What do we Think About When we Learn?

Sidney K. D'Mello
University of Colorado Boulder

Have your ever reflected on your stream of thoughts when you last attempted to learn something? Were your thoughts focused on the content of what you were trying to learn? Or did you drift back to memories of past experiences or fast forward to future plans? Did you experience any strong emotions? Were you curious, bored, confused, frustrated, enraged, or were you emotionally blasé? Did you wonder where these thoughts and feeling came from? Were they triggered by the external environment, the learning activity, the learning content, or by some elusive source? How long did they last? Were they fleeting or did they persist? And did they matter at all? Did you find them informative, productive, distracting, or were they merely incidental? Did you try to regulate them in any way? If so, were you successful? And so on…

Our research team (henceforth "we") is fascinated by questions on the *phenomenology* of the learning experience. Why? Because deep learning is a conscious phenomenon (Baars & Franklin, 2003) and the contents of consciousness, be it knowledge chunks, thoughts, feelings, and so on, underlie the learning process. Of course unconscious processes are involved as well, but aside from priming and other trivial forms of learning, consciousness is necessary for deep learning (Baars & Franklin, 2003). Deep learning requires learners to acquire complex content, generate inferences, address causal questions, diagnose and solve problems, make conceptual comparisons, generate coherent explanations, and demonstrate application and transfer of knowledge (Graesser, Ozuru, & Sullins, 2010). It can be contrasted with shallow learning, such as skimming, memorization, and most forms of procedural learning.

So, what do people think and feel during deep learning? A process-pure account would restrict the scope to thoughts and feelings related to the learning content and task context. In contrast, research indicates that deep learning engenders a broader and diffuse set of mental content. It extends beyond cognition into the realm of emotion (D'Mello & Graesser, 2012; Pekrun & Linnenbrink-Garcia, 2014). It also implicates thoughts which can be partially or completely unrelated to the learning task (e.g., zone outs, fantasies, prospective memories). In fact, the propensity to experience a high degree (20% to 50%) of "off-task" thoughts (see next section for clarification on "off-task" thoughts) has been widely documented when people complete cognitive tasks in the lab (Smallwood & Schooler, 2015), engage in learning in the lab and real-world (Olney, Risko, D'Mello, & Graesser, 2015), and go about their everyday lives (Killingsworth & Gilbert, 2010).

This chapter is about mental phenomena that are unrelated to the learning task and content, but are central to the learning process. This may appear paradoxical, but the paradox is an illusion caused by the narrow scope of cognitive theories of learning. Psychology, and the learning theories derived from it, has historically been concerned with stimulus-response processing. However, an emerging branch of cognition and brain science emphasizes the study of stimulus-independent, spontaneous, or self-generated thought (Christoff, Irving, Fox, Spreng, & Andrews-Hanna, 2016; Smallwood & Schooler, 2015). My goal is to bring this literature into the fold by integrating it with learning theories and to inform the design of learning technologies. I begin with a theoretical model of how *spontaneous* thoughts arise during learning from a variety of stimuli including text, images, videos, audio and so on.

Theoretical Model of Spontaneous Thoughts and Thought Triggers during Learning

What are off-task thoughts, why are they so frequent, and how are they related to learning? First, a note on terminology…. Despite my prior colloquial use of the terms "off-task thought" and "stimulus independent thought," these terms are ambiguous in the context of learning, at least when the unit of analysis is an atomic thought. For example, is a learner who reflects on how many pages are left to read on-task (because he/she is reading) or off-task (because the thought content is not germane to constructing a mental model of the text)? If a word in a text cues a memory unrelated to the content of the text, is the resultant thought stimulus-independent or stimulus-dependent? To avoid such ambiguity, I prefer to distinguish between learning-goal-congruent (LGC) and learning-goal-incongruent (LGI) thoughts. A LGC thought is any thought germane to constructing, maintaining, or utilizing a mental model of the learning content. It can extended beyond the learning task and stimulus, but should directly support the learning goal. In contrast, an LGI thought might be related to the task and stimulus, but does not facilitate the learning goal. Thus, a metacognitive reflection is an LGC thought, while focusing on an irrelevant detail (e.g., the typeface) is an LGI thought as are the above two examples.

Figure 1 provides a simplified model of how spontaneous thoughts arise during learning. The basic idea is that LGC and LGI thoughts compete for conscious access, which is a limited resource because consciousness is serial and has limited capacity (Baars, 1993). LGC thoughts claim the seat of consciousness to the extent to which executive control is successful at suppressing LGI thoughts (Kane & McVay, 2012). This, in turn, is depends on the strength of the ongoing mental model relative to various coalitions of LGI thoughts (Feng, D'Mello, & Graesser, 2013; Smallwood, 2011).

<<insert Figure 1 here>>

LGI thoughts gain strength relative to the availability of executive resources (Smallwood & Schooler, 2006) and from various internal and external sources. Some well-understood sources — which also prescribe thought content — include internal factors like competing current concerns (e.g., laundry), prospective thoughts and planning (e.g., dinner plans), and feeling states (e.g., hunger pangs), as well as external factors from the task environment, such as task-related interferences (e.g., "how much longer?"), and distractions (e.g., a door slammed) (Baird, Smallwood, & Schooler, 2011; Klinger, 1987; Stawarczyk, Majerus, Maj, Van der Linden, & D'Argembeau, 2011).

Critically, automatic and/or deliberate long-term memory retrieval triggered by stimulus processing is a significant source of LGI thoughts. Memory associations which are relevant to the mental model would strengthen it and contribute to the ongoing stream of LGC thoughts. However, stimulus processing can also lead irrelevant autobiographical (e.g., reading the word "water" in a science text triggers a memory of the past weekend spent at the beach), prospective (e.g., reading "water" leads to prospection about a need to buy sparkling water for dinner), and semantic (e.g., reading "water" brings the chemical formula H_2O to mind) memories. Aside from memory retrieval, the stimulus itself can also be a source of LGI thoughts – for example when learners focus on irrelevant or seductive details (e.g., the typeface).

Finally, LGI thoughts are more internally driven, thereby involving a decoupling of attention from the external environment and a disruption in stimulus processing (Smallwood, Beach, Schooler, & Handy, 2008). This form of perceptual decoupling (Schooler et al., 2011) causes encoding failures (Seibert & Ellis, 1991), a weakened mental model, and ultimately diminished learning (Smallwood, McSpadden, & Schooler, 2008). A weak mental model further increases the likelihood of LGI thoughts, resulting in more perceptual decoupling, an even weaker mental model, and a continuation of this vicious cascading cycle.

Research Studies on Mind Wandering during Learning

Evidence for multiple aspects of the model comes from research on learning from text, film, and intelligent tutoring systems (ITS), among other stimuli. These studies tracked a specific type of LGI thought—mind wandering (or more colloquially, zone outs).

Incidence of mind wandering and its relationship to learning. I conducted a selective meta-analysis of 25 studies (*N* = 2787) conducted in our lab in the domains of (1) reading: (Faber, Mills, Kopp, & D'Mello, 2017; Feng et al., 2013; Fulmer, D'Mello, Strain, & Graesser, 2015; Kopp, D'Mello, & Mills, 2015; Mills, D'Mello, & Kopp, 2015; Mills et al., 2013; Mills, Graesser, Risko, & D'Mello, 2017;

Phillips, Mills, D'Mello, & Risko, 2016); (2) film comprehension: (Kopp, Mills, & D'Mello, 2016); (3) interacting with an intelligent tutoring system (ITS) (Hutt et al., 2017; Mills, D'Mello, Bosch, & Olney, 2015); (4) viewing online lectures: (Wilson et al., in review); (5) memorizing urban scenes (Krasich et al., in review); and (6) engaging with mixed media, such as text, audio, audio + text: (Kopp & D'Mello, 2016). About half the studies were conducted with college students in the lab or online. Most others were conducted with U.S. adults recruited from Amazon Mechanical Turk, while one study involved high-school students in the classroom. Approximately two-thirds of the studies involved reading comprehension. Observations were averaged across conditions for within-subjects studies, whereas condition was simply ignored for between-subject studies. In the majority (>90%) of studies, learners were pseudo randomly probed to report whether they were zoned out (or not) at the time of the probe (called probe-caught mind wandering). In the remainder of the studies, learners simply reported when they caught themselves mind wandering (called self-caught mind wandering). There are theoretical distinctions between the two (Smallwood & Schooler, 2015), but this is not of importance here.

How frequent is mind wandering during learning? The mind wandering incidence was computed as the proportion of "yes" (mind wandering) responses to the probes for probe-caught mind wandering or the mind wandering rate per minute (capped at 1 per minute) for self-caught mind wandering (the measure ranges from 0 to 1). A random effects model (using the metafor package in R (Viechtbauer, 2010)) indicated significant heterogeneity in the distribution (Figure 2), $Q(24) = 159$, $p < .0001$. The mean weighted effect size across studies of .28 [.26, .31], $p < .001$, suggesting that mind wandering occurs about 28% of the time during learning, a rate that is consistent with previous research (see Smallwood and Schooler (2015) for a review).

<<insert Figure 2 here>>

We correlated posttest scores with the mind wandering rate and transformed the correlation with a Fisher's r-to-z transformation. The weighted mean correlation under a random effects model r_+ ($k = 25$) of -.24 [-0.29 -0.20] was significant ($p < .001$), but the test of heterogeneity was not, $Q(24) = 31.7$, $p = .14$ (Figure 3). However, the results were virtually identical when estimated via a fixed effects model, r_+ ($k = 25$) of -.25 [-0.29 -0.21], suggesting a negative relationship between mind wandering and learning (as measured by posttest scores). This correlation is within the range of the weighted effect (r_+ ($k = 76$) = -.19 [-.28, -.20]) reported in a meta-analysis on the relationship between off-task thought and performance across a range of tasks, with several involving reading comprehension (Randall, Oswald, & Beier, 2014).

<<insert Figure 3>>

Executive control and executive resources. The model predicts that executive control will fail to suppress LGI thoughts when the mental model is weak. Accordingly, Feng et al. (2013), Mills et al. (2013), and Mills, D'Mello, et al. (2015) found that learners mind wandered more and had weaker mental models after reading experimentally manipulated difficult (vs. easy) texts. Forrin (2016) replicated this finding but only for sentence-by-sentence text presentations. In a different vein, Kopp et al. (2016) explicitly communicated the mental model by asking participants to read the plot of a film prior to viewing the film, finding that this reduced mind wandering compared to reading an unrelated plot.

The model also posits that LGI thoughts arise to the extent that there are available executive resources. Accordingly, Faber et al. (2017) reported less mind wandering when participants read a text with a less fluent typeface, presumably because this consumed more resources for encoding. Taking a different approach, Kopp and D'Mello (2016) reported more mind wandering in an audio-only condition compared to text-only and audio+text conditions (see Sousa, Carriere, and Smilek (2013) for a similar finding). They attributed this finding to an unoccupied visual channel – and thereby more available resources – in the audio-only condition. Phillips et al. (2016) reported more mind wandering when participants re-read a text comparing to reading it once or during the first read, presumably because re-reading consumed fewer resources (among other factors).

Perceptual decoupling. The model posits that mind wandering engenders a form of perceptual decoupling (i.e., attention is decoupled from the environment), which partly accounts for its negative relationship with learning. Mills et al. (2017) tested this hypothesis in the context of self-paced reading of expository texts. The assumption was that reading times of "cognitively coupled" readers should be related to text complexity in that reading times should increase for difficult sections and decrease for easier ones. Accordingly, they operationalized cognitive coupling by regressing each participant's paragraph-level reading times on measures of text complexity (i.e., Flesch-Kincaid Grade Level and Word Concreteness scores computed via Coh-Metrix (Graesser, McNamara, & Kulikowich, 2011)). Results across four data sets indicated that coupling negatively predicted mind wandering and positively predicted comprehension. Importantly, coupling mediated the relationship between mind wandering and comprehension, supporting the hypothesis that mind wandering causes a decoupling of attention from the external stimuli.

Content analysis of mind wandering. Much of the model is concerned with different types of mind wandering and their various sources. Research suggests that mind wandering involves thoughts pertaining to sensory and emotional states, the self, current concerns, prospective memory, stimuli, environmental distractions, and fantasies (e.g., Krawietz, Tamplin, & Radvansky, 2012; Schooler, Reichle, & Halpern, 2004; Smallwood et al., 2016; Song & Wang, 2012). In these studies, participants report the type of mind wandering thought from predetermined categories (e.g., to what extent was your thought related to a plan), which requires subjective interpretation and is limited to an *a priori* list of categories.

In contrast, Faber and D'Mello (in review) instructed participants to type out the content of their thoughts whenever they caught themselves zoning out while reading a text or viewing a narrative film for 20-mins each. Participants also reported any stimulus-based triggers of the zone outs. The researchers developed a coding scheme to assign the 1218 thoughts to one of 10 categories (kappa = .71). There were no major differences across the two stimuli, so these results are grouped and shown in Figure 4.

<<insert Figure 4>>

The results confirm several aspects of the model. Starting with the routine findings, the analysis confirmed that a significant portion of mind wandering tends to be prospective and future oriented (Baird et al., 2011), introspective thoughts pervade consciousness, and the task environment triggers mind wandering via environmental distractions and task-related interferences (Stawarczyk et al., 2011). Together, these three categories accounted for 45% of the mind wandering reports. What is more interesting, however, is that an equal amount (44%) of mind wandering thoughts was related to the stimulus itself or involved episodic, semantic, and other (unspecific) memories.

Interestingly, these thought categories were triggered by the stimulus itself. An analysis of the stimulus-based triggers revealed that episodic, semantic, unspecific memories and stimulus-related thoughts were more likely to be associated with stimulus-related triggers than prospection, introspection, environmental distractions, and task-related interferences. For example, the trigger "all the talk about water" from the text stimulus and the memory "[a] beach nearby me at home that I always go to" are related, because water and beach share associations like the sea and swimming. Further, Latent Semantic Analyses (Deerwester, Dumais, Furnas, Landauer, & Harshman, 1990) confirmed that the content of the triggers was semantically associated with the content of the stimulus-related and memory-based mind wandering thoughts. Thus, the automaticity of memory retrieval is a double edged sword. Although memory associations are instrumental in mental model construction and are a major component of most models of comprehension (McNamara & Magliano, 2009), they also lead the mind to wander far and away.

Attention-aware Technologies that Detect and Combat Mind Wandering

Given the incidence of mind wandering and its negative relationship with learning, I argue that next-generation learning technologies should include mechanisms to address mind wandering and related states of inattention (D'Mello, 2016). Accordingly, we are developing such attention-aware learning technologies that use eye tracking and other forms of sensing to model and adapt to learner attention while learning from multimedia (D'Mello, Olney, Williams, & Hays, 2012), during computerized reading (D'Mello, Mills, Bixler, & Bosch, 2017), and even while entire classrooms of students interact with an ITS in schools (Hutt et al., 2017). Below, we describe one such technology (see Figure 5) that uses eye tracking and machine learning to detect mind wandering and dynamically responds with interpolated comprehension assessments and re-reading opportunities (D'Mello et al., 2017).

<<insert Figure 5>>

Mind wandering detection. We used a supervised learning approach to detect mind wandering. Data used to train the detector were collected as 98 learners read a 57-page (or 57-computer screens) scientific text on surface tension in liquids (Boys, 1895). Learners used the arrow key to navigate forward. They self-reported when they caught themselves mind wandering throughout the reading session. Eye gaze was tracked with a Tobii TX 300 eye tracker. We used global eye-gaze features to train a support vector machine classifier to discriminate between mind wandering (pages with a self-report – 32%) and normal reading (see Faber, Bixler, and D'Mello (in press) for an overview of the methodology) in a manner that generalizes to new learners. The model had a precision of 69% and a recall of 67%, which we deemed to be sufficiently accurate dynamic intervention.

Intervention. The mind wandering detector was integrated into the computerized reading interface in order to provide real-time page-by-page estimates of the likelihood of mind wandering for new learners. The main intervention strategy consisted of asking comprehension questions on the page where mind wandering was detected and providing opportunities to re-read as needed. Specifically, two surface-level multiple choice questions were created for each of the 57 pages. Mind wandering detection occurred when the learner attempted to navigate to the next page, upon which eye gaze from the page just read was submitted to the mind wandering detector, which provided a mind wandering likelihood. If the likelihood was determined to be sufficiently high (based on a probabilistic prediction), one of the questions (randomly selected) was presented to the learner. If the learner answered the question correctly, feedback was provided, and the learner could advance to the next page. If the learner answered incorrectly, they were encouraged to re-read the page. When the learner was ready to continue, (s)he received a second (randomly selected) question, but was allowed to advance regardless of the correctness of their response.

Validation study. We conducted a randomized controlled trial (N = 104) to evaluate the technology. The experiment had two conditions: an intervention condition and a yoked control condition. Participants in the intervention condition received the intervention as described above (i.e., based on detected mind wandering likelihoods). Each participant in the yoked control condition was paired with a participant in the intervention condition. He or she received an intervention question on the same pages as their paired intervention participant regardless of the mind wandering likelihood. After reading, participants completed a 38-item multiple choice comprehension assessment. The questions were randomly selected from the 57 pages (one per page) with the exception that a higher selection priority was given to pages that were re-read on account of the intervention. Participants in the yoked control condition received the same posttest questions as their intervention condition counterparts.

We analyzed posttest performance on unseen questions (i.e., questions not presented as part of the intervention). There was no significant condition difference on overall scores (p = .846). The intervention and control conditions scored 57.6% (SD = 15.7%) and 58.1% (SD = 12.9%), respectively. Next, we examined posttest performance as a function of mind wandering during reading. As expected, we found no significant differences on pages where both the intervention and control participants had low (p = .759) or high (p = .922) mind wandering likelihoods. There was also no significant difference (p = .630) for pages where the intervention condition had high, but the control condition had low, mind wandering likelihoods. However, the intervention condition (M = 64.3%, SD = 26.3%) significantly (p = .003, d = .47 sigma) outperformed the control condition (M = 48.9%, SD = 29.8%) for pages where the intervention participants had low, but the control condition had high, mind wandering likelihoods. This pattern of results suggests that the intervention had the intended effect of reducing comprehension deficits attributable to mind wandering because it led to equitable performance when mind wandering was high and improved performance when it was low.

Revised technology. Despite the promising result, we identified several limitations with the technology as elaborated in D'Mello et al. (2017). Most significantly, it encouraged keyword spotting and a general shallow-level processing style. To address this, we modified the technology by: (a) segmenting the 57 pages into 15 coherent units and only intervening at the end of a unit; (b) replacing the surface-level multiple-choice questions with deeper-level questions that required learners to generate self-explanations; and (c) providing feedback and opportunities to re-read and revise explanations. We also improved other aspects of the technology, such as the user interface and intervention trigger mechanism. The validation study measured both surface- and inference-level comprehension, immediately and after a one-week delay. Preliminary results suggest a positive effect for the intervention (compared to a yoked-control) for delayed inference-level questions (Mills, Bixler, & D'Mello, in prep.).

Conclusion

What do we think when we learn? Most learning theories assume that barring overt disengagement and occasional distractions, engaged learners' thoughts are directed towards the learning content. The research tells a different story. Despite learners' best intentions to concentrate on the learning content, their minds will nevertheless wander, thereby reducing learning efficiency and effectiveness. Thus, it is critical for learning theories and technologies to broaden their scope by attending to inattention.

Acknowledgement

I am grateful to the past and present members of our lab, especially Caitlin Mills, Myrthe Faber, Nigel Bosch, and Robert Bixler. None of this work would have been possible without the inspiration, mentorship, encouragement, and support of Art Graesser. This research was supported by the National Science Foundation (NSF) (DRL 1235958 and IIS 1523091). Any opinions, findings and conclusions, or recommendations expressed in this paper are mine and do not necessarily reflect the views of NSF.

References

Baars, B. J. (1993). *A cognitive theory of consciousness*. Cambridge, UK.: Cambridge University Press.

Baars, B. J., & Franklin, S. (2003). How conscious experience and working memory interact. *Trends in Cognitive Sciences*, *7*(4), 166-172.

Baird, B., Smallwood, J., & Schooler, J. W. (2011). Back to the future: autobiographical planning and the functionality of mind-wandering. *Consciousness and Cognition, 20*(4), 1604-1611.

Boys, C. V. (1895). *Soap bubbles, their colours and the forces which mold them*: Society for Promoting Christian Knowledge.

Christoff, K., Irving, Z. C., Fox, K. C., Spreng, R. N., & Andrews-Hanna, J. R. (2016). Mind-wandering as spontaneous thought: a dynamic framework. *Nature Reviews Neuroscience*, *17*(11), 718-731.

D'Mello, S., & Graesser, A. (2012). Dynamics of affective states during complex learning. *Learning and Instruction*, *22*(2), 145-157. doi: 10.1016/j.learninstruc.2011.10.001

D'Mello, S., Olney, A., Williams, C., & Hays, P. (2012). Gaze tutor: A gaze-reactive intelligent tutoring system. *International Journal of human-computer studies*, *70*(5), 377-398.

D'Mello, S. K. (2016). Giving Eyesight to the Blind: Towards attention-aware AIED. *International Journal of Artificial Intelligence In Education, 26*(2), 645-659.

D'Mello, S. K., Mills, C., Bixler, R., & Bosch, N. (2017). Zone out no more: Mitigating mind wandering during computerized reading. In X. Hu, T. Barnes, A. Hershkovitz & L. Paquette (Eds.), *Proceedings of the 10th International Conference on Educational Data Mining* (pp. 8-15): International Educational Data Mining Society.

Deerwester, S., Dumais, S., Furnas, G., Landauer, T., & Harshman, R. (1990). Indexing by Latent Semantic Analysis. *Journal of the American Society for Information Science, 41*(6), 391-407.

Faber, M., Bixler, R., & D'Mello, S. K. (in press). An automated behavioral measure of mind wandering during computerized reading. *Behavior Research Methods*.

Faber, M., & D'Mello, S. K. (in review). What do we think about when we mind wander? A content analysis of thoughts, triggers, and thought trains in semantically-rich task contexts.

Faber, M., Mills, C., Kopp, K., & D'Mello, S., K. (2017). The effect of disfluency on mind wandering during text comprehension. *Psychonomic Bulletin & Review, 24*(3), 914-919.

Feng, S., D'Mello, S., & Graesser, A. (2013). Mindwandering while reading easy and difficult texts. *Psychonomic Bulletin & Review, 20*(1), 586-592.

Forrin, N. (2016). *How Reading Difficulty Influences Mind-Wandering: The Theoretical Importance of Measuring Interest.* (PhD), University of Waterloo, Waterloo, ON.

Fulmer, S., D'Mello, S., Strain, A., & Graesser, A. (2015). Interest-based text preference moderates the effect of text difficulty on engagement and learning. *Contemporary Educational Psychology, 41*, 98-110.

Graesser, A., Ozuru, Y., & Sullins, J. (2010). What is a good question? In M. McKeown & G. Kucan (Eds.), *Bringing Reading Research to Life* (pp. 112-141). New York: Guilford.

Graesser, A. C., McNamara, D. S., & Kulikowich, J. M. (2011). Coh-Metrix Providing Multilevel Analyses of Text Characteristics. *Educational Researcher, 40*(5), 223-234.

Hutt, S., Mills, C., Bosch, N., Krasich, K., Brockmole, J. R., & D'Mello, S. K. (2017). Out of the Fr-Eye-ing Pan: Towards Gaze-Based Models of Attention during Learning with Technology in the Classroom. In M. Bielikova, E. Herder, F. Cena & M. Desmarais (Eds.), *Proceedings of the 2017 Conference on User Modeling, Adaptation, and Personalization* (pp. 94-103). New York: ACM.

Kane, M. J., & McVay, J. C. (2012). What Mind Wandering Reveals About Executive-Control Abilities and Failures. *Current Directions in Psychological Science, 21*(5), 348-354.

Killingsworth, M. A., & Gilbert, D. T. (2010). A wandering mind is an unhappy mind. *Science, 330*(6006), 932-932.

Klinger, E. (1987). Current concerns and disengagement from incentives. *Motivation, intention, and volition* (pp. 337-347): Springer.

Kopp, K., D'Mello, S., & Mills, C. (2015). Influencing the occurrence of mind wandering while reading. *Consciousness and Cognition, 34*(1), 52-62.

Kopp, K., & D'Mello, S. K. (2016). The Impact of Modality on Mind Wandering during Comprehension. *Applied Cognitive Psychology, 24*, 914-919.

Kopp, K., Mills, S., & D'Mello, S. K. (2016). Mind Wandering during Film Comprehension: The Role of Prior Knowledge and Situational Interest. *Psychonomic Bulletin & Review*.

Krasich, K., McManus, B., Hutt, C., Faber, M., D'Mello, S. K., & Brockmole, J. (in review). Changes in Gaze Control while Mind Wandering during Scene Processing: Implications for Decades of Research on Eye Movements and Visual Attention.

Krawietz, S. A., Tamplin, A. K., & Radvansky, G. A. (2012). Aging and mind wandering during text comprehension. *Psychology and aging, 27*(4), 951-958.

McNamara, D. S., & Magliano, J. (2009). Toward a comprehensive model of comprehension. *Psychology of learning and motivation, 51*, 297-384.

Mills, C., Bixler, R., & D'Mello, S. K. (in prep.). Dynamic "Deep" Attentional Reengagement during Reading via Automated Mind Wandering Detection.

Mills, C., D'Mello, S. K., & Kopp, K. (2015). The influence of consequence value and text difficulty on affect, attention, and learning while reading instructional texts. *Learning and Instruction, 40*, 9-20.

Mills, C., D’Mello, S., Bosch, N., & Olney, A. M. (2015). Mind wandering during learning with an intelligent tutoring system. In C. Conati, N. Heffernan, A. Mitrovic & M. F. Verdejo (Eds.), *Proceedings of the 17th International Conference on Artificial Intelligence in Education (AIED 2015)* (pp. 267-276). Berlin Heidelberg: Springer-Verlag.

Mills, C., D’Mello, S. K., Lehman, B., Bosch, N., Strain, A., & Graesser, A. (2013). What Makes Learning Fun? Exploring the Influence of Choice and Difficulty on Mind Wandering and Engagement during Learning. In K. Yacef, C. Lane, J. Mostow & P. Pavlik (Eds.), *Proceedings of the 16th International Conference on Artificial Intelligence in Education (AIED 2013)* (pp. 71-80). Berlin Heidelberg: Springer-Verlag.

Mills, C., Graesser, A., Risko, E., & D’Mello, S. K. (2017). Cognitive Coupling during Reading. *Journal of Experimental Psychology: General, 146*(6), 872-833.

Olney, A., Risko, E. F., D'Mello, S. K., & Graesser, A. C. (2015). Attention in educational contexts: The role of the learning task in guiding attention. In J. Fawcett, E. F. Risko & A. Kingstone (Eds.), *The Handbook of Attention* (pp. 623-642). Cambridge, MA: MIT Press.

Pekrun, R., & Linnenbrink-Garcia, L. (Eds.). (2014). *International handbook of emotions in education*. New York, NY: Routledge.

Phillips, N., Mills, C., D'Mello, S., K., & Risko, E. (2016). On the influence of re-reading on mind wandering. *The Quarterly Journal of Experimental Psychology, 69*(12), 2338-2357.

Randall, J. G., Oswald, F. L., & Beier, M. E. (2014). Mind-wandering, cognition, and performance: A theory-driven meta-analysis of attention regulation. *Psychological Bulletin, 140*(6), 1411-1431.

Schooler, J. W., Reichle, E. D., & Halpern, D. V. (2004). Zoning out during reading: Evidence for dissociations between experience and metaconsciousness. In D. T. Levin (Ed.), *Thinking and seeing: Visual metacognition in adults and children* (pp. 204–226). Cambridge, MA: MIT Press.

Schooler, J. W., Smallwood, J., Christoff, K., Handy, T. C., Reichle, E. D., & Sayette, M. A. (2011). Meta-awareness, perceptual decoupling and the wandering mind. *Trends in Cognitive Sciences, 15*(7), 319-326.

Seibert, P. S., & Ellis, H. C. (1991). Irrelevant thoughts, emotional mood states, and cognitive task performance. *Memory & Cognition, 19*(5), 507-513.

Smallwood, J. (2011). Mind-wandering while reading: Attentional decoupling, mindless reading and the cascade model of inattention. *Language and Linguistics Compass, 5*(2), 63-77.

Smallwood, J., Beach, E., Schooler, J. W., & Handy, T. C. (2008). Going AWOL in the brain: Mind wandering reduces cortical analysis of external events. *Journal of Cognitive Neuroscience, 20*(3), 458-469.

Smallwood, J., Karapanagiotidis, T., Ruby, F., Medea, B., de Caso, I., Konishi, M., . . . Jefferies, E. (2016). Representing representation: Integration between the temporal lobe and the posterior cingulate influences the content and form of spontaneous thought. *Plos One, 11*(4), 1-19.

Smallwood, J., McSpadden, M., & Schooler, J. W. (2008). When attention matters: The curious incident of the wandering mind. *Memory & Cognition, 36*(6), 1144-1150. doi: 10.3758/mc.36.6.1144

Smallwood, J., & Schooler, J. W. (2006). The restless mind. *Psychological Bulletin, 132*(6), 946.

Smallwood, J., & Schooler, J. W. (2015). The science of mind wandering: empirically navigating the stream of consciousness. *Annu. Rev. Psychol, 66*, 487-518.

Song, X., & Wang, X. (2012). Mind wandering in Chinese daily lives–an experience sampling study. *Plos One, 7*(9), 1-9.

Sousa, T. L. V., Carriere, J. S., & Smilek, D. (2013). The way we encounter reading material influences how frequently we mind wander. *Frontiers in Psychology, 4*(892), 1-8.

Stawarczyk, D., Majerus, S., Maj, M., Van der Linden, M., & D'Argembeau, A. (2011). Mind-wandering: Phenomenology and function as assessed with a novel experience sampling method. *Acta psychologica, 136*(3), 370-381.

Viechtbauer, W. (2010). Conducting meta-analyses in R with the metafor package. *Journal of Statistical Software, 36*(3), 1-48.

Wilson, K., Martinez, M., Mills, C., D'Mello, S. K., Smilek, D., & Risko, E. (in review). Instructor presence effect: Liking does not always lead to learning

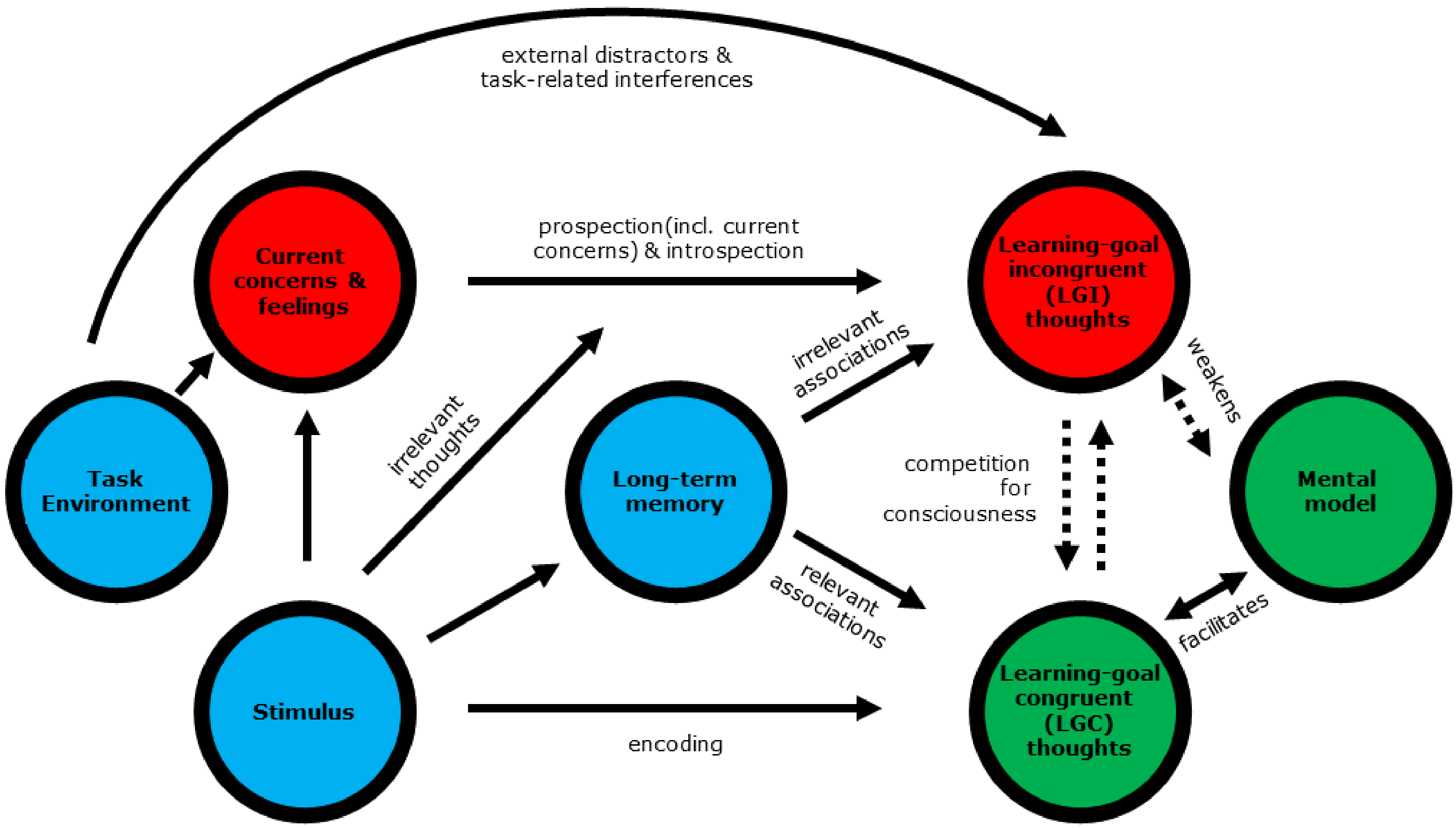

Figure 1. Model of thoughts and their triggers during learning

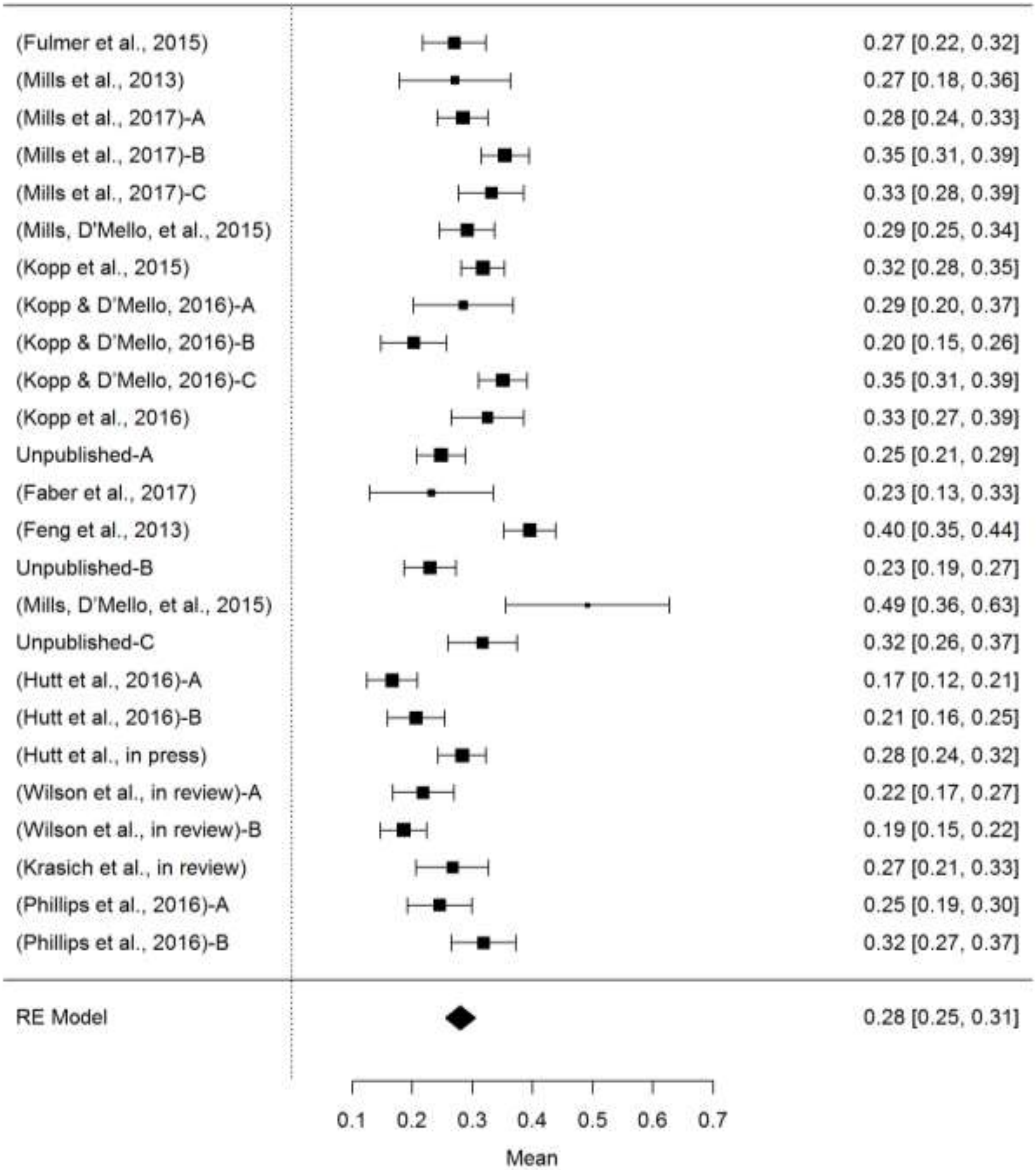

Figure 2. Forest plot of studies on the incidence of mind wandering during learning

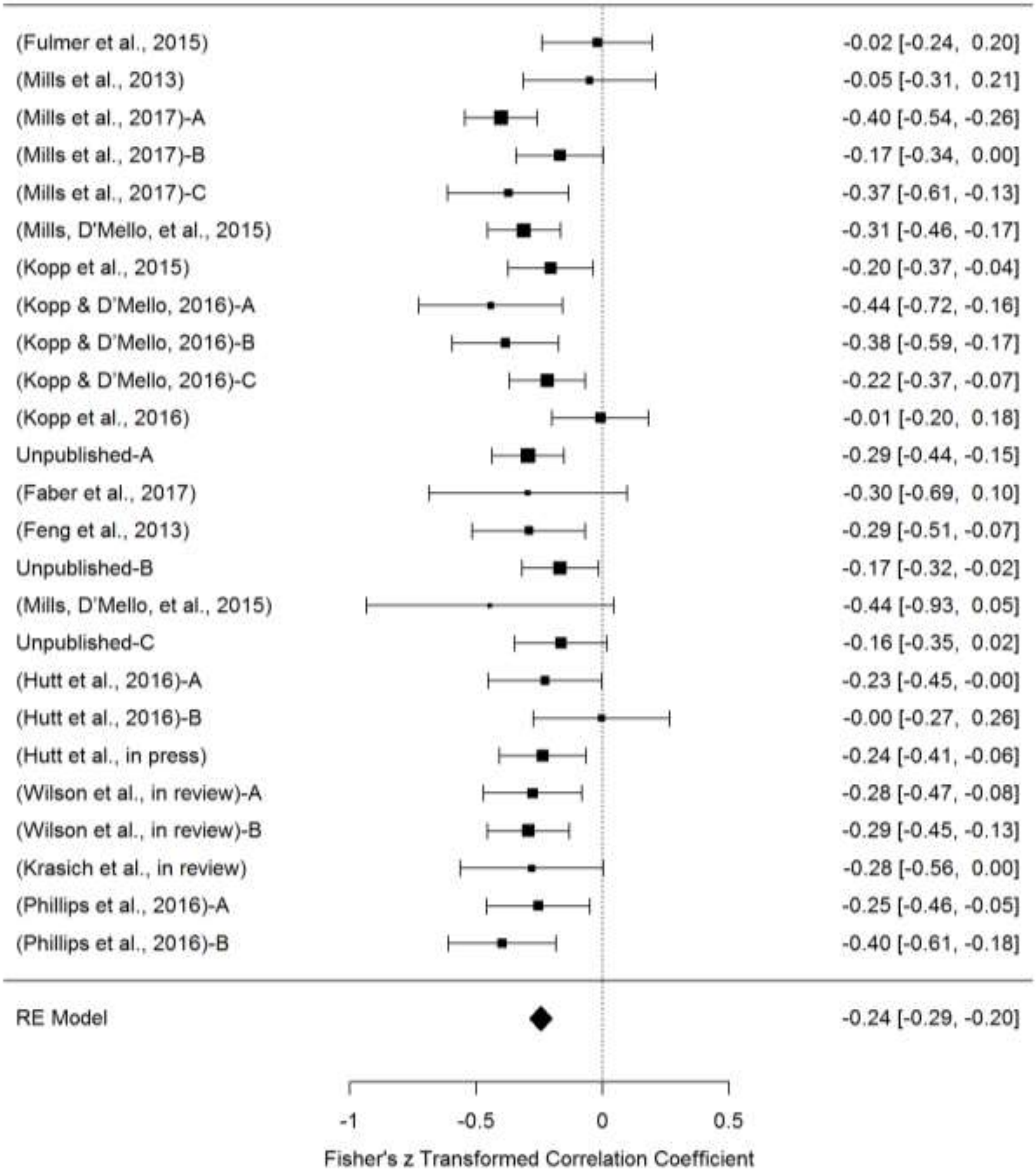

Figure 3. Forest plot of studies on the incidence of mind wandering during learning

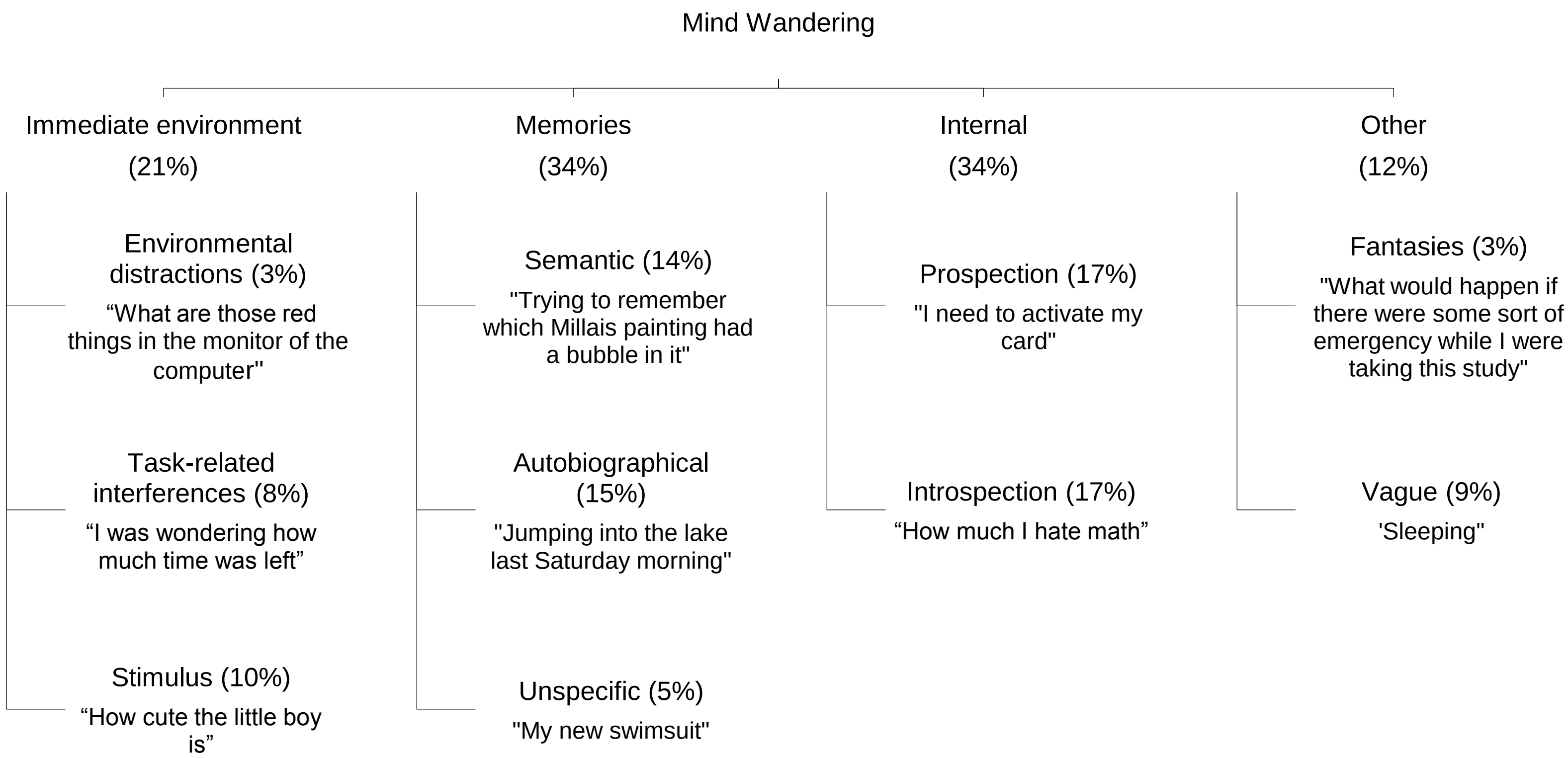

Figure 4. Thought categories, percentages per subcategory and summed across categories, and examples

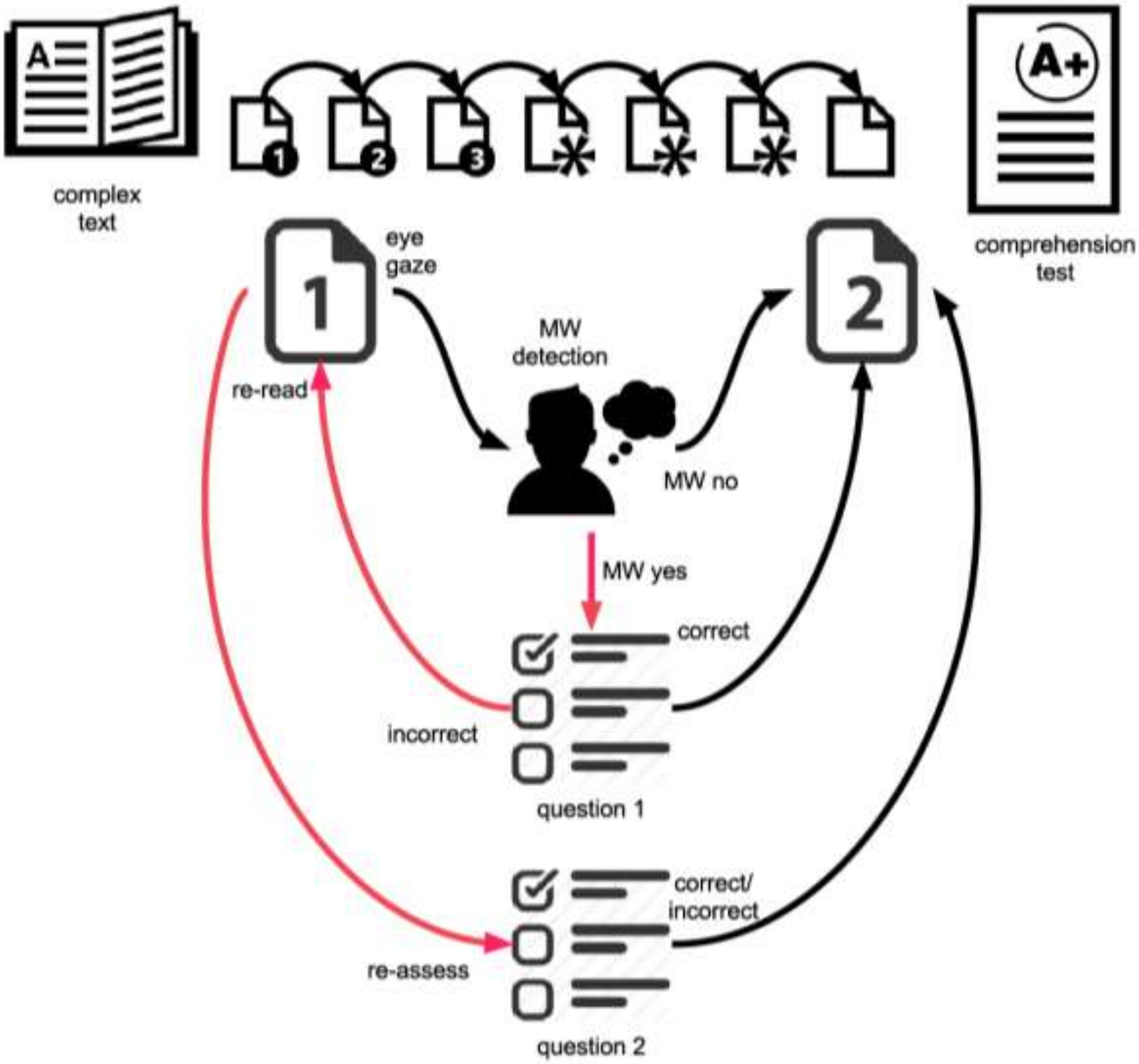

Figure 5: Mind wandering detection and intervention during computerized reading