Students' mind wandering in macroscopic and submicroscopic textual narrations and its relationship with their reading comprehension

Abstract

The aim of the current study was to investigate students' mind wandering while reading different types of textual narrations (macroscopic and submicroscopic) in chemistry. Another goal was to determine the relationship between mind wandering and students' reading comprehension. The participants were 65 female ninth grade students in Oman. Using a computer screen, participants were required to read about sodium chloride. A probe-catch procedure was used to measure students' mind wandering. Half of the slides presented textual narrations at the macroscopic level and the other half presented narrations at the submicroscopic level. We gave the students a paper and pencil reading comprehension test at the conclusion of the reading task. The findings indicated that participants' mind wandering while reading submicroscopic textual narrations was significantly higher when compared to reading macroscopic textual narrations. Also, there was a significant negative relationship between mind wandering and reading comprehension for both macroscopic and submicroscopic textual narrations. Implications and future research are discussed.

Keywords: Cognitive abilities; macroscopic textual narrations; mind wandering; reading comprehension; Sodium Chloride; submicroscopic textual narrations

Introduction

General students' performance in chemistry has been associated with their reading comprehension (Pyburn, Pazicni, Benassib, & Tappinc, 2013). Students with high language comprehension have a cognitive advantage over students with low language comprehension. They are able to: 1) inhibit irrelevant details and 2) use prior knowledge efficiently. What is more, language comprehension ability compensates for lack of prior knowledge (Pyburn et al., 2013). However, little is known about learners' reading comprehension of different types of textual narrations in chemistry (macroscopic and submicroscopic) and whether students' attention to both types of narration is consistent. When attention is not devoted to the text, mind wandering takes place. Linking this mind wandering to macroscopic and submicroscopic textual narrations has not been given proper attention in chemistry education research. The closest line of research is the investigation of the effect of field dependent attributes on students' performance in chemistry. Field dependent students are those who are easily distracted by irrelevant material. Their performance in chemistry is found to be negatively affected by their field dependency (Al-Naeme & Johnstone, 1991; Danili & Reid, 2006). Field dependent attributes seem to affect students' test performance regardless of the type or content of test questions: algorithmic questions or questions where language is important (Danili & Reid, 2006). The scope of this study is to investigate students' mind wandering while reading macroscopic and submicroscopic textual narrations in chemistry.

Cognitive processing of macroscopic and submicroscopic levels of chemistry

The triplet nature of chemistry (macroscopic, submicroscopic and symbolic) has been an indispensable subject of research and discussion in chemistry education literatures (Dumon &

Mzoughi-Khadhraoui, 2014; Milenković, Segedinac, & Hrin, 2014; Prilliman, 2014; Ryan & Herrington, 2014; Taber, 2013; Warfa, Roehrig, Schneider, & Nyachwaya, 2014). The three levels included in this triplet nature of chemistry are considered as levels of thought (Johnstone, 2000). Students' performance in chemistry has been attributed to their ability to conceptualize chemical phenomena and entities in terms of these three levels. Much of the difficulty students have in learning chemistry and the related misconceptions have been considered to be a result of their inability to comprehend the details of the phenomenon undertaken at the three levels and their failure to move spontaneously among them (Kelly, 2014; Milenković et al., 2014; Prilliman, 2014; Ryan & Herrington, 2014; Sanger, Vaughn, & Binkley, 2013; Sjöström & Talanquer, 2014; Warfa et al., 2014). In addition, most of the learners do not seem to spontaneously provide a submicroscopic explanation of chemical phenomena unless they are cued to do so (Al-Balushi, 2012, 2013a).

There have been different attempts to cognitively understand students' cognitive processing of macroscopic and submicroscopic concepts. Since the macroscopic level is the observable domain of chemistry and the submicroscopic level is the unobservable level, students' conceptualization of each of them has not been the same (Gulacar, Eliks, & Bowman, 2014; Springer, 2014; Taber, 2013). Different studies investigated students' cognitive processes when conceptualizing macroscopic and submicroscopic entities and processes. Generally speaking, the level of abstractness for submicroscopic concepts is considered to be higher than for macroscopic concepts of the physical world (Al-Balushi, 2011, 2013b; Al-Balushi & Coll, 2013; Gericke & Hagberg, 2007; Taber, 2013). In fact, viewing and manipulating chemical representations in the physical world or providing learners with information-rich representations places less cognitive load than processing them solely in the student's mind (Cranford, Tiettmeyer, Chuprinko, Jordan, & Grove, 2014; Springer, 2014). In addition, higher-performance students, who are able to handle higher cognitive loads could represent the chemical phenomena at macroscopic, submicroscopic and symbolic levels better than lower-performance students (Gulacar et al., 2014). Interestingly, presenting unconnected macroscopic and submicroscopic information places more cognitive load on learners' working memory than does integrating different levels by which learners could conceptualize linkages among them (Milenković et al., 2014).

Another cognitive aspect related to students' conceptualization of the macroscopic and submicroscopic entities and processes is their conception of "size and scale". Students' estimation of the spatial scales of submicroscopic entities is less accurate compared with macroscopic ones (Jones, Gardner, Taylor, Wiebe, & Forrester, 2011; Jones & Taylor, 2009; Tretter, Jones, & Minogue, 2006). Not only is students' estimation of scales negatively affected as they move from the macroscopic to submicroscopic, but also their doubt in the existence of natural entities increases. Students express more suspicion about the existence of more abstract theoretical entities, such as electron clouds and photons, than less abstract entities, such as meteorites, body cells and bacteria (Al-Balushi, 2011, 2013b). In addition, since they lack definite details, more theoretical entities trigger more vivid mental images than more concrete entities (Al-Balushi, 2013b). Another cognitive attribute that distinguishes students' conceptualization at both the macroscopic and submicroscopic level is spatial ability. Much of students' success in understanding different macroscopic and submicroscopic entities and phenomena is linked to their spatial ability (Carter, Larussa, & Bodner, 1987; Pribyl & Bodner, 1987; Wang & Barrow, 2011; Wu & Shah, 2004; Yang, Andre, Greenbowe, & Tibell, 2003).

Collectively, the research results discussed above reveal that learners' cognitive processing and conceptualization of entities and phenomena at the macroscopic and submicroscopic levels in chemistry are related to the level of abstractness (Al-Balushi, 2011, 2013b; Al-Balushi & Coll, 2013; Gericke & Hagberg, 2007; Taber, 2013), cognitive load (Cranford, Tiettmeyer, Chuprinko, Jordan, & Grove, 2014; Gulacar et al., 2014; Springer, 2014), learners' estimation of size and scale at both levels (Jones, Gardner, Taylor, Wiebe, & Forrester, 2011; Jones & Taylor, 2009; Tretter, Jones, & Minogue, 2006) learners' distrust of the existence of scientific entities (Al-Balushi, 2011, 2013b) and spatial ability required (Carter, Larussa, & Bodner, 1987; Pribyl & Bodner, 1987; Wang & Barrow, 2011; Wu & Shah, 2004; Yang, Andre, Greenbowe, & Tibell, 2003). Due to the differences between macroscopic and submicroscopic levels, the current study focuses on finding whether mind wandering can be added to the list of these differences (mentioned above) and eventually contributes to our interpretations of students' comprehension. It should be noted that some of the above cognitive parameters might be considered to be causes of the differences between macroscopic and submicroscopic, while others might be considered to be consequences of these differences. Mind wandering is probably one of the consequences. However, the disparity between these cognitive parameters is outside the scope of this paper.

It might be argued that if students' minds are wandering, it means that they are not putting in the necessary mental effort, i.e. they are not paying attention. This would obviously lead to a slower reading rate and lower comprehension. However, since we are comparing between two different types of textual narrations (i.e. macroscopic and submicroscopic), findings will help us decide which type, if any, leads to more mind wandering. Understanding this will help chemistry educators, especially curriculum designers and teachers, to initiate instructional techniques that reduce mind wandering when it comes to using the type of text that leads to more mind wandering.

Mind wandering

Mind wandering is defined as decoupling attention from an immediate task context toward unrelated concerns (Schooler et al., 2011; Smallwood & Schooler, 2006). Mind wandering is an attention state where the individual is not completely focused on the task at hand. Importantly, mind wandering is principally described as a failure of cognitive control (McVay, Kane, & Kwapil, 2009; Reichle, Reineberg, & Schooler, 2010; Smallwood, McSpadden, & Schooler, 2008). Literature shows that mind wandering has been studied in several tasks. These tasks are signal detection, verbal encoding, visuomotor tasks, reading, sustained attention, working memory and intelligence testing (Antrobus, 1968; Reichle et al., 2010; Schooler, Reichle, & Halpern, 2004).

Perhaps the situation in which the disruptive effects of mind wandering have been most thoroughly explored is that of reading (Reichle et al., 2010; Schooler et al., 2004; Smallwood, 2011; Smallwood et al., 2008; Smilek, Carriere, & Cheyne, 2010). During reading, when the mind starts wandering to unrelated feelings and thoughts, the eyes keep on scanning the words without paying attention to their meaning (Smallwood, 2011). More specifically, mind wandering leads to item-specific comprehension deficits as well as model-building deficits (Smallwood et al., 2008). In addition, mind wandering is associated with a reduced coupling between motor responses and their lexical determinants (Smallwood, 2011). Unfortunately, this disengagement from the external environment that has been observed in reading tasks appears to occur in many other performance settings, with important implications (Matthew & Thomas, 2014; Smallwood, 2001).

A study conducted by Foulsham, Farley, and Kingetone (2013) investigated the differences in eye movements and mind wandering made during reading. Participants were introduced to 48 key sentences (24 with low frequency target words and 24 with high frequency target words). Eye movement was recorded while reading. Mind wandering was measured by using a probe screen that asked subjects to answer whether they were on task or not. The study presented multiple differences between reading prior to a mind wandering response and reading when on task. The consequences of students' mind wandering were slower reading times, longer average fixation duration and an absence of the word frequency effect on gaze duration. Interestingly, during mind wandering the link between eye scanning and word identification decoupled, supporting the disengagement given above.

To date, mind wandering is measured by self-report measures. Previous investigations have used one of two methods: self-catch or probe-catch. In a "self-catch" procedure, participants are instructed to self-monitor their attention and respond when it strays from the task, thus identifying their own mind wandering (Ward & Wegner, 2013). An alternative is the "probe-catch" procedure, whereby a probe sporadically asks participants whether they were on task or mind wandering. The self-catch procedure requires meta-awareness and thus monitors episodes where the participant is both off task and becomes aware of this fact (Ward & Wegner, 2013). In the present study, we used the probe-catch procedure—asking participants to respond to thought probes.

Purpose of study

The purpose of the current study was to explore whether mind wandering would differ when reading different types of textual narrations (macroscopic and submicroscopic). In addition, the relationship between mind wandering and reading comprehension was measured. Thus the study investigates two research questions:

1. Does students' mind wandering while reading textual narrations in chemistry differ for macroscopic and submicroscopic texts?
2. What is the nature of the relationship between students' mind wandering and their comprehension of textual narrations (macroscopic and submicroscopic) in chemistry?

Methodology

Participants

The participants were 65 grade nine female students in two different female schools in Muscat, the capital of the Sultanate of Oman. The school system in Oman has two different phases: A) the basic education phase which includes cycle I (grades 1–4) and cycle II (grades 5–10), and B) the post-basic education phase which includes grades 11 and 12. Cycle I schools are mixed gender schools; however, the rest of the grade levels are offered in gender-based schools. Arabic is the mother tongue of the participants, and the language of instruction for science subjects in Omani public schools is Arabic.

Design and Procedures

We used a randomized design in which a series of mind-wandering measures were recorded for a single group within a period of time during which participants were given two types of textual narrations (macroscopic and submicroscopic) to read. The order of which type of narration came first was assigned randomly to participants. The experiment took place in the school's computer lab. A text about table salt (sodium chloride) was shown to each participant on a computer screen. Since the language of instruction is Arabic, all materials were presented in Arabic. The text was presented on six slides each of which was shown for three minutes. Three slides presented macroscopic passages and three slides presented submicroscopic passages. To control for the order effect, the order of macroscopic/submicroscopic textual slides was designed in two versions which were received *randomly* by the participants. The first version (X-version) started with the macroscopic slides while the second version (Y-version) started with the submicroscopic slides. Table 1 illustrates the sequence of the experiment.

After each text slide, the computer presented for 30 seconds a slide that had a mind wandering question asking participants to determine whether their thoughts were on or off task. During the 30 seconds, the participant was instructed to respond to the question on a paper-based answer sheet. Then when these 30 seconds were over, the computer screen moved to another text slide that was presented for three minutes. Once all slides had been shown and participants had responded to all six mind wandering questions, a comprehension test was given for 20 minutes. Since participants were required to answer the mind-wandering question during which they needed to focus and check out an answer in a given paper, we believe that their mind wandering diminished after each question, before they moved to the next reading slide.

The word count for the textual slides was 272.5 on average: macroscopic (3 slides; 273.67 words in average; total=821) and submicroscopic (3 slides; 271.33 words in average; total=814). This variation in word count among slides was caused by the desire to have complete idea(s) within each slide. Splitting the same idea between two slides was thought to add a distraction to participants.

Table 1: The Sequence of the Experiment

Slide	Content	X-version of order (received *randomly* by one half of the participants)	Y-version of order (received *randomly* by the other half of the participants)	Duration (min)
1st	Instructions			
2nd	First section of text	Macroscopic	Submicroscopic	3
3rd	First mind wandering question	-	-	0.5
4th	Second section of text	Macroscopic	Submicroscopic	3
5th	Second mind wandering question	-	-	0.5
6th	Third section of text	Macroscopic	Submicroscopic	3
7th	Third mind wandering question	-	-	0.5
8th	Fourth section of text	Submicroscopic	Macroscopic	3
9th	Fourth mind wandering question	-	-	0.5
10th	Fifth section of text	Submicroscopic	Macroscopic	3
11th	Fifth mind wandering question	-	-	0.5
12th	Sixth section of text	Submicroscopic	Macroscopic	3
13th	Sixth mind wandering question	-	-	0.5
14th	Directing participants to do the reading comprehension test which was given for 20 minutes	-	-	0.5

The participants were made aware before they left for the computer lab that they would be asked to respond to a research instrument. It was also made clear to participants that their completion of the instrument would not count as part of their course mark. The study was performed in compliance with the relevant laws and Ministry of Education guidelines, with the school's permission to conduct the study being obtained. No risks, such as tiredness or potential serious damage to participants, were anticipated in the study as the time they spent during the administration was relatively short and the nature of the instrument was at the participants' cognitive level. Safety precautions in the computer lab were taken into consideration. The computer lab that hosted the study was built by the Ministry, equipped with modern devices and designed according to high safety specifications. The study was implemented by a cooperative teacher who was present during the implementation of the study. At no time were participants left alone in the lab without monitoring. Data obtained from the study were dealt with securely by the researchers and no one other than the two of them was made aware of the participants' scores. Participants' identities were kept anonymous.

Instruments and materials

The textual narrations. The textual narrations were about table salt (sodium chloride). There were two types of narrations: macroscopic and submicroscopic. Appendix A illustrates the topics included in each type. To minimize the intervention of text familiarity, it was the intention not to provide participants with textual passages that they had encountered before. Thus, the textual narrations used in the current study were constructed by the authors. Omani student science textbooks were reviewed and two American published high school chemistry textbooks were consulted (Myers, Oldham, & Tocci, 2004; Wilbraham, Staley, Matta, & Waterman, 2004).

The scientific content of the narrations was validated by a panel of four referees: two science educators working at a national university and two experienced ninth grade chemistry teachers. The panel was asked to check the content for scientific accuracy, readability of the text and its appropriateness for grade nine students. Based on this panel's suggestions, some minor linguistic corrections in phrases were made.

Mind wandering. The present study used a probe-catch procedure with randomly presented probes. Participants were given text to read and were periodically probed with questions regarding whether at that moment their thoughts were on or off task. This is considered to be a valid method to measure mind wandering during reading (Dixon & Bortolussi, 2013; Foulsham et al., 2013; Schooler et al., 2011; Smallwood, Fishman, & Schooler, 2007; Smallwood et al., 2008; Smallwood & Schooler, 2006). During the current experiment, participants were probed six times while they were reading the textual narrations presented on the computer screen. Each probe was given in a new slide after each textual slide (see Table 1). Three mind wandering probes were given while they were reading the macroscopic text and three while they were reading the submicroscopic text. The mind wandering question that participants were instructed to answer was: "Were you fully attending when you were reading the last slide or were you thinking about something else?" Participants were asked to rate their attention on a 5-point Likert scale: 1: *I was thinking about something different all the tim*e (5 points); 2: *I was thinking about something different most of the tim*e (4 points); 3: *I was attending to the text some of the time and thinking about something different the rest of the time* (3 points); 4: *I was attending to the text most of the time* (2 points); 5: *I was attending to the text all the time* (1 point).

It might be predicted that since participants were anticipating the mind-wandering question, they would simultaneously have been thinking about these probes, as if the nature of the study could lead to mind wandering. Also, one might argue that since participants knew that they had to answer a test at the end, then answering the mind-wandering questions was not totally independent. Thus, some participants might make more effort to focus on what they were reading because of their anticipation of the test. However, this aspect of the study was controlled for both macroscopic and submicroscopic narrations. Therefore, one should not worry that the nature of the study might confound the findings since the same procedure was applied to both types of narrations.

The reading comprehension test. After participants finished reading and responding to the computer slides, a test (paper and pencil) was given to participants at the end of the experiment which aimed to measure their reading comprehension. There were 20 multiple-choice items, ten of them measured the comprehension of the macroscopic text and the other ten measured the comprehension of the submicroscopic text. One point was given to each correct response. Thus, the total score of the test was 20. The test was reviewed by the same panel that reviewed the textual narrations. Minor linguistic changes were made as a result of this reviewing process.

Piloting the experiment

The experiment was piloted on a female grade nine classroom of 20 students to check: 1) the flow of the computer slides and the setting of the whole experiment; 2) the readability of the computer slides and the comprehension test; and 3) the reliability of the comprehension test. The participants were asked to point out any unclear phrases. Minor corrections resulted from this process. The comprehension test reliability coefficient was .71.

Data analysis

Data was entered into the IBM SPSS statistics. Students' mind wandering total score, macroscopic mind wandering, submicroscopic mind wandering, macroscopic test score, submicroscopic test score and total test score were computed. Descriptive statistics, t-test paired-samples statistics and correlations were computed.

The decision to use parametric statistics to describe and analyse mind wandering Likert-scale data is supported by statistical analysis literatures (Boone & Boone, 2012; Knapp, 1990; Minium, King, & Bear, 1993; Murray, 2013; Norman, 2010; Sullivan & Artino, 2013) suggesting two schools of thought regarding the appropriate statistical analyses for Likert-scale data. One school of thought asks researchers to use the median instead of the mean when analysing such data. However, the second school of thought considers using means and standard deviations as an appropriate method to represent Likert-scale data and welcomes 'any operations that yield lawful relationships and accurate predictions' (Minium, King, & Bear, 1993, p. 77). Norman (2010) states that 'parametric methods can be utilized without concern for "getting the wrong answer"' (p. 625).

Results

The study has six variables of interest. They are: 1) participants' overall mind wandering performance, 2) mind wandering performance for macroscopic textual narrations, 3) mind wandering performance for submicroscopic textual narrations, 4) reading comprehension test score, 5) performance on the macroscopic questions of the comprehension test and 6) performance on the submicroscopic questions of the comprehension test. The descriptive statistics are shown in Table 2. It can be observed that participants' overall mind wandering (m=2.03; SD=0.63) is not considered high. According to the Likert scale mentioned in the Methodology section above, this score falls under 'attending to the text most of the time'. On the other hand, their reading comprehension performance (m=9.50; SD=3.86) was moderate (47.5% of the maximum score). The macroscopic reading comprehension sub-score (*m*=4.88; *SD*=2.17) was moderate (48.8% of the maximum score) and the submicroscopic reading comprehension sub-score (*m*=4.70; *SD*=2.27) was also moderate (47% of the maximum score). Since the information and concepts about table salt presented in the textual narrations given to participants are covered at more advanced grade levels, their moderate comprehension performance level was not surprising.

Table 2: Descriptive Statistics for All Variables

Instrument	Variable	N	M	SD
Mind wandering	1. MW* score	65	2.03	0.63
	2. Macroscopic MW	65	1.92	0.76
	3. Submicroscopic MW	65	2.14	0.73
Reading comprehension test	4. Comprehension score**	65	9.50	3.86
	5. Macroscopic sub-score	61	4.88	2.17
	6. Submicroscopic sub-score	60	4.70	2.27

*MW: mind wandering. ** total score: 20, score range: 1 – 17.

To answer the first question: *Does students' mind wandering while reading textual narrations in chemistry differ for macroscopic and submicroscopic texts?* a paired-samples *t*-test was computed (Table 3). The results indicate that the mean score on mind wandering performance for submicroscopic textual narrations (m = 2.14; SD=0.73) was significantly greater at the $p < .001$ level than the mean score on mind wandering performance for macroscopic textual narrations (m = 1.92; SD=0.76). In spite of the significant statistical differences between the mind wandering means for macroscopic and submicroscopic, it was noted that neither mind wandering means were high. They fell under the category of 'attending to the text most of the time'. This reflects that participants were paying attention to the task and taking the experiment seriously.

Table 3: *t*-test Paired-Samples Statistics

	N	M	SD	2-tail sig

Macroscopic MW[a]	65	1.92	0.76	0.00**
Submicroscopic MW[a]	65	2.14	0.73	

[a]MW: mind wandering. ** p <0.001

To answer the second question: *What is the relationship between students' mind wandering and their comprehension of textual narrations (macroscopic and submicroscopic) in chemistry?* a Pearson correlation was conducted among the variables (Table 4). There was a negative significant correlation coefficient (r=-0.49) between participants' mind mind-wandering score and their reading comprehension.

Table 4: Pearson Correlations among Variables

Instrument	Variables	1	2	3	4	5
Mind Wandering (MW)	1. MW score	1				
	2. Macroscopic MW	.85**	1			
	3. Submicroscopic MW	.83**	.42**	1		
Reading comprehension test	4. Comprehension score	-.49**	-.33**	-.51**	1	
	5. Macroscopic sub-score	-.53**	-.34**	-.54**	.87**	1
	6. Submicroscopic sub-score	-.31**	-.19	-.34**	.88**	.52**

** p<.001

Discussions and Conclusions

Previous research links mind wandering to poor reading comprehension (Foulsham et al., 2013; Schooler et al., 2011). This conclusion has been supported in the current study by the significant negative correlation between mind wandering and reading comprehension. In addition, the results of the current study indicate that participants had significantly greater mind wandering for the submicroscopic textual narrations than they had for the macroscopic textual narrations. Thus the findings of the current study add to the main conclusion in chemistry education literature that learners' cognitive processing of macroscopic content differs from their processing of submicroscopic content (Al-Balushi, 2011, 2013a, 2013b; Al-Balushi & Coll, 2013; Jones et al., 2011; Jones & Taylor, 2009; Taber, 2013; Tretter et al., 2006). Figure 1 illustrates these differences.

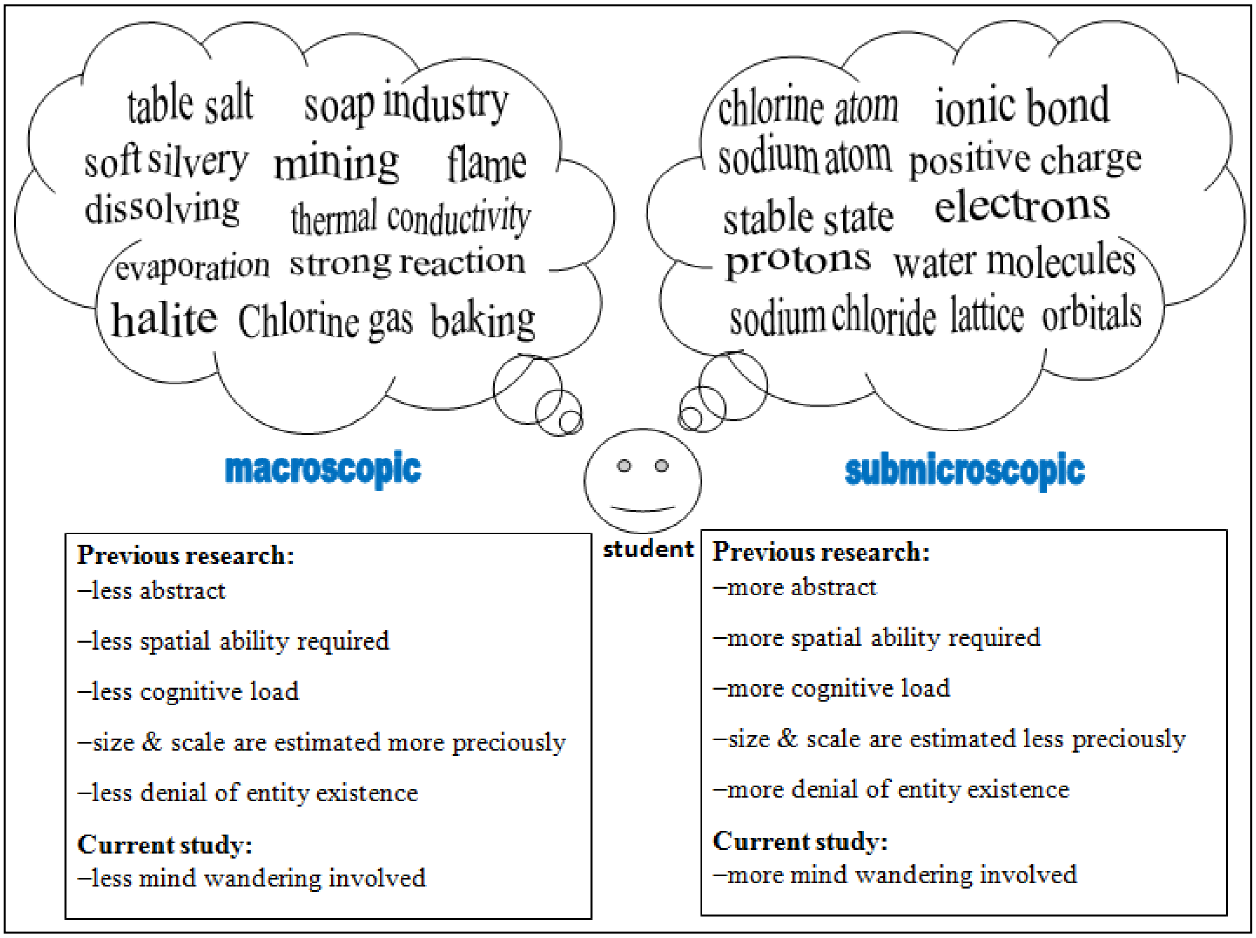

Figure 1. Cognitive differences between macroscopic and submicroscopic levels in chemistry

Different studies have tackled the phenomenon of mind wandering during reading and could help us understand the higher mind wandering score during the reading of submicroscopic narrations. One factor that contributes to keeping the mind focused is the interaction between the text information and representations of the more general context related to what is being read (Schooler et al., 2011; Smallwood, 2011). During mind wandering this interaction is reduced, and the reader becomes unable to build a situational model of what they read. Their inability to choose the important linguistic features of the text and link different text elements leads to weak attention and prevents constructing desired meaning (Foulsham et al., 2013; Smallwood et al., 2007; Smallwood et al., 2008). A coupled processing between two types of representations takes place during normal reading: 1) external information presented by the text which is being read and 2) internal representations in mind of the reader. When the brain starts mind wandering, this coupling interaction breaks down. This reduced external coupling justifies the significant negative impact of mind wandering on reading comprehension (Schooler et al., 2011; Smallwood, 2011; Smallwood et al., 2007). Also, mindless reading reduces the processing of visual information (Smilek et al., 2010) and reading pace becomes slower (Foulsham et al., 2013).

Less interesting text leads to more mind wandering (Dixon & Bortolussi, 2013). Also, the presence of difficult, new and/or low frequency words within the text is associated with longer gaze durations and leads to longer total inspection times (Foulsham et al., 2013; Sereno & Rayner, 2003; Smallwood et al., 2008), contributing to slower reading pace (Foulsham et al., 2013) and worse reading comprehension (Smallwood et al., 2008). This description of words could match submicroscopic words. They are more abstract (Al-Balushi, 2011, 2013b; Al-Balushi & Coll, 2013; Gericke & Hagberg, 2007; Taber, 2013), less frequently encountered by learners than macroscopic description of natural phenomena and they represent more difficult concepts than macroscopic words (Kelly, 2014; Milenković et al., 2014; Prilliman, 2014; Ryan & Herrington, 2014; Sanger et al., 2013; Sjöström & Talanquer, 2014; Warfa et al., 2014). Students, when interacting with submicroscopic explanations, are required to believe in the existence of different unobservable theoretical entities, to comprehend their characteristics and behaviors and to utilize this knowledge in constructing explanations for different phenomena. There is no doubt that this is an advanced level of cognitive processing (Taber, 2013).

We admit that each of the two narrations (macroscopic and submicroscopic) possesses a degree of unfamiliarity and exerts a level of cognitive load on the mind of the learner. Thus, one would anticipate that characteristics such as unfamiliarity and greater cognitive load would result in less efficient reading. However, we did not know, before the results of the current study, whether this unfamiliarity and cognitive load were at the level that would lead one type of text to have a greater mind-wandering effect than the other. The current study contributes partially to providing an answer to this query. Obviously, these cognitive demands are not necessarily at the same extensive level when dealing with macroscopic entities and processes. Although a great deal of macroscopic terminology and materials are not familiar to students, and they start learning about new chemicals in the school laboratory (Taber, 2013), they could still see these materials, observe the changes happening to them, manipulate their quantities and watch the consequences and relate to observations familiar from their everyday and previous experience more than they do for submicroscopic terminology. This helps our brains to chunk information by relating new knowledge to existing mental schemata and thus reduces the load on the memory span (Taber, 2013). This is not available to such an extent at the submicroscopic level. Thus, the new abstract and theoretical terminology presented in the submicroscopic narrations in the current study might hinder students' attempts to make sense of what is being presented. To conceptualize the submicroscopic entities and phenomena, students have to rely, on many occasions, on their imagination. Relying solely on the student's mind to process chemical representations would increase the cognitive load and reduce the possibility of producing meaningful learning (Springer, 2014). Previous research reveals that not everybody can imagine submicroscopic entities and their dynamic interactions (Al-Balushi, 2009; Al-Balushi & Coll, 2013). Thus, it could be plausible to suggest that because of the unfamiliarity and abstract nature of submicroscopic words and the cognitive load they add while reading them, they were associated with slower reading peace, longer gaze durations and longer total inspection times, leading to longer mind wandering. Nevertheless, more in-depth data, both quantitative and qualitative, are needed to explore the degree of unfamiliarity and cognitive load that learners experience when interacting with macroscopic and submicroscopic narrations.

One solution to mind wandering is metacognitive training such as mindfulness-based cognitive therapy which trains individuals to reduce mind wandering by changing the relationship between individuals and their thoughts (Smallwood et al., 2007). In fact, metacognitive skills play an important role in students' performance in chemistry (Mathabathe & Potgieter, 2014; Taber, 2013). This idea could be considered as a future quasi-experimental study, in which a remedial programme that is based on metacognitive training is offered to participants while reading chemistry text. The effect on mind wandering could then be measured. Another solution could be making the text more interesting (Dixon & Bortolussi, 2013) by incorporating diagrams. Further research could investigate learners' mind wandering when presented with submicroscopic text only and with text combined with submicroscopic diagrams.

One of the limitations of the current study is that it does not count cognitive load while participants are conducting the task. Further research could use one of the cognitive load measures (Milenković et al., 2014) and calculate how it mediates the relationship between reading comprehension at both levels (macroscopic and submicroscopic) and mind wandering. Another limitation of the current study is that it overlooks the possible effect of participants' spatial ability in their reading comprehension of the macroscopic and submicroscopic textual narrations. It would be interesting if learners' spatial ability is added to the research variables, and its relationship with mind wandering and reading comprehension is analyzed.

Appendix A The content of each textual slide

Text Slide	Content
	Macroscopic
Slide 1	– *Introduction: importance of table salt in our lives** – History of table salt – Its physical appearance – Where it can be found – Different uses – Production: by evaporation of sea water
Slide 2	– Production: by freezing of sea water in cold regions – Production: by mining – Its scientific name and the chemical elements that compose it – Physical properties of sodium
Slide 3	– Uses of sodium in industry – Biological uses of sodium in the human body – Physical properties of chlorine – Uses of chlorine in industry
	Submicroscopic
Slide 4	– Location of sodium and chlorine in the periodic table – Chemical properties of alkali metals group – Chemical properties of halogens group – Description of the reaction between sodium atoms and chlorine atoms to produce sodium chloride
Slide 5	– Description of how the formation of sodium chloride leads to chemical stability for sodium and chlorine atoms – Description of the sodium chloride crystal, the arrangement of atoms and the chemical bond between them
Slide 6	– The chemical explanation of the dissolving of sodium chloride in water – The electrochemical analysis of sodium chloride solution

* If the participant receives the submicroscopic slides first (Y-version), this introduction is presented at the beginning of the first slide displayed to her (slide no. 4 in this table).

References

Al-Balushi, S. M. (2009). Factors Influencing Pre-Service Science Teachers' Imagination at the Microscopic Level in Chemistry. *International Journal of Science and Mathematics Education, 7*(6), 1089-1110.

Al-Balushi, S. M. (2011). Students' evaluation of the credibility of scientific models that represent natural entities and phenomena. *International Journal of Science and Mathematics Education, 9*(3), 571-601.

Al-Balushi, S. M. (2012). The effect of macroscopic and submicroscopic pictorial representations on pre-service science teachers' explanations. *International Journal of Academic Research Part B, 4*(6), 10-14.

Al-Balushi, S. M. (2013a). The effect of different textual narrations on students' explanations at the submicroscopic level in chemistry. *Eurasia Journal of Mathematics, Science & Technology Education, 9*(1), 3-10.

Al-Balushi, S. M. (2013b). The relationship between learners' distrust of scientific models, their spatial ability, and the vividness of their mental images. *International Journal of Science and Mathematics Education, 11*(3), 707-732.

Al-Balushi, S. M., & Coll, R. (2013). Exploring verbal, visual and schematic learners' static and dynamic mental images of scientific species and processes in relation to their spatial ability. *International Journal of Science Education, 35*(3), 460-489.

Al-Naeme, F., & Johnstone, A. H. (1991). Room for scientific thought. *International Journal of Science Education, 13*, 187-192.

Antrobus, J. (1968). Information theory and stimulus-independent thought. *British Journal of Psychology, 59*, 423-430.

Boone, H., & Boone, D. (2012). Analyzing Likert data. *Journal of Extension, 50,* Article Number 2TOT2.

Carter, C. S., Larussa, M. A., & Bodner, G. M. (1987). A study of two measures of spatial ability as predictors of success in different levels of general chemistry. *Journal of Research in Science Teaching*, *24*(7), 645-657.

Cranford, K., Tiettmeyer, J., Chuprinko, B., Jordan, S., & Grove, N. (2014). Measuring load on working memory: The use of heart rate as a means of measuring chemistry students' cognitive load. *Journal of Chemical Education*, *91*, 641-647.

Danili, E., & Reid, N. (2006). Cognitive factors that can potentially affect pupils' test performance. *Chemistry Education Research and Practice, 7*(2), 64-83.

Dixon, P., & Bortolussi, M. (2013). Construction, integration, and mind wandering in reading. *Canadian Journal of Experimental Psychology*, *67*(1), 1-10.

Dumon, A., & Mzoughi-Khadhraoui, I. (2014). Teaching chemical change modeling to Tunisian students: an ''expanded chemistry triplet'' for analyzing teachers' discourse. *Chemistry Education Research and Practice, 15,* 70-80.

Foulsham, T., Farley, J., & Kingstone, A. (2013). Mind wandering in sentence reading: Decoupling the link between mind and eye. *Canadian Journal of Experimental Psychology*, *67*(1), 51-59.

Gericke, N. M., & Hagberg, M. (2007). Definition of historical models of gene function and their relation to students' understanding of genetics. *Science and Education*, *16*, 849-881.

Gulacar, O., Eliks, I., & Bowman, C. (2014). Differences in general cognitive abilities and domain-specific skills of higher- and lower-achieving students in stoichiometry. *Journal of Chemical Education, 91*, 961-968.

Johnstone, A. H. (2000). Teaching of chemistry - logical or psychological? *Chemistry Education Research and Practice*, *1*(1), 9-15.

Jones, M. G., Gardner, G., Taylor, A., Wiebe, E., & Forrester, J. (2011). Conceptualizing magnification and scale: The roles of spatial visualization and logical thinking. *Research in Science Education, 41*, 357-368.

Jones, M. G., & Taylor, A. (2009). Developing a sense of scale: Looking backward. *Journal of Research in Science Teaching*, *46*(4), 460-475.

Kelly, R. (2014). Using variation theory with metacognitive monitoring to develop insights into how students learn from molecular visualizations. *Journal of Chemical Education, 91*, 1152-1161.

Knapp, T. (1990). Treating ordinal scales as interval scales: An attempt to resolve the controversy. *Nursing Research*, *39*, 121–123.

Matthew, Y., & Thomas, S. (2014). Driving with the wandering mind: the effect that mind-wandering has on driving performance. *Human Factors*, *56* (2), 260-269.

McVay, J., & Kane, M. (2010). Does mind wandering reflect executive function or executive failure? Comment on Smallwood and Schooler (2006) and Watkins (2008). *Psychological Bulletin, 136*, 188- 197.

McVay, J., Kane, M., & Kwapil, T. (2009). Tracking the train of thought from the laboratory into everyday life: An experience-sampling study of mind wandering across controlled and ecological contexts. *Psychonomic Bulletin & Review*, *16*, 857-863.

Milenković, D., Segedinac, M., & Hrin, T. (2014). Increasing high school students' chemistry performance and reducing cognitive load through an instructional strategy based on the interaction of multiple levels of knowledge representation. *Journal of Chemical Education*, *91*, 1409-1416.

Minium, E., King, B., & Bear, G. (1993). *Statistical reasoning in psychology and education* (3rd ed.). New York, NY: John Wiley & Sons.

Mooneyham, B., & Schooler, J. (2013). The costs and benefits of mind-wandering: a review. *Canadian Journal of Experimental Psychology*, *67* (1), 11 - 18.

Murray, J. (2013). Likert data: What to use, parametric or non-parametric? *International Journal of Business and Social Science, 4*, 258–264.

Myers, R., Oldham, K., & Tocci, S. (2004). *Chemistry*. Orlando, FL: Holt, Rinehart and Winston.

Norman G. (2010). Likert scales, levels of measurement and the ‘‘laws’’ of statistics. *Advanced Health Science Education: Theory & Practice*, *15*, 625–632.

Pribyl, J. R., & Bodner, G. M. (1987). Spatial ability and its role in organic chemistry: A study of four organic courses. *Journal of Research in Science Teaching*, *24*, 229-240.

Prilliman, S. (2014). Integrating particulate representations into AP chemistry and introductory chemistry courses. *Journal of Chemical Education, 91*, 1291-1298.

Pyburn, D., Pazicni, S., Benassib, V., & Tappinc, E. (2013). Assessing the relation between language comprehension and performance in general chemistry. *Chemistry Education Research and Practice, 14*, 524-541.

Reichle, E., Reineberg, A., & Schooler, J. (2010). Eye movements during mindless reading. *Psychological Science, 21*, 1300-1310.

Ryan, S., & Herrington, D. (2014). Sticky ions: A student-centered activity using magnetic models to explore the dissolving of ionic compounds. *Journal of Chemical Education, 91*, 860-863.

Sanger, M., Vaughn, K., & Binkley, D. (2013). Concept learning versus problem solving: evaluating a threat to the validity of a particulate gas law question. *Journal of Chemical Education, 90*, 700-709.

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

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

Sereno, S., & Rayner, K. (2003). Measuring word recognition in reading: Eye movements and event-related potentials. *TRENDS in Cognitive Sciences, 7*(11), 489-493.

Sjöström, J., & Talanquer, V. (2014). Humanizing chemistry education: From simple contextualization to multifaceted problematization. *Journal of Chemical Education, 91*, 1125-1131.

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

Smallwood, J., Fishman, D., & Schooler, J. (2007). Counting the cost of an absent mind: Mind wandering as an underrecognized influence on educational performance. *Psychonomic Bulletin & Review, 14*(2), 230-236.

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

Smallwood, J., & Schooler, J. (2006). The restless mind. *Psychological Bulletin, 132*(6), 946-958.

Smilek, D., Carriere, J., & Cheyne, J. (2010). Out of mind, out of sight: Eye blinking as indicator and embodiment of mind wandering. *Psychological Science, XX*(X), 1-4.

Springer, M. (2014). Improving students' understanding of molecular structure through broad-based use of computer models in the undergraduate organic chemistry lecture. *Journal of Chemical Education, 91*, 1162-1168.

Sullivan, G., & Artino, A. (2013). Analyzing and interpreting data from Likert-type scales. *Journal of Graduate Medical Education, 5*, 541–542.

Taber, K. S. (2013). Revisiting the chemistry triplet: drawing upon the nature of chemical knowledge and the psychology of learning to inform chemistry education. *Chemistry Education Research and Practice, 14*, 156-168.

Tretter, T., Jones, M. G., & Minogue, J. (2006). Accuracy of scale conceptions in science: Mental maneuverings across many orders of spatial magnitude. *Journal of Research in Science Teaching, 43*(10), 1061-1085.

Wang, C.-Y., & Barrow, L. H. (2011). Characteristics and levels of sophistication: An analysis of chemistry students' ability to think with mental models. *Research in Science Education, 41*(4), 561-586, DOI 510.1007/s11165-11010-19180-11167.

Ward, A., & Wegner, D. (2013). Mind-blanking: when the mind goes away. *Frontiers in Psychology, 4*, 4-16.

Warfa, A., Roehrig, G., Schneider, J., & Nyachwaya, J. (2014). Role of teacher-initiated discourses in students' development of representational fluency in chemistry: a case study. *Journal of Chemical Education, 91*, 784-792.

Wilbraham, A., Staley, D., Matta, M., & Waterman, E. (2004). *Chemistry*. Needham, MA: Prentice Hall.

Wu, H., & Shah, P. (2004). Exploring visuospatial thinking in chemistry learning. *Science Education, 88*, 465-492.

Yang, E., Andre, T., Greenbowe, T. J., & Tibell, L. (2003). Spatial ability and the impact of visualization/animation on learning electrochemistry. *International Journal of Science Education*, *25*(3), 329-349.