wandering

By: Caitlin Mills, University of Notre Dame

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Introduction

Mind wandering occurs when there is an attentional shift away from external task-related thoughts toward internal task-unrelated thoughts (Smallwood, Fishman, & Schooler, 2007; Smallwood & Schooler, 2006). The experience of mind wandering is common, accounting for up to 50% of our waking thoughts (Killingsworth & Gilbert, 2010). In education contexts, it also occurs frequently: 20–40% of the time during reading, 40% of the time during online video lectures, and about 17% of the time during learning with intelligent tutoring systems (Mills, D'Mello, & Kopp, 2015; Hutt, Mills, White, Donnelly, & D'Mello, in press; Risko, Anderson, Sarwal, Engelhardt, & Kingstone, 2012).

Although mind wandering can be beneficial for creativity and future planning (Baird et al., 2012; Baird, Smallwood, & Schooler, 2011), it has been shown to be detrimental in education (Randall, Oswald, & Beier, 2014; Smallwood et al., 2007). For example, a recent meta-analysis with 88 independent samples (Randall et al., 2014) found that mind wandering is consistently negatively related to learning, with this correlation being more pronounced during complex tasks (e.g., problem solving, reading comprehension). Thus, it is important to make efforts to build intelligent systems and other digital learning technologies that can reengage students' attention when their minds begin to wander. Recently, D'Mello (2015) expressed this need as “attending to attention” during learning. To make strides toward effective interventions, however, the first step is to discern when mind wandering occurs in real time, which comes with its own set of challenges. For example, there are few to no behavioral markers indicating when an episode of mind wandering occurs or how long it lasts.

The internal nature of mind wandering makes detecting its occurrence difficult. A student who is deeply engaged in learning can often appear similar to another student who is thinking about something else completely. Although mind wandering is related to other forms of disengagement (e.g., gaming the system, WTF behaviors), it lacks overt behavioral signals in comparison (Baker et al., 2008; Wixon, Baker, Gobert, Ocumpaugh, & Bachmann, 2012). Additionally, the onset and duration of other disengaged behaviors can be clearly demarcated, which is not possible for mind wandering.

Mind wandering occurs often, is negatively related to learning, and is difficult to assess. Because “attending to attention” is a relatively new concept in learning technologies, this paper attempts to synthesize these points using an evidence centered design (ECD) approach. The aim is to provide a foundation that others can refine and develop to ultimately make greater strides in attention-aware learning systems, starting with the detection of mind wandering.
This paper describes an ECD approach for mind wandering detection, mainly through nonintrusive channels of data. The three critical components of ECD are described in detail in three sections: (1) student model, (2) task model, and (3) evidence model. Each of these ECD components is an integral part of a cohesive model of how mind wandering can be measured reliably during learning.

**Student Model**

The student model indicates the important aspects of students’ knowledge, skills, and abilities (KSAs) that should be considered when researching a focal construct. Given that the focal construct in this paper is mind wandering (or lapses in attention) during reading, it is important to measure specific attributes of students that are known to influence the frequency and overall experience of mind wandering.

Some of the important KSAs that provide sources of variance in measuring mind wandering come from differences in students’ working memory capacity (Kane & Engle, 2003), affective states, interest, prior knowledge, reading fluency, and other cognitive and noncognitive factors related to attention. For example, working memory capacity and negative moods are both tied to overall rates of mind wandering (Kane & Engle, 2003; Smallwood, Fitzgerald, Miles, & Phillips, 2009). Prior knowledge and interest have also been found to interact in order to influence rates of mind wandering (in the context of film; Kopp, Mills, & D’Mello, 2015). Finally, it is important to gauge students’ performance during a learning task because mind wandering has been negatively related to learning in a variety of contexts (Randall et al., 2014). Although these potential sources of irrelevant variance are not currently modeled as part of mind wandering detectors, they may be useful moving forward in refining mind wandering detection methods.

Mind wandering can also be hard to assess because it requires students to be metacognitively aware of their attention, presenting some additional sources of construct-irrelevant variance. Mind wandering detectors must begin with some data to train the detector on (i.e., some valid reports of mind wandering during learning). These data are typically collected by asking students to engage in either a probe-caught or a self-caught method of reporting mind wandering. The former is a thought sampling probe in the middle of a learning session, and in the latter students report mind wandering once they catch themselves thinking about something else. Both these methods inherently rely on students accurately assessing their current attentional state, which means we may not always have an accurate account of when mind wandering occurs.
Task Model

ECD considers a task model the type of environment that elicits the focal construct. The current task model focuses on computerized self-paced reading tasks, which are used as a platform to investigate mind wandering. We chose computerized self-paced reading environments for a number of reasons. First, mind wandering occurs quite often during computerized self-paced reading tasks, with students reporting mind wandering approximately 20–40% of the time. Second, mind wandering is negatively related to comprehension in self-paced reading tasks, making the overarching goal of detecting and responding to mind wandering during reading ecologically valid. Finally, computerized self-paced reading affords the ability to log important information regarding the KSAs mentioned above.

A key feature of the task model in this example is that the number of screens, the words on each screen, and what they look like can be easily manipulated, and all are important factors related to mind wandering. For example, text complexity can be leveraged as a variable feature since mind wandering tends to occur more frequently when texts are difficult (Feng, D'Mello, & Graesser, 2013; Mills, D'Mello, & Kopp, 2015). Other variable features are manipulations of mind wandering through typeface or through interest by letting students choose what they want to read. For example, a recent study found that students reported more mind wandering while reading a text in a Comic Sans typeface compared with Arial (Faber, Mills, Kopp, D'Mello, 2016).

Some of the potential task products are reading time and rereading. For example, as students progress from one screen of text to the next, a reading time per screen can be gleaned. This is important because we know from previous research that reading time can be an important indicator of attention and comprehension (Franklin, Smallwood, & Schooler, 2011; Mills & D'Mello, 2015b; Wallot, O'Brien, Haussmann, Kloos, & Lyby, 2014). We can also tell whether students went back to reread pages, either because they did not understand or because they lost focus. Other task products include eye gaze features that can help determine what the participant was looking at and for how long.

Evidence Model

The third model in ECD is the evidence model, which highlights students’ behaviors and outcomes that are theoretically related to the KSAs of interest. Some of these behaviors may help reveal the behavioral patterns characteristic of mind wandering episodes. For example, leading up to an episode of mind wandering, students might display reading times that are indicative of their current attentional state. Extremely quick reading times might suggest that students are skimming the text. In those cases, they
might be flipping through the screens quickly without allowing enough time for comprehension. Another pattern of reading times that would be associated with less attention is when students display longer reading times—even becoming idle on a page (or screen) of text. Students may have zoned out when they are idle, making their reading time much longer than average.

Another potential observation that is important to consider is how someone performs on a comprehension test. In general, both actual rates of mind wandering and detected episodes of mind wandering should be negatively related to reading comprehension scores. If questions can be linked to specific content in the text, performance should be worse on questions directly linked to episodes of mind wandering.

If the potential observations appear to be measuring the focal construct reliably, one application in which mind wandering detection might be useful would be real-time interventions. The instant mind wandering occurred, a reactive mind wandering intervention would reorient the student’s attention and make sure he or she did not miss any important information. These types of interventions could be deployed in online learning platforms where reading is integral to a learning session.

**Major Findings**

There have been several recent attempts to automatically detect mind wandering during reading. All the studies mentioned here used a student-independent cross-validation method to ensure better generalization to new students.

The first example of a mind wandering detector that is relevant to ECD was completed by Mills & D’Mello (2015b). Nonintrusive log file information was used to detect mind wandering during self-paced reading. Mind wandering reports were collected via thought probes that occurred on pseudo-random pages (i.e., a page is similar to a computer screen) while participants were reading. The thought probe would occur when a participant tried to advance to the next screen to avoid confounding the reading time measure for a screen of text. Students responded either yes or no about whether they were mind wandering at the time of the probe.

Text features and reading behaviors readily available in log files were extracted on the pages immediately preceding a thought probe. Supervised machine learning was applied to predict mind wandering during a screen of text with an accuracy 21% above chance. A feature analysis revealed that mind wandering was related to longer reading times and more complex text. Finally, both actual and predicted rates of mind wandering were negatively correlated with comprehension after reading, showing some evidence of predictive validity.
Other recent research explored different data sources collected during self-paced reading tasks (Bixler, Blanchard, Garrison, & D’Mello, 2015; Blanchard, Bixler, Joyce, & D’Mello, 2014; Franklin et al., 2011; Mills & D’Mello, 2015a). In these studies, mind wandering was similarly measured via thought probes occurring on pseudo-random pages. Binary classifiers were then trained to classify whether a person responded yes or no to the probes. Blanchard et al. (2014) used physiological features (skin conductance and temperature) to accurately classify mind wandering 74% of the time (Cohen’s kappa = .22). Other work has shown the feasibility of using eye gaze to accurately classify whether someone is mind wandering on a screen (computer screen with text), achieving accuracy rates above 70% (Bixler & D’Mello, 2014, 2015). With eye gaze, detection has been successful for both probe-caught mind wandering and self-caught mind wandering in separate studies.

Future Work and Potential Applications

Mind wandering is a ubiquitous phenomenon that can be detrimental to reading comprehension (Smallwood et al., 2007). Although many efforts have been devoted to preventing mind wandering from occurring in the first place, very little research has been done to reactively respond to mind wandering episodes as they arise in order to improve learning. This may be due in part to the fact that reliable detection of mind wandering is necessary to realize this goal. Although there are some challenges in mind wandering detection, initial work suggests that it can be done. Here, an ECD framework is described that outlines some of these challenges in mind wandering detection, as well as potentially important student and task-related factors to consider.

An important future direction is to extend this ECD framework to other contexts where mind wandering detection would be beneficial, namely, to intelligent tutoring systems and other online learning environments. Indeed, recent studies have examined the rates of mind wandering in an intelligent tutoring system, as well as the possibility for automatic detection of mind wandering using eye gaze in this context (Hutt et al., in press; Mills, D’Mello, Bosch, & Olney, 2015). Including different types of learning environments will specifically extend the task model, thus providing more diverse opportunities to refine our understanding of the focal construct. Incorporating intelligent tutoring systems and other learning environments into this ECD example will ultimately help to bring us closer to attention-aware learning systems.

Future work may also begin to use mind wandering detectors to test automatic interventions for combating the negative effects of mind wandering on reading comprehension. If successful, real-time mind wandering interventions have the potential to be used in current learning technologies, such as
intelligent tutoring systems, as a way to help optimize students’ learning experience when they inevitably start to mind wander.
References


Appendix: Design Pattern

Authors

<table>
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<tr>
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Overview

Summary

- Mind wandering occurs frequently in both everyday life and education contexts. Here, mind wandering is examined in computerized self-paced reading tasks, where it is estimated to occur 20–40% of the time.
- Data logged while students read from computerized self-paced learning tasks was used to detect mind wandering. Some of the key variables of interest were related to the task itself (e.g., features of the text being read), student behavior (e.g., reading times), and student outcomes (e.g., comprehension).

Rationale

- Attention is important for learning to occur.
  - Lapses in attention may result in missing important information necessary to build an overall mental model.
- Rates of mind wandering have been found to be negatively related to performance (Randall et al., 2015).
  - The negative relationship is even stronger for more complex tasks, like reading comprehension.

Detecting mind wandering will facilitate the following overarching goals:

- Gain a better understanding of the behaviors that precede mind wandering episodes during reading.
- In doing so, develop mind wandering detectors that can be used to deploy real-time interventions that aim to regain students’ attention when their minds begin to wander.

Student Model

Focal Construct

- Mind wandering: Attentional shift from external, task-related thoughts toward internal self-generate thoughts

Additional knowledge, skills, and abilities

- Student’s prior knowledge
- Working memory capacity
- Interest
- Metacognitive awareness

References


## Task Model

**Characteristic Features of the Task**
- Reading should take place in a computerized self-paced learning task.
- Mind wandering probes can be presented on random pages if mind wandering is to be measured via self-report.

**Variable Features of the Task**
- Text difficulty/complexity
- Learning goal/instructions for the reading assignment
- Words per screen (i.e., text can be broken up into variable chunks that are presented one screen at a time)
- How much/how long students are expected to read (500 words vs. 5,000 words)
- Typeface that the text is presented in (e.g., Arial, Times New Roman, Comic Sans)

**Potential Task Products**
- Reading time (i.e., time spent reading per screen of text)
- Rereading behaviors (i.e., how often students go back and reread the same page)
- Perceptions of the texts
  - difficulty
  - interest
- Eye gaze characteristics (e.g., fixations, saccades, blink rate)

## Evidence Model

**Potential Observations**
- Lower comprehension scores for questions that correspond to parts of the text where mind wandering was self-reported (or predicted)
- Extremely long or slow reading time behaviors (skimming behaviors, becoming idle on a screen)
- Longer fixation durations and more blinking preceding episodes of mind wandering

**Potential Frameworks**
- Develop student-independent detectors of mind wandering using machine learning algorithms
  - Goal of generalizing to new students
- Use mind wandering detectors to implement real-time interventions during computerized reading tasks in order to redirect student attention