Mind Wandering Trait-level Tendencies During Lecture Viewing: A Pilot Study

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ABSTRACT

Mind wandering (MW) is defined as a shift of attention to task-unrelated internal thoughts that is pervasive and disruptive for learning performance. Current state-of-the-art gaze-based attention-aware intelligent systems are capable of detecting MW from eye movements and delivering interventions to mitigate its negative effects. However, the beneficial functions of MW and its trait-level tendency, defined as the content of MW experience, are still largely neglected by these systems. In this pilot study, we address the questions of whether different MW trait-level tendencies can be detected through off-screen fixations' frequency and duration and blink rate during a lecture viewing task. We focus on prospective planning and creative problem-solving as two of the main MW trait-level tendencies. Despite the non-significance, the descriptive values show a higher frequency and duration of off-screen fixations, but lower blink rate, in the creative problem-solving MW condition. Interestingly, we do find a highly significant correlation between MW level and engagement scores in the prospective planning MW group. Potential explanations for the observed results are discussed. Overall, these findings represent a preliminary step towards the development of more accurate and adaptive learning technologies, and call for further studies on MW trait-level tendency detection.

CCS CONCEPTS

• **Applied computing** → **Computer-managed instruction**; • **Human-centered computing** → *Empirical studies in HCI*; Laboratory experiments.

KEYWORDS

mind-wandering, education, learning, eye-movements

ACM Reference Format:
Francesca Zermiani, Andreas Bulling, and Maria Wirzberger. 2022. Mind Wandering Trait-level Tendencies During Lecture Viewing: A Pilot Study. In *2022 Symposium on Eye Tracking Research and Applications (ETRA '22), June 8–11, 2022, Seattle, WA, USA.* ACM, New York, NY, USA, 7 pages. https://doi.org/10.1145/3517031.3529241

ETRA '22, June 8–11, 2022, Seattle, WA, USA

ACM ISBN 978-1-4503-9252-5/22/06…$15.00
https://doi.org/10.1145/3517031.3529241

1 INTRODUCTION

Imagine Alice, a student sitting in a classroom. Instead of listening to her Biology teacher's explanation of a cell structure, she finds herself thinking about her dinner plans for the evening – therefore missing information that will likely become relevant for the exam. Sitting right next to her is Bob. Similar to Alice, instead of listening to the current lecture, Bob is thinking about material presented in his Arts course earlier that day. In stark contrast to Alice, however, this thought process leads to a great idea for his Arts assignment. Alice and Bob's internal thoughts illustrate shifts of attention, referred to as mind wandering (MW), which can surface in a learning environment and have different types of content — or trait-level tendencies [Hutt et al. 2019].

In this work, we focus on the primary trait-level tendencies of MW, namely prospective planning and creative problem-solving [Mooneyham and Schooler 2013; Smallwood and Schooler 2014], and investigate potential qualitative differences between them. We present a pilot study as a first exploratory step towards the detection of trait-level tendencies of MW from eye movements. Building on [Zhang et al. 2020], we explore MW during one of their video lectures and introduce new stimuli to evoke MW episodes with distinct trait-level inclinations (i.e., MW with a focus on prospective planning against MW with a focus on creative problem-solving), throughout a *priming* technique. Priming refers to an experimental strategy that aims at inducing or facilitating a specific stimulus response or behavior, following the pre-processing of a prime stimulus associated to the target stimulus [Janiszewski and Wyer Jr. 2014]. Priming has been successfully performed in MW studies with the aim of inducing MW through cue-words related to the subjects' personal concerns [McVay and Kane 2013], and controlling the frequency and temporal focus of MW through irrelevant stimulus words [Vannucci et al. 2017]. Our scenarios follow the principle of *indirect behavioral priming*, a type of content priming that targets an increase in the accessibility of behaviors that are related to certain goals, by triggering the content of those goals (see [Janiszewski and Wyer Jr. 2014] for a review of content priming research).

Our stimuli consist of two different scenarios (see Appendix A.2) presented to the subjects prior to the video lecture. The activation of two fictitious goals, in combination with the imminent future component (i.e., both goals have a deadline set for a fictitious 'tomorrow'), intends to prime corresponding task-unrelated internal thoughts, in accordance with the previously mentioned literature linking MW and future goals. The goals are (a) packing for vacation as the prospective planning task, and (b) the completion of a creative writing task. As an exploratory pilot study, we compare the following gaze metrics between conditions: (a) the frequency of 'looking at nothing' behaviors (defined as the number of off-screen fixations, namely outside of the display in which the video stimulus is presented), (b) the duration of 'looking at nothing' behaviors (defined as the duration of the off-screen fixations), and (c) the blink frequency (defined as the number of blink events). In particular, we address the questions of whether the frequency of off-screen fixations, the duration of off-screen fixations and the blink rate differ in the creative as opposed to the prospective planning MW trait-level tendency. Based on previous findings [Salvi and Bowden 2016], we hypothesize that the creative trait-level tendency of MW should exhibit more frequent and longer off-screen fixations and an increase in blinking rate.

2 RELATED WORK

2.1 Mind Wandering and Trait-level Tendency

Mind wandering is generally defined as an attentional shift from the primary task to task-unrelated self-generated internal thoughts [Antrobus 1968; Smallwood and Schooler 2006, 2014], thus interrupting the information processing and integration that are fundamental for successful learning [Smallwood et al. 2007]. This cognitive phenomenon has been shown to be pervasive in educational contexts [Risko et al. 2012, 2013] and to negatively correlate with learning performance across tasks [D'Mello 2018; Randall et al. 2014]. Alongside the line of research investigating the disruptions caused by MW, considerable scientific attention has been given to identifying its beneficial functions and trait-level tendency, often associated with *prospective planning* and *creative problem-solving* [Mooneyham and Schooler 2013; Smallwood and Schooler 2014].

Prospective or autobiographical planning refers to the cognitive function of predicting and organizing those future goals that might be significant to us. As most of the thoughts we generate during MW are future-oriented [Baird et al. 2011; D'Argembeau et al. 2011; Smallwood et al. 2009], in particular when they refer to ourselves and our goals, prospective planning would be facilitated by MW [Baird et al. 2011]. Our MW moments would also stimulate creativity. Previous studies exploring the bridge between these two conditions exhibit a beneficial impact of MW on creative idea generation [Baird et al. 2012; Baumgart et al. 2020]. Emerging evidence also suggests a fundamental similarity between the different stages of creativity (i.e., a *dual-process model* involving an idea generation phase and a following idea evaluation phase) and those belonging to MW [Fox and Beaty 2019].

2.2 Gaze-based Attention-aware Technologies

Several eye-tracking studies have recognized specific gaze behaviors associated with MW mostly during reading [Bixler and D'Mello 2016; Faber et al. 2018; Franklin et al. 2013], lecture viewing [Huang et al. 2019; Hutt et al. 2017a; Zhang et al. 2020], real-world scene processing [Krasich et al. 2018], and film viewing [Mills et al. 2016], often with inconsistent findings emphasizing the necessity of considering task demands and parameters when investigating MW [Faber et al. 2020]. In the past decade, the systematic study of this link has led to the development of gaze-based attention-aware learning technology, with the goal of mitigating the negative consequences of MW in learning contexts. Such intelligent tutoring systems are capable of detecting MW from the learners' eye movements and delivering real-time interventions, such as reiteration, attention redirection phrases and questions [Hutt et al. 2021, 2017b; Mills et al. 2021].

Despite the negative correlation between MW and learning outcomes across tasks and the rapid development of intervention tools, the different MW trait-level tendencies and their beneficial outcomes are still largely neglected by current attention-aware learning technologies. This might be due to the challenging nature of conducting experimental research on MW. Key challenges include (1) the lack of strategies to directly induce MW in a controlled experimental set-up across different tasks, often resulting in vague causal effects, (2) the highly-covert nature of internal self-generated thoughts, and (3) the degree of reliability of experience sampling methods — as self-reports and thought probes are still the most common methods to collect ground truth for MW [Smallwood and Schooler 2014].

Promising results from studies involving eye tracking and internally driven cognition have shown that when shifting our attention inward, specific gaze behaviors can be observed, such as blinking and fixating a blank space in our visual field (e.g., staring at a blank wall or out of the window), often referred to as 'looking at nothing' behavior [Salvi and Bowden 2016]. The link between internal thoughts and 'looking at nothing' has been primarily observed during object visual imagery, where the eye movements during the recall of a visual stimulus (i.e., while looking at nothing) mirror the eye movements occurring while actually looking at the visual stimulus [Brandt and Stark 1997; Spivey and Geng 2001]. A similar mechanism would occur during MW and internally driven cognition that does not assume the recall or representation of mental images. For instance, previous findings show that looking-away from the text behaviors and longer fixations are more likely to occur before episodes of mindless reading [Reichle et al. 2010]. This looking at nothing behavior would thus result in looking *away* from the current visual stimulus, in other words reducing the cognitive processing of an external stimulus — by looking at nothing — would enhance insight and creativity [Salvi and Bowden 2016]. Furthermore, the function of suppressing external stimuli is also supported by blinking, which promotes insight problem solving [Salvi et al. 2015] and creativity [Chermahini and Hommel 2010]. Increases in blinking rate have also been found in MW during reading [Smilek et al. 2010], supporting the link between this gaze behavior and internal cognitive attention.

3 METHODS

3.1 Participants

23 adult subjects (*M* age = 25.30 years, *SD* = 5.88 years, 60.86% female) volunteered for this pilot study after signing an informed consent. They received either a monetary compensation of 10€/hour or course credits for their participation. Among them, 78.26% were undergraduate students of different degrees, mostly related to the fields of Computer Science (61.11%) and Behavioral Sciences (38.88%). Of the total amount, 12 participants were randomly assigned to the prospective-planning MW condition. All subjects had to meet

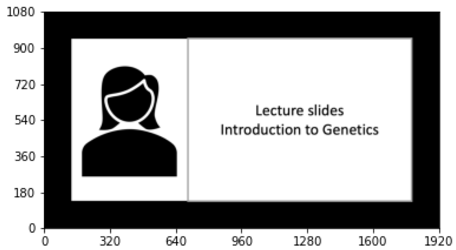

Figure 1: Illustrative representation of the stimulus video material [1]. The video lecture always displays the teacher on the left side and the slides on the right side. Screen resolution is shown on the X and Y axes (pixels).

the requirement of normal or corrected-to-normal eye sight to participate in the study.

3.2 Stimuli and Apparatus

The video was a 22-minute scripted lecture with the title "Introduction to Genetics" (see [Zhang et al. 2020] for more details about the video[1]). The video showed an instructor window and a slides window (Fig. 1). A 1080*1920 resolution laptop screen was used to play the video, with an approximate viewing distance of 60 cm. Gaze data were recorded by a Tobii Pro Nano eye tracker at 60 Hz. The experiment was entirely implemented in the Tobii Pro Lab software [Tobii Pro AB 2014].

3.3 Procedure

We followed a similar procedure to [Zhang et al. 2020]. After providing a written informed consent, participants completed a pre-test to retrieve standard demographic information and measure prior knowledge on the subject. The pre-test was adapted from [Zhang et al. 2020] and consisted of demographic questions (i.e., age, gender, education, occupation/study subject, whether they were English native-speakers) and five multiple-choice questions that had to be completed in 5 minutes. Afterwards, subjects received instructions and a definition of MW, a definition of task-related interference (TRI), as well as a short exercise to learn to distinguish between these conditions (all definitions and exercise were retrieved by [Zhang et al. 2020], see Appendix A.1). In particular, participants were told to consider any thoughts coming up spontaneously during the video lecture that are unrelated to the content of lecture itself as MW [Lindquist and McLean 2011]. They learned to differentiate this from TRI, defined as spontaneous thoughts still related to some characteristics of the video lecture [Smallwood and Schooler 2014]. They checked their understanding by completing an exercise with seven different scenarios to classify as either MW or TRI. The experimenter clarified any questions or doubts regarding the exercise.

Subsequently, the subjects were randomly assigned to the prospective planning MW tendency condition or the creative problem-solving MW tendency condition. From now on, we will address these conditions as respectively *future MW* and *creative MW*. In the future MW condition, subjects were asked to imagine the following scenario: *"You are a student of Biology and it is the last day of lectures before the holiday break. You need to watch your last video lecture for the "Introduction to Genetics" course, with mandatory online attendance. Tomorrow morning you are going on holidays and you have not packed yet."*. In the creative MW condition, the presented scenario still involved a student of Biology on the last day of lectures before the holiday break. However, on the following day the student is supposed to submit the final assignment for a creative writing class, with topic "what would happen if you were a wizard", which the student has not started to write yet. Following the scenarios, participants were presented six manipulation questions for each condition, which were answered verbally to the experimenter. Scenarios and questions were presented through a PowerPoint presentation, in full-screen display, with written prompts and images. Both scenarios and their respective questions can be found in the Appendix (A.2). For all participants across conditions, we collected MW ground truth through thought probes. The video lecture was therefore interrupted at four established times by a text of a grey background saying: "*Right before this break, were you mind wandering? Please answer only YES or NO aloud*". Answers were manually annotated. Following [Zhang et al. 2020], the thought probes interrupted the video at 3 min 19 sec, 10 min 48 sec, 15 min 01 sec, and 21 min 15 sec.

Before watching the video, the eye tracking software performed a 5-point calibration and participants were presented again with the priming scenario, according to their condition. After watching the video and answering the thought probes, they completed a short post-test questionnaire consisting of four questions. Subjects rated how much they thought about the priming scenario during the video ("*Throughout the video lecture, have you thought about the "student scenario" you were given?"* on a scale from 1 – *very often* to 4 – *never*). In the post-test, participants also gave a score to their interest in the presented topic and their attention level: "*The material covered in this lesson was interesting*" and "*My attention was fully focused on the video*", on a scale "from 1 – *strongly agree* to 5 – *strongly disagree*" (as in [Zhang et al. 2020]). Finally, following a retrospective method, participants could report some examples of their MW episodes during the video lecture: "*What were you thinking while you were mind-wandering? Please give us a few examples.*" (as in [Zhang et al. 2020]). These MW reports were not considered during analysis for the current pilot study. All questionnaires and instructions (i.e., pre-test, MW/TRI definitions, exercise, and post-test) were generated and administered through SoSci Survey[2] [Leiner, D. J. 2019].

3.4 Data Analysis

Data processing and analysis were conducted in Python [Van Rossum and Drake 2009] (Version 3.8), whereas statistical analyses were performed with RStudio [RStudio Team 2021]. After exporting the data, the manually-annotated answers to the thought probes were incorporated in the raw gaze data frame. As the four thought probe questions were presented in the form of written text interrupting the video, they generated reading gaze data. We therefore extracted the raw gaze data only associated with video watching. This resulted in five data frame segments for each participant, corresponding

[1] All material retrieved from [Zhang et al. 2020] was accessed via https://osf.io/zhcaf/.

[2] Accessed via https://www.soscisurvey.de/.

to the video lecture segments. Within these segments, we subsequently extracted gaze features that occurred in the 30 seconds before each thought probe onset time, based on [Bixler and D'Mello 2016; Hutt et al. 2017a, 2016]. We labeled as MW only those windows preceding a positive probe report. We analyzed two types of features from these 30-second windows: off-screen fixations and blinks.

To obtain off-screen fixations, we first selected all eye movement types classified as "Fixation" within the window size. All fixations with an X-coordinate smaller or larger than 1920 pixels and a Y-coordinate smaller or larger than 1080 pixels were considered as off-screen, based on our screen resolution (1080*1920). A similar procedure was used for blink events. First, we obtained all eye movements classified as "EyesNotFound" and only those with a duration in the range of 100-300 ms were considered as blinks, based on [Grandchamp et al. 2014; VanderWerf et al. 2003]. These gaze features were compared between-groups. A Shapiro-Wilk test for normality revealed that our data were not normally distributed, hence we performed a Mann-Whitney U test to compare differences between our two groups. Finally, post-test scores for priming scenario and engagement level were analysed and correlated to MW level by performing Spearman Rank correlation (ρ) tests.

4 RESULTS

4.1 Gaze Features

Off-screen fixations had a higher frequency in the creative MW condition compared to future MW (40 vs. 7 off-screen fixation events). However, their comparison resulted in a non-significant difference (p = .491, d = 0.628). No significant difference appeared for off-screen fixations' duration (p = .621, d = -0.295), although descriptive values again pointed at a higher duration for the creative MW group (13210 vs. 1782 ms). Blink rate comparison resulted in a lower number of blink events for the creative MW group (90 vs. 204 blink events), with non-significant comparison (p = .335, d = -0.602). According to [Cohen 1988], the effects point at a medium-sized range effect. Our analyses achieved a power of $1 - \beta = .200$, for α = .05 and the theoretically assumed medium-size effect $d = 0.5$.

4.2 Mind Wandering, Engagement and Priming Scenario

MW levels in both conditions, defined as the percentage of probe-caught MW for each participant, were correlated with the averages of engagement-level scores reported by participants during the post-test ("*The material covered in this lesson was interesting*" and "*My attention was fully focused on the video*"), as well as with the scores regarding the priming scenario ("*Throughout the video lecture, have you thought about the "student scenario" you were given?*") (Table 1). We found a significant correlation only between MW level and engagement in the future MW group (ρ = -.79). We therefore further investigated whether the correlation was significant for both engagement-level questions, namely interest in the topic or self-perceived attention on the video. We found a highly significant correlation between future MW level and attention scores (ρ = -.88). In general, 47.82% of participants reported that they had thought about the priming scenario *sometimes* (39.13% *rarely*, 8.69% *never*, 4.34% *very often*).

5 DISCUSSION AND CONCLUSION

For the first time, we presented a novel gaze analysis of MW trait-level tendencies, induced via priming scenarios, in our eye tracking pilot study. In particular, we hypothesized that creative MW should show a higher frequency and duration of 'looking at nothing' behavior (i.e., off-screen fixations), as well as a higher blink rate. Our obtained descriptive values exhibit a higher number and duration of off-screen fixations, but lower blink rate, in the creative MW condition. However, upon performing the significance test our hypotheses cannot be confirmed.

We first postulate that the non-observed significant difference in such gaze features between groups is likely due to the insufficient amount of data. Our post hoc power analysis revealed poor statistical power for the theoretically assumed population effect size, which provides additional values for interpreting non-significant results [O'Keefe 2007]. This might also explain the observed non-normal distribution of our data. Although our study is a first step in this line of research, we suggest future work to increase the sample size and improve statistical power. We would expect a significant difference in off-screen fixations frequency and duration between creative vs. future MW conditions, given a larger amount of data points.

Our observed results could also be due to our experimental set up, in particular to the priming scenarios. Participants' reports of how frequently they thought about the assigned scenario during the video lecture revealed a majority of negative answers. Future work should therefore improve the strength and plausibility of the priming scenarios, to obtain significant results in the analyzed gaze features between creative and future MW trait-level tendencies. As a consequence, the main lecture viewing task and presented material would have a lower chance of taking over most of the available cognitive resources. In future iterations, we will consider strengthening the priming effect by formulating scenarios more closely related to the participants' current personal concerns and triggering them at multiple times throughout the learning task, following [McVay and Kane 2013]'s approach. In addition, introducing post-test comprehension/retention scores would have added valuable evidence to our pilot study design. Such post-test analysis might shed more light on our observed results and could be addressed in future work.

Finally, off-screen fixations (frequency and duration) and blink rate represented an interesting first starting point to identify qualitative differences in MW trait-level tendencies. On one hand however, the eye-blink rate itself exhibits significant variation and can be affected by workload and time spent on task [Stern and Skelly 1984], as well as by sleepiness level [Barbato et al. 2007] and times of the day [Barbato et al. 2000]. On the other hand, the eye-MW link can be influenced by task and processing demands, also resulting in diverse gaze behaviors [Faber et al. 2020]. Given the initial findings from our novel pilot study, we propose future studies to enhance our exploratory design by taking these factors into consideration and, for instance, include measurements of perceived cognitive load and sleepiness level or set specific times for data collection. Furthermore, additional gaze features could be investigated, such as

Table 1: Averages of MW levels and their correlation with engagement and priming scenario

Condition	MW level (%)	SD	MW - Engagement (MW-interest, MW-attention)	MW - Priming scenario
Future MW	41.66	19.46	-0.79** (-0.26, -0.88***)	-0.19
Creative MW	45.45	36.77	-0.15 (-0.17, 0.02)	-0.53

Note: *** p < .001, ** p < .01, * p < .05.

the extraction and analysis of fixation allocations and on- and off-screen fixations shifts. Different modalities — like head movements — could also be combined with gaze.

Interestingly, we did find a highly significant correlation between MW level and perceived engagement, which is in accordance with findings related to probe-caught MW from [Zhang et al. 2020]. Upon further fine-grained investigation, we found that this significant correlation is specifically observed in the future MW group (ρ = -.79), in particular between future MW level and perceived attention (ρ = -.88). This might indicate a latent difference between these two MW trait-level tendencies and how they are perceived, with perceived attention having a direct consequence on future-MW levels, but not on creative-MW ones. In other words, the more a person reported themselves as fully focused, the lower MW levels were caught by the probes, given a scenario that would prompt future prospective planning MW. This difference might also be related to the type of training received to distinguish between MW and non-MW (or TRI) or the probe-caught method itself, which — despite being among the standard measurements for MW — still presents limitations [Smallwood and Schooler 2014].

In conclusion, the obtained results can be considered as a starting point for further analyses of MW trait-level tendencies during learning. In order to develop more adaptive MW-detection systems and more sensitive intervention tools, we need to consider not only the costs of MW but also its cognitive functions and benefits in learning contexts. This novel pilot study also emphasizes the need for additional studies investigating new approaches and stimuli for controlled inducement and measurement of MW.

ACKNOWLEDGMENTS

The authors thank the International Max Planck Research School for Intelligent Systems (IMPRS-IS) for supporting Francesca Zermiani. We wish to extend our special thanks to Ekta Sood (University of Stuttgart) for her advice throughout the research process, Florian Strohm (University of Stuttgart) for providing assistance during data analysis in Python, and René Skukies (University of Stuttgart) for his support with statistical analysis. The authors would also like to thank Anastasia Lado and Laura Bareiß (University of Stuttgart) for their support during participant recruitment.

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A SUPPLEMENTARY MATERIAL

A.1 Presented Instructions and Exercise

During the video, we will ask you this question: Right before this break, were you mind wandering? Please answer only YES or NO aloud.

Instructions for distinguishing Mind Wandering (MW) and Task-Related Interference (TRI) — Definition of MW: "Any thoughts experienced throughout the lecture that are not related to the content being presented during the lecture", including cases where "thoughts simply pop into your head" and "you may choose to think about something other than the lecture content" (as in Lindquist and McLean, 2011). Therefore, you should answer ‚YES' under these cases. — Definition of TRI: Your thought is still about some aspects of the lecture, albeit not the content per se. For example, you might think "how much longer is this video going to end?", "This lecture is interesting/boring.", "The lecturer just made an error.", "The knowledge is difficult to understand.", "I worry about the quiz after the video." In these and some other cases, you are still thinking something about the lecture, albeit not the content per se. Therefore, your attention is not completely offline, and we are not interested in these cases. Therefore, you should answer ‚NO' under these cases.

Check your understanding — While watching the video, you may catch yourself doing things described in the following statements. Please classify these statements into the correct category by crossing MW or TRI. You can use the instructions above if you want.

(1) You find yourself thinking about your plans for tonight. (MW) or (TRI)?
(2) You find yourself wondering what the post-video questions will be like. (MW) or (TRI)?
(3) You find yourself thinking about what food to eat later while watching the video. (MW) or (TRI)?
(4) You find yourself thinking about how much longer the video will be. (MW) or (TRI)?
(5) You find yourself thinking about what you did last weekend. (MW) or (TRI)?
(6) You find yourself thinking about your trip to France when the lecturer mentioned "France". (MW) or (TRI)?
(7) You find yourself complaining how boring the video is. (MW) or (TRI)?

A.2 Priming Scenarios

Future MW. You are a student of Biology and it is the last day of lectures before the holiday break. You need to watch your last video lecture for the "Introduction to Genetics" course, with mandatory online attendance. Tomorrow morning you are going on holidays and you have not packed yet.

Manipulation questions for future MW priming scenario:

(1) Where will you go on holidays?
(2) Who is coming with you?
(3) How long will you stay away?
(4) By what means will you travel?
(5) How many luggage will you bring?
(6) Do you already have plans?

Creative MW. You are a student of Biology and it is the last day of lectures before the holiday break. You need to watch your last video lecture for the "Introduction to Genetics" course, with mandatory online attendance. Tomorrow morning you have to submit the final assignment for the creative writing class you signed up for. You need to write a story about "what would happen if you were a wizard" and you have not started to work on your story yet.

Manipulation questions for creative MW priming scenario:

(1) What type of text would you like to write?
(2) Are you usually a slow- or fast-writer?
(3) When will you most likely submit your assignment?
(4) Will you ask someone to proofread your text? Whom?
(5) If you were a wizard, would you be a good or bad one?
(6) Would you like to have a magic assistant?