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# THE EFFECTS OF EPISTEMIC BELIEFS IN SCIENCE AND GENDER DIFFERENCE ON UNIVERSITY STUDENTS' SCIENCE-TEXT READING: AN EYE-TRACKING STUDY

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ABSTRACT. The primary purpose of this study was to explore not only the effects of epistemic beliefs in science on science-text reading but also the gender differences in epistemic beliefs and the reading process. The interactions between gender and epistemic beliefs during reading were also explored. A total of 25 university students, 13 male and 12 female, were paid to participate in the study. The scientific epistemological beliefs (SEBs) questionnaire was used to probe the subjects' epistemic beliefs in science, while the eye-tracking method was employed to record their science-text reading process. It was demonstrated that the participants in the study had developed sophisticated SEBs. Complicated SEBs were associated with higher cognitive attention to the reading of data-related information but less mental effort to fact, scientific explanations, and the microview photos. As for the gender difference, female students displayed less mental effort in comprehending scientific explanations, but attended more to data and the microview graphic. It is argued that female learners are better at processing textual information. Interactions between SEBs and gender were found and discussed.

KEYWORDS: epistemic beliefs, eye movements, eye tracking, gender difference, science-text reading, scientific epistemological beliefs

## INTRODUCTION

Epistemic beliefs (or personal epistemological beliefs), generally described as "beliefs about the nature of knowledge and knowing" (Hofer & Pintrich, 1997; Kitchener, 1983), have gradually received more attention in educational studies, due probably to the potential link between students' personal epistemological beliefs and learning outcomes (Cano, 2005; Hofer, 2000; Ozkal, Tekkaya, Cakiroglu & Sungur, 2009; Stathopoulou & Vosniadou, 2007). In order to further ameliorate teaching and learning performance, a considerable number of studies have concentrated on the role of personal epistemic beliefs in learning. However, there is still a paucity of research concerning the relationship between epistemic beliefs and the learning process (Schreiber & Shinn, 2003). With particular respect to the effect of epistemic beliefs in science, that is, scientific epistemological beliefs

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(SEBs), on the effectiveness and efficiency of science learning, previous research has already explored the associations between SEBs, motivation in learning science (Lin, Deng, Chai & Tsai, 2013), and conceptions of learning science (Liang & Tsai, 2010). Nevertheless, a limited number of studies have investigated the relationship between SEBs and the science learning process.

In learning academic subjects, reading has been well recognized as a crucial way of obtaining subject-related knowledge. Scientific knowledge, which consists of complicated domain structures and abstract content, is usually presented by both written text and graphical representations. An early review by Mayer & Moreno (2002) suggested that the simultaneous use of text and pictures in the learning environment could help students achieve more favorable learning outcomes. Another recent study by Starbek, Starcic Erjavec & Peklaj (2010) revealed that the use of multimedia instruction could be closely linked to better learning comprehension and knowledge acquisition. However, how readers with different epistemic beliefs in science process complicated science texts with multimedia representations has not been examined. Moreover, in the literature, a limited amount of research has been conducted on the role of gender differences in the reading of science texts. Actually, previous studies have already shown that the inborn differences between males and females could be one of the critical factors that potentially affect learning effectiveness and efficiency (Flores, Coward & Crooks, 2010–2011; Kaushanskaya, Marian & Yoo, 2011). Accordingly, whether gender differences exist in the science reading process should be worthy of further discussion in this study.

In recent years, educational research has increasingly concentrated on the use of eye-tracking technology because of the capacity of eye trackers to record online cognitive activities (e.g. She & Chen, 2009; Yang, Chang, Chien, Chien & Tseng, 2013, Anderson, Love & Tsai 2014). Several studies have demonstrated that eye movement data could give professionals and practitioners in the educational field further insights and could shed more light on the future development and design of multimedia learning (Hyönä, 2010; Liu, Lai & Chuang, 2011; Slykhuis, Wiebe & Annetta, 2005; Yang et al., 2013). It is noted that although there is a growing interest in the application of eye-tracking methods to science learning studies, relatively little attention has been paid to investigating the relationship between learner characteristics and the process of science learning. Hence, attempts were made in this study to investigate the relationship between learner characteristics including SEBs and gender, and the process of science reading indicated by eye movement patterns.

## Literature Review

### *The Roles of Epistemic Beliefs in Science in Science Learning and Reading*

Personal epistemic beliefs have been one of the key issues in previous educational studies, probably because of the close connection between students' epistemic beliefs and their learning performance. More specifically, in terms of the theoretical development of epistemology, although there are several different perspectives and viewpoints regarding the dimensionality and disciplinary differences in personal epistemology (Hofer, 2000; Lin et al., 2013), it is agreed that epistemic beliefs could play a central role in affecting student learning and comprehension (Cano, 2005; Hofer, 2000; Ozkal et al., 2009; Stathopoulou & Vosniadou, 2007). For instance, an early report by Cano & Cardelle-Elawar (2004) indicated that students' epistemic beliefs could be closely linked to their academic performance. Another related study by Trautwein & Lüdtke (2007) revealed that students who have a higher belief in the certainty of knowledge are likely to have a lower level of academic achievement.

In view of the key impacts of personal epistemic beliefs on students' learning outcomes, there has been a recent growing interest in investigating the relationship between SEBs and learning in science (e.g. Tsai, Ho, Liang, & Lin 2011a; Lin et al., 2013). SEBs, which refer to individual beliefs about the nature of scientific knowledge and knowing, were initially derived from students' personal epistemic views in the domain of science (Lin et al., 2013; Liang & Tsai, 2010). Relevant studies have indicated that SEBs are one of the key components that could potentially affect the effectiveness and efficiency of science learning. For instance, in a prior review, Stathopoulou & Vosniadou (2007) showed that physics-related epistemological beliefs could be closely related to secondary school students' physics conceptual understanding. In another recent report, Liang & Tsai (2010) further revealed that the source and justification aspects of science major college students' SEBs could be a key factor influencing their conceptions of science learning.

Based on the findings of previous studies, it is reasonable to conclude that SEBs would also affect science-text reading behaviors. Several recent studies support such a conclusion. For example, Strømsø, Bråten & Britt (2011) found that readers who believed in personal interpretations and knowledge justification would exercise various criteria for evaluating the trustworthiness of science texts. Yang, Chen & Tsai (2013b) showed a similar result that students with more complicated epistemic beliefs in science would be more likely to evaluate online information about a science issue from different angles. Kendeou, Muis & Fulton (2011) demonstrated that readers adjust their text comprehension processes as a function of the interaction between epistemic beliefs and text structure. In addition, Ferguson & Bråten (2013) found that multiple text comprehension was associated with readers' beliefs about the sources of and justification of knowledge. Inferring from the previous study reports, it is hypothesized in this study that SEBs should play an important role in mediating the processing of scientific information.

### *Reading of Science Texts as Reading of Multimedia Materials and Gender Differences*

Mayer's cognitive theory of multimedia learning originated from Paivio's dual-coding theory (Mayer & Sims, 1994), which theorizes that cognitive information could be processed through either the visual or the verbal channel (Reed, 2006). It has been shown that multimedia materials are widely used in present-day education to improve student achievement. Mayer (2003) has suggested that "the promise of multimedia learning is that students can learn more deeply from well-designed multimedia messages consisting of words and pictures than from more traditional modes of communication involving words alone" (pp. 125). Given that scientific knowledge is usually communicated and transmitted by both written and graphical forms of representation, reading of science texts therefore involves the processing of both verbal and visual information. Hence, how an individual reads and learns from science texts is an issue closely related to multimedia learning.

However, although how science learners process multimedia information has gained increasing attention from science education researchers (e.g. She & Chen, 2009; Yang et al., 2013a), relatively little work has been devoted to investigating the role of gender. Gender differences have been one of the focal points in psychological and educational studies probably owing to the innate differences between men and women. A recent review on the brain studies of the past 20 years confirms gender differences in the brain structure (Ruigrok, Salimi-Khorshidi, Lai, Baron-Cohen, Lombard, Tait & Suckling, 2014). As far as science learning is concerned, the gender issue also attracts considerable research attention (e.g. Sanchez & Wiley, 2010; Yang & Anderson, 2003). Studies have reported that males are judged to have better performance in mental and spatial ability tests than their female counterparts (Flores et al., 2010–2011), whereas it has been found that women are superior to men in language learning performance such as "verbal fluency and synonym-generation" (Kaushanskaya et al., 2011, p. 24). In another study, Lowrie & Diezmann (2011) revealed that "Boys outperformed girls on graphical languages that required the interpretation of information represented on an axis and graphical languages that required movement between two and three-dimensional representations" (p. 109).

In the literature related to multimedia learning, some gender effects have been identified. For example, an early game-based learning study by Passig & Levin (1999) demonstrated that male and female learners have a different need for multimedia learning interfaces. That is, compared with male learners, females tend to have a preference for verbal learning interfaces and multicolored designs. Although prior studies have indicated that redundant information in multimedia learning environments could lead to learners' information overload, some researchers have shown that males benefit from a dual mode presentation of text (text with redundant speech), while females gain more from a single mode presentation (Riding & Grimley, 1999; Flores et al., 2010–11). On the other hand, when the material is presented in two distinct types of mode (i.e. verbal and graphics), Coward, Crooks, Flores & Dao (2012) found that the gender effect was apparent not on the modes of presentation but on the comprehension of the text. In sum, it is apparent that a gender effect exists in the process of information decoding and knowledge construction. Therefore, based on previous study suggestions, it is necessary that the gender difference should be one of the critical issues in this study in order to further clarify the process of science reading.

### *The Use of Eye-Tracking Technology in Exploring the Process of Science Learning*

Over the past few decades, academic studies have shown that eye-tracking technology has been successfully applied in different research fields such as behavioral brain research, cognitive psychology, memory, and language studies (Barnes, 2008; Kowler, 2011; Kreiner, Sturt & Garrod, 2008; Rayner, 1998, 2009). Recently, growing attention has been paid to using eye-tracking technology in educational studies, maybe because eye-tracking data could give researchers in educational fields a better understanding of participants' learning and information processing. van Gog & Scheiter (2010) indicated that "for research on multimedia multi-representational learning materials, eye tracking can provide unique information concerning what medium or representations are visually attended to, in what order, and for how long" (p. 95). Liu et al. (2011) further suggest that "real-time eye-tracking measurements can be valuable in the support and validation of conclusions generated by earlier multimedia studies" (pp. 2410).

In the domain of science education, an increasing use of this method can be found to explore issues such as learning in multimedia environments (e.g. She & Chen, 2009; Yang et al., 2013a), problem solving (e.g. Tsai, Hou, Lai, Liu & Yang 2011b; Liu & Shen, 2011; Chen & Yang, 2014), instructional strategies (Mason, Tornatora & Pluchino, 2013; Chuang & Liu, 2011), and learning from science texts (e.g. Mikkilä-Erdmann, Penttinen, Anto & Olkinuora, 2008; Mason, Pluchino, Tornatora & Ariasi, 2013; Ho, Tsai, Wang & Tsai, 2014). While these studies focus on mapping the online processes of knowledge construction, few studies have examined how learner characteristics may interact with online cognitive activities. By further analyzing students' eye movement patterns with respect to their SEBs and gender, we hope to gain more insights into how students of different beliefs as well as gender traits may process scientific information differently.

## METHODOLOGY

### *Participants*

A total of 25 students from a national university in Taipei were paid to participate in this study. Twelve of them were in science majors, while 13 came from the social science deportments. There were 13 male and 12 female participants. Their ages ranged from 18 to 25.

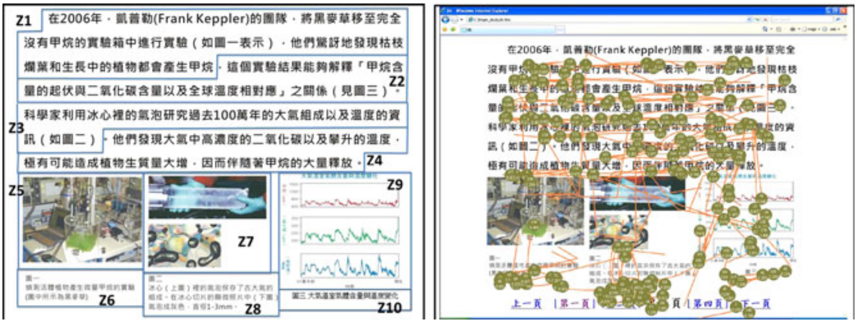
### *The Science Reading Material*

The reading material, adopted from an article published in the journal of *Scientific American*, presented an issue related to global warming. In the article, the sources and production of greenhouse gases and changes in global temperature were discussed. This article was presented as four PowerPoint slides on a 1,280 × 1,024 pixel computer screen. Except for the second slide that showed only written text, the rest contained both written and graphical information. Graphics displayed in the reading material included a conceptual model of axial precession, data diagrams indicating changes in greenhouse gases and temperatures in history, a photo of a methane experiment, a photo of an ice core and a microview of ancient air bubbles in the ice core, and a photo showing methane production under the ocean. The main argument of the article is that living plants also produce methane, which may explain the trend of changes in global temperature in history.

### The Eye-Tracking Method

*Apparatus.* The eye-tracking system used in the study is faceLAB 4.6 developed by the Seeing Machines Company. It is a remote system allowing researchers to naturally and nonintrusively track participants' eye movements. Its average sampling rate is 60 Hz with a 0.5 – 1 degree of rotational error. Based on previous eye movement studies (Rayner, 1998; Slykhuis et al., 2005), a fixation was determined as a gaze lasting at least 200 ms. The software of GazeTracker 8.0 was used to analyze the eye movement data. The apparatus has been applied in some recent multimedia learning studies (e.g. Liu et al., 2011; Tsai et al., 2011b; Yang et al., 2013a).

*Look-Zone, Areas of Interest, and Eye Movement Measures.* On each PPT slide, as shown in Fig. 1, a region of interest was defined by the researchers as a look-zone (LZ). Different LZs were assigned different content categories according to the information included in the LZ. The eye movements in each LZ were then measured by the gaze analysis software (GazeTracker). The researchers then defined areas of interest (AOIs) where LZs of the same content categories were put together for further analysis. As a result, 13 AOI classes reflecting the main elements of a popular science report were specified. These major elements represent written or graphical information about facts, data, experiments,



在2006年，凱普勒(Frank Keppler)的團隊，將黑麥草移至完全沒有甲烷的實驗箱中進行實驗（如圖一表示），他們驚訝地發現枯枝爛葉和生長中的植物都會產生甲烷，這個實驗結果能夠解釋「甲烷含量的起伏與二氧化碳含量以及全球溫度相對應」之關係（見圖三）。科學家利用冰心裡的氣泡研究過去100萬年的大氣組成以及溫度的資訊（如圖二），他們發現大氣中高濃度的二氧化碳以及攀升的溫度，極有可能造成植物生質量大增，因而伴隨著甲烷的大量釋放。

*Fig. 1.* *On the left*, an example of the reading material (page 3) with look-zones (LZs), and *on the right*, the eye movement data (*the dots*)

theories, scientific explanations, scientific models, and so forth. The definitions for the 13 AOI classes are listed in Table 1. Means of eye movement data in LZs of the same AOI class were calculated for later analysis. Examples of the reading material, LZs, and eye movement are displayed in Fig. 1.

*The Eye Movement Measures Used for Indicating the Reading Process.* In the study, the main eye movement measures abstracted for analysis included total reading time (TTZ), percentage of total fixation duration (PTFD), and the average fixation duration (AFD). According to prior eye movement studies (Rayner, 2009; Lai, Tsai, Yang, Hsu, Liu, Lee, Lee et al., 2013), total reading time is a temporal measure indicating time spent on information processing, while percentage of total fixation duration (or percentage of reading time) shows visual or cognitive attention distribution while reading. The measure of PTFD reveals both temporal and spatial information about eye movements. Meanwhile, AFD is usually used to suggest word/text difficulty or mental effort needed for comprehending the word or text meaning. In the study, since the numbers of words in different written text areas were not the same, the total reading time in each written text area was further divided by the number of words in the area. Consequently, TTZ for a written AOI implied the average time spent processing a word. Additionally, given that the size of the graphics varied, the measures of TTZ and the PTFD are presented together to indicate the visual attention distribution for different graphical AOIs.

### *The SEBs Instrument*

The SEBs instrument with 26 items was mainly adopted from an epistemic study by Conley, Pintrich, Vekiri & Harrison (2004) and another recent SEBs study by Liang, Lee & Tsai (2010) which tested Conley's SEBs instrument with Taiwanese students. A five-point Likert scale ranging from "strongly agree = 5" to "strongly disagree = 1" was used in this study. Four dimensions including source, certainty, development, and justification were contained in the SEBs instrument. The source dimension with five items is associated with personal beliefs about the scientific knowledge from authority sources. The certainty dimension with six items is to evaluate individual beliefs in absolute answers in science. The development dimension with six items is to measure personal beliefs about science as a developing and evolving subject. The justification dimension with nine items is concerned not only with individual beliefs about the role of experiments in science but also with the use of scientific evidence to reason (Conley et al., 2004; Liang et al., 2010).

**TABLE 1**

Regions of Interest and their corresponding contents

| *Area of interest (AOI)* | *Form* | *Description* |
|---|---|---|
| 1. Fact | Written | A depiction of the scientific facts pertaining to the themes of global warming and greenhouse gases |
| 2. Data | Written | A depiction of the scientific data pertaining to the themes of global warming and greenhouse gases |
| 3. Experiment | Written | A depiction of the scientific experiments pertaining to the themes of global warming and greenhouse gases |
| 4. Scientific explanation | Written | A scientific explanation of global warming and greenhouse gases |
| 5. Theory | Written | A depiction of the theories pertaining to the themes of global warming and greenhouse gases |
| 6. The axial precession model | Graphical | A graphic of the axial precession model |
| 7. Description of the axial precession | Written | A depiction of axial precession (under picture) |
| 8. Methane reactions | Graphical | Photos of the methane experiment setting and methane substances |
| 9. Description of the methane experiment and product | Written | A depiction of the methane experiment and production (under picture) |
| 10. Ice core and the microview of air bubbles in the ice core | Graphical | A photo of the ice core and the microview of air bubbles in the ice core |
| 11. Description of the ice core and the microview of air bubbles in the ice core | Written | A depiction of the ice core and the air bubbles |
| 12. Data diagram | Graphical | A numerical diagram of the relations between global warming and greenhouse gas |
| 13. Data diagram description | Written | A depiction of the data (under picture) |

## RESEARCH QUESTIONS

The primary purpose of this study is not only to investigate the relationship between the SEBs and the process of science reading recorded by the eye-tracking technology but also to examine gender differences in SEBs and the reading process. Moreover, the interactions between gender and SEBs are explored. Hence, the following research questions were proposed:

1. What SEBs had the university students developed?
2. How did the university students read the science text with respect to the required reading time, the distribution of visual attention, and the mental effort made for processing different text components?
3. Was there any relationship between the SEBs and the science-text reading process with reference to the reading time, the attention distribution, and the mental effort?
4. Were there any gender differences in the university students' SEBs and the science-text reading process?
5. Were there any interactions between gender and SEBs in relation to the science-text reading process?

## Data Analysis and Results

### *University Students' SEBs*

According to the descriptive analysis, the participants in the study possessed different epistemic views toward the nature of knowledge and knowing in science. On a five-point Likert scale, these students scored an average of 2.61 (SD = 0.56) for the beliefs about authority source of knowledge and 2.30 (SD = 0.61) for beliefs about the certainty of knowledge. Meanwhile, the students seemed to agree highly with beliefs about science being an evolving subject and justified knowledge in science (means = 4.32 and 4.22; SDs = 0.60 and 0.54, respectively). Noticeably, for the source and certainty dimensions, higher scores indicate simpler SEBs. The result implies that the university students in this study have developed sophisticated epistemic beliefs about the nature of knowledge and knowing in science.

### *Attention and Mental Effort Distributed During Science-Text Reading*

The means of eye movement measures for different AOI classes are displayed in Table 2. As shown in the table, the subjects spent most of their reading time on the written AOIs containing data (AIO2) and theories (AOI5). As for the graphical AOIs, they attended more to the axial precession model as well as its matching description (AOI6 and AOI7) and data diagram (AOI12). The percentage of total fixations indicated that more of the students' attention was distributed to written data (AOI2), fact (AOI1),

**TABLE 2**

Means of eye movement measures with respect to different AOI classes

| *Measure* | *AOI1* | *AOI2* | *AOI3* | *AOI4* | *AOI5* | *AOI6* | *AOI7* |
|---|---|---|---|---|---|---|---|
| TTZ (s) | 9.99 | 12.07 | 8.21 | 6.26 | 12.68 | 10.96 | 7.00 |
| PTFD (%) | 20.56 | 29.19 | 15.80 | 11.36 | 17.68 | 12.07 | 7.08 |
| AFD (s) | 0.32 | 0.32 | 0.32 | 0.30 | 0.31 | 0.35 | 0.25 |

| *Measure* | *AOI8* | *AOI9* | *AOI10* | *AOI11* | *AOI12* | *AOI13* |
|---|---|---|---|---|---|---|
| TTZ (s) | 2.89 | 1.60 | 5.20 | 3.77 | 7.23 | 4.03 |
| PTFD (%) | 5.57 | 3.02 | 8.89 | 6.53 | 8.39 | 4.19 |
| AFD (s) | 0.39 | 0.32 | 0.33 | 0.33 | 0.34 | 0.32 |

and theory (AOI5). The AFD data showed that the participants' mental effort for the reading of written information was similar across the different AOIs, while for the graphical information, higher effort was found on the reading of the axial precession model (AOI6) and the methane reactions (AOI8). In short, the eye movement data suggested that the participants distributed their cognitive resources differently when encountering different knowledge representations. Higher mental effort (indicated by AFD) was found for the graphics of the conceptual model (AOI6, the axial precession model) and the experiment-related photos (AOI8, methane reactions), while overall attention (suggested by TTZ and PTFD) was more on the data (AOI2) and theory (AOI5) descriptions.

### *Associations Between SEBs and Eye Movement Measures*

In order to answer the third research question, Pearson correlation analyses were conducted for the SEBs and eye movement measures including the total reading time in zone (TTZ), percentage of total fixation duration (PTFD), and average fixation duration (AFD) for all 13 AOIs. The result is shown in Table 3. According to Table 3, the SEBs were not correlated to the reading time (TTZ) of the 13 AOIs except that beliefs about the development in science were negatively correlated with TTZ for the description of axial precession (AOI7, $r = -0.46$, $p < 0.05$). This finding suggests that the more complex beliefs the participants had about the development of science, the less time they spent on the written area of axial precession.

As suggested by the correlation coefficients shown in Table 3, the SEB scores in the dimensions of the source of knowledge and certainty of

**TABLE 3**

The Pearson correlations between SEBs and eye movement measures

| *Dimension* | *AOI1* | *AOI2* | *AOI3* | *AOI4* | *AOI5* | *AOI6* | *AOI7* | *AOI8* | *AOI9* | *AOI10* | *AOI11* | *AOI12* | *AOI13* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| The Pearson correlations between the SEBs and TTZ for all AOIs | | | | | | | | | | | | | |
| Source | 0.01 | −0.04 | 0.30 | −0.18 | 0.27 | 0.13 | 0.18 | 0.03 | 0.25 | 0.04 | 0.19 | −0.03 | 0.01 |
| Certainty | 0.11 | 0.04 | 0.25 | 0.03 | −0.08 | −0.03 | 0.07 | −0.04 | −0.09 | −0.15 | −0.22 | −0.33 | 0.00 |
| Development | −0.14 | 0.14 | −0.33 | 0.11 | −0.32 | 0.12 | −0.48* | −0.01 | 0.13 | −0.11 | −0.21 | 0.12 | 0.23 |
| Justification | 0.15 | 0.18 | −0.08 | 0.37 | −0.09 | 0.14 | −0.22 | 0.07 | 0.07 | −0.09 | −0.19 | −0.07 | 0.04 |
| The Pearson correlations between the SEBs and PTFD for all AOIs | | | | | | | | | | | | | |
| Source | −0.32 | −0.13 | 0.26 | −0.41** | 0.35 | −0.03 | 0.19 | 0.14 | 0.16 | 0.16 | 0.23 | −0.23 | −0.11 |
| Certainty | 0.08 | −0.26 | 0.33 | 0.00 | 0.18 | 0.05 | 0.09 | 0.00 | −0.42* | −0.09 | −0.24 | −0.23 | 0.02 |
| Development | −0.07 | 0.25 | −0.35 | 0.09 | −0.35** | 0.30 | −0.46* | 0.16 | 0.03 | 0.03 | −0.27 | 0.23 | 0.22 |
| Justification | −0.05 | 0.31** | −0.40** | 0.33 | −0.10 | 0.05 | −0.19 | 0.20 | −0.07 | −0.25 | −0.37** | −0.04 | 0.10 |
| The Pearson correlations between the SEBs and AFDs for all AOIs | | | | | | | | | | | | | |
| Source | 0.28 | 0.03 | −0.09 | 0.20 | 0.14 | −0.03 | 0.23 | 0.04 | 0.18 | 0.05 | −0.18 | 0.36** | −0.13 |
| Certainty | 0.24 | 0.05 | 0.13 | 0.37** | 0.86 | −0.17 | −0.10 | 0.02 | 0.31 | −0.03 | −0.06 | 0.15 | −0.14 |
| Development | −0.49* | 0.19 | 0.07 | −0.47* | −0.29 | −0.07 | −0.03 | −0.12 | 0.07 | −0.31 | 0.00 | −0.07 | 0.03 |
| Justification | −0.17 | 0.26 | 0.11 | −0.13 | −0.15 | −0.30 | −0.06 | −0.12 | −0.32 | −0.43* | −0.25 | −0.03 | −0.04 |

*TTZ* total time in zone, *PTFD* percentage of total fixation duration, *AFD* average fixation duration
$*p < 0.05$; $**p < 0.1$

knowledge were negatively correlated with percentages of total reading time (PTFD) in the areas of scientific explanation (AOI4) and the description of methane reactions (AOI9), respectively. Noticeably, the higher the scores for the source and certainty of knowledge, the simpler the views on these two dimensions. Accordingly, the negative associations imply that complicated SEBs (i.e. lower SEB scores) in the two dimensions corresponded to higher attention to these two AOIs. Meanwhile, Table 3 also shows that the SEB scores in the dimensions of development and justification were negatively correlated with the percentages of total reading time in the AOIs regarding prior scientific investigation (AOI3), theory (AOI5), description of the axial precession (AOI7), and description of the ice core and its microview (AOI11). Nevertheless, approximately positive correlations ($p < 0.1$) were found between SEBs in the dimension of justification (AOI2) and the percentages of total reading time for data description ($r = 0.31$, $p < 0.1$) as well as scientific explanation ($r = 0.33$, $p < 0.1$).

In summary, the correlation result in Table 3 suggests that SEBs in the dimensions of source, certainty, and justification play a role in mediating students' mental attention to written texts related to scientific evidence (AOI2, AOI9) and explanation (AOI4). Seemingly, the more complex the SEBs in these dimensions, the more attention is paid to the related texts. On the other hand, sophisticated SEBs in the dimensions of development and justification in science may reduce learners' attention to descriptions of prior scientific investigations (AOI3, AOI11), existing theories (AOI5), and models (AOI7).

Moreover, the correlation analysis shown in Table 3 for SEBs and AFD indicates that the more sophisticated the SEBs in the source dimension, the less mental effort was placed on the AOI12 diagram containing data, while more sophisticated SEBs (in the dimensions of certainty and development) were associated with less effort contributed to the scientific explanation (AOI4). In addition, higher SEBs in the justification dimension were found to be correlated with lower AFD in AOI10, showing the microview photo. In short, these findings suggest that students with sophisticated SEBs exhibited less mental effort on information related to data, scientific explanations, and the microview photo. Seemingly, for the students with more sophisticated SEBs, these information areas were easier to read.

Overall, Table 3 shows that scientific epistemic beliefs correlate most significantly with visual attention distributions indicated by PTFD and the average time needed to fixate a word (AFD). In other words, the correlation data suggest that the epistemic beliefs play a role directing mostly adult learners' cognitive attention and effort. Although some correlation coefficients displayed in Table 3 are significant at the 90 % confidence level, considering the limited number of participants, these approximately significant results cannot be neglected.

### *Gender Differences in SEBs and the Science-Text Reading Process*

In order to answer the fourth research question, one-way analysis of variance was adopted to investigate whether there were any gender differences in the SEBs and eye movement measures. The study results as displayed in Table 4

**TABLE 4**

Significant results of the one-way ANOVA for gender differences in SEBs and eye movement measures

| *Difference* | *Content* | *F value* | *Mean* |
|---|---|---|---|
| SEBs | Certainty of knowledge | 3.41*** | Male = 2.50; female = 2.05 |
| TTZ for AOI1 | Fact | 3.05*** | Male = 11.47; female = 8.08 |
| TTZ for AOI4 | Scientific explanation | 6.06* | Male = 7.57; female = 4.56 |
| PTFD for AOI1 | Fact | 3.72*** | Male = 22.23; female = 18.40 |
| PTFD for AOI2 | Data | 4.53* | Male = 26.52; female = *32.65* |
| PTFD for AOI4 | Scientific explanation | 9.42** | Male = 13.48; female = 8.61 |
| PTFD for AOI10 | Ice core and the microview of air bubbles | 3.04*** | Male = 6.77; female = 11.64 |
| AFD for AOI4 | Scientific explanations | 5.58* | Male = 0.31; female = 0.28 |

*TTZ* total time in zone, *PTFD* parentage of total fixation duration in zone, *AFD* average fixation duration
*$p < 0.05$; **$p<0.01$; ***$p < 0.1$

reveal that the male and female students had different epistemic beliefs about the certainty of scientific knowledge. It was shown that the male subjects compared to females tended to believe more that scientific knowledge is certain. According to the result of ANOVA on TTZ and PTFD data, the female students attended more to the data description (AOI2) and the picture of the ice core and its microview (AOI10), while the male subjects paid more attention to the facts (AOI1) and scientific explanation (AOI4). Moreover, the AFD analysis suggests that scientific explanations (AOI4) might be easier to read for female subjects. In sum, our study shows that the female subjects were better at processing textual information.

### *Interactions Between Gender and SEBs During Science-Text Reading*

To explore the interactions between gender and SEBs during science-text reading, two-way ANOVA was conducted on the AFD, TTZ, and PTFD data. Since the four dimensions of SEBs were assessed as continuous variables, each of them was further divided into low and high levels using the mean scores as the baseline. The ANOVA summary tables are presented in the Appendix, and the interactions are displayed in Fig. 2. The results suggest that scientific epistemic beliefs about the authority source of knowledge, certainty of knowledge, and justification in science interacted most significantly with gender during the science-text reading. The major findings are summarized as follows.

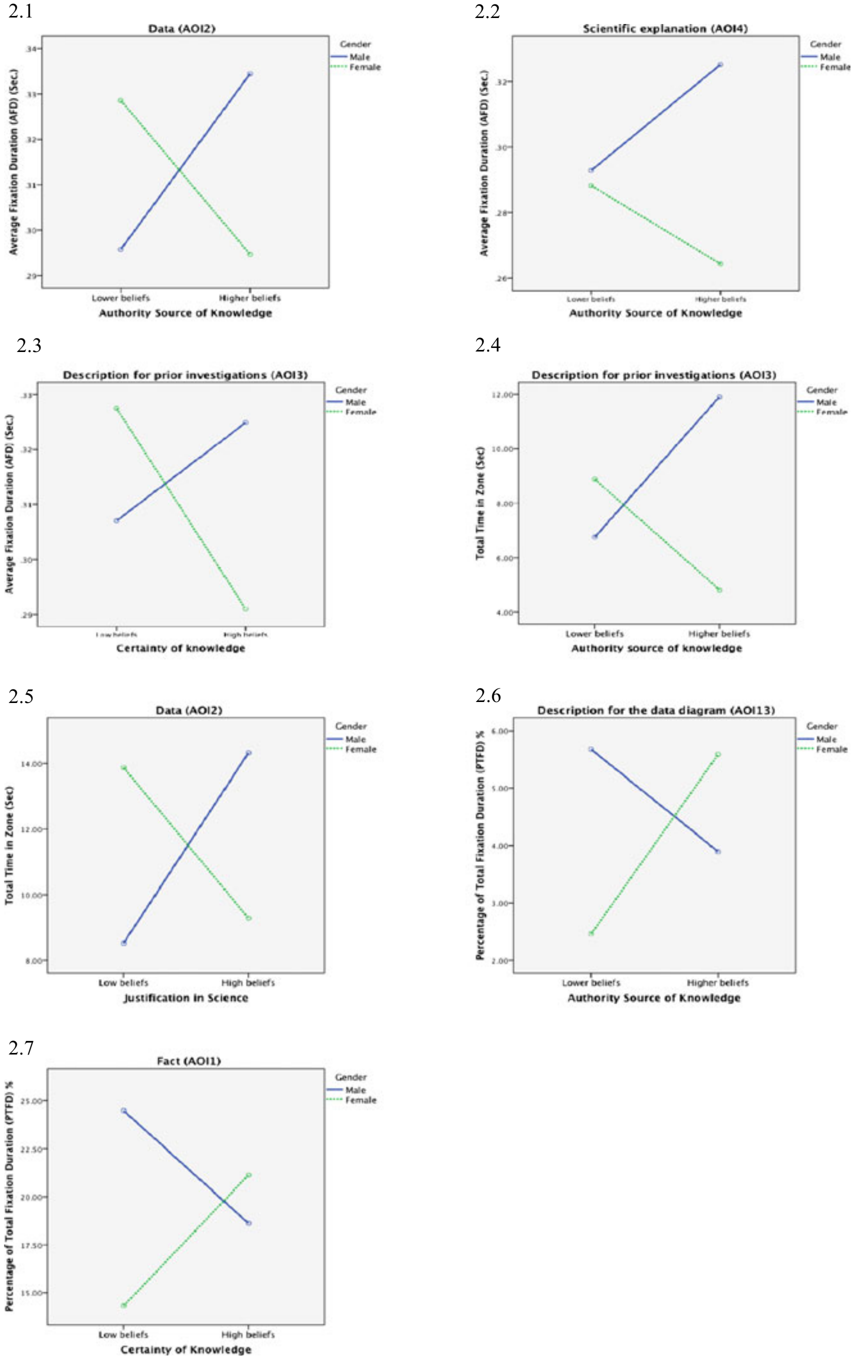


*Fig. 2.* Results of two-way ANOVA for the interactions between SEBs and gender during science-text reading (All the interactions are significant at the 95 % confidence level)

In the male group, students with strong beliefs about the *authority source of knowledge* displayed higher AFD on data (AOI2) and scientific explanation (AOI4), while for females, it was those with weak beliefs about source of knowledge who showed higher AFD in these areas (see Fig. 2(2.1, 2.2) and Tables 5 and 6). Similar interactions between gender and beliefs about the *certainty of knowledge* were found for the reading of the description of prior investigations (AOI3) (see Fig. 2(2.3) and Table 7). The analysis of the total fixation in zone (TTZ) indicated that males with high beliefs but females with low beliefs about *authority source of knowledge* needed more time to understand the description for prior investigation (AOI3) (refer to Fig. 2(2.4) and Table 8). The same trend was found for beliefs about *justification in science* and the reading of data (AOI2) (see Fig. 2(2.5) and Table 9). The analysis of the PTFD data showed that weaker beliefs in the male group but stronger beliefs in the female group about the *authority source of knowledge* resulted in more visual attention to the description of the data diagram (AOI13) (see Fig. 2(2.6) and Table 10). Similarly, male subjects who believed less, whereas female subjects who believed more, that *knowledge is certain* focused more of their attention on the fact area (AOI1) (refer to Fig. 2(2.7) and Table 11).

In sum, the two-way ANOVA confirmed that scientific epistemic beliefs bring about different effects on male and female subjects as they read the science article. Most significantly, our study shows that for male subjects, sophisticated SEBs seem to induce less mental effort (as indicated by AFD) but higher reading time as well as attention distribution (as suggested by TTZ and PTFD, respectively) when reading data related information (see Fig. 2(2.1, 2.5, 2.6). Similarly, the more complicated SEBs that the male students showed, the higher attention but less mental effort that they paid to the factual information regarding global warming (see Fig. 2(2.3, 2.7). As far as the reading of scientific explanation is concerned (see Fig. 2(2.2)), male students with complicated SEBs showed less mental effort. The above effects of SEBs were just the opposite for female students.

## DISCUSSION

This study explored the relationship between the SEBs and the process of science-text reading recorded by eye-tracking technology, and the gender differences in SEBs and the reading process. It has been demonstrated that these university students in general doubted the certainty of scientific knowledge, recognized that experts are not the sole source of knowledge, and believed that science undergoes development and justification.

Further correlation analyses for SEBs and eye movement measures (i.e. TTZ, PTFZ, and AFD) demonstrate that scientific epistemic beliefs play a role mediating mainly learners' visual attention and mental effort during the science-text reading. Such a result agrees with the psychological theories about cognition in which the epistemic level of cognition guide cognitive processes (e.g. Hofer & Pintrich, 1997; Kitchener, 1983). As displayed in Table 3, the phenomena that different SEB dimensions are associating with different cognitive activities as implied by the eye movement measures supports that a person's epistemic theory is made up of different dimensions interacting with different aspects of learning and cognition (Hofer & Pintrich, 1997).

The correlation analysis reveals that learners with complex SEBs in the source, certainty, and justification dimensions attended more to scientific evidence and explanations, while complex SEBs in the development and justification dimensions result in less attention to factual information, existing theory, and model, suggesting that subjects with more sophisticated SEBs are better at directing their attention to information aiming to support or dispute the target arguments. It is likely that these subjects recognized the importance of scientific evidence and explanation in the process of scientific argumentation. Meanwhile, subjects who have stronger beliefs about development and justification in science might regard facts, existing theories, and models as temporary. As a result, less attention was paid to such information.

For science educators, the findings of the correlation analysis suggest a need to consider the effects of SEBs if teachers plan to employ science reading to forester students' science learning. According to the study findings, learners with simple SEBs might benefit from instructional tools, such as highlighting or different cueing strategies, to locate critical regions in the presentation of information (Yang et al., 2013a). In addition, detailed explanations of data may be needed to help the learners with simple SEBs to understand the arguments or concepts exhibited by data. When the science texts are used to promote the development of SEBs or the understanding of the nature of science, science teachers would need to do more than merely present the factual information. Additional information regarding how the scientific knowledge has been constructed may help to stimulate the change in SEBs (Yang & Tsai, 2010).

With respect to the gender differences, it has been found that compared to the male subjects, the female students believed more that scientific knowledge is uncertain. They spent more time and distributed more of their attention to processing data and the graphic displaying the ice core and its microview. On the other hand, the female subjects seemed to encounter less difficulty in reading the written scientific explanations. These findings are consistent with previous reports revealing that female learners were better motivated to read and process textual information (McGeown, Goodwin, Henderson & Wright 2012; Yang & Anderson, 2003). Accordingly, it is recommended that science educators may provide different reading instructions for different genders so that they can start from what they are good at. For male students, an initial emphasis could be placed on the understanding and interpretation of graphical representations before proceeding to the reading of the main text, whereas more verbal explanations and discussions on the text content should be given to female learners before exploring the graphical presentations. A recent study by Sanchez & Wiley (2010) found that animations could reduce the gender gap in science learning from illustrations. Therefore, science teachers may use animations to support the science learning of female learners. For example, it is reported in this study that the female subjects attended to the pictures of the ice core and its microview more significantly than did the males. Such a finding might imply females' difficulty in transforming the macrostructure of the ice core into the microstructure of its content. Based on Sanchez and Wiley's suggestion, it would be helpful if an animation showing how the microview is related to the macrostructure of the ice core could be shown to female students.

The above-mentioned gender differences were further found to interact with students' scientific epistemic beliefs. The result of the two-way ANOVA showed that when reading evidence and theory-related information, sophisticated SEBs were associated with high mental efforts but low visual attention and reading time for female subjects, but for male students, sophisticated SEBs go with low mental efforts but high visual attention and reading time. If students with sophisticated SEBs are believed to have better reading strategies and performance, the instructional concern for females with simple SEBs should focus on how to enhance their mental effort to process text information. On the other hand, male students with simple SEBs would need an instruction that can increase their cognition attention on the text content.

In other words, science teachers should keep in mind that the main problem for female subjects who hold simple SEBs could be that they probably do not have an in-depth understanding about the roles of evidence and theory as subjects with complicated SEBs do. As a result, more time and attention are allocated to understand the text content. On the other hand, for male students with simple SEBs, their problem is likely that they might encounter difficulty deciphering the text meanings because of inadequate reading skills. Consequently, their attention to meaning construction is deliberately avoided. Based on above arguments, the adaptive reading instructions can be developed. For example, for female learners' with simple SEBs, the reading instruction should emphasize the understanding of the relationship between theory and evidence, while for male students with simple SEBs, the main task is to encourage the construction of the text meanings related to theory and evidence.

At last, we would like to note that in our study, most of students' attention (in terns of PTFD) was on the written areas, but the graphical areas seemed to arouse higher mental effort (indicated by AFD) (see Table 2). Such a result suggests that different knowledge representations may bring about different information processing behaviors. It is also interesting to note that most of the significant differences found in the study were related to written areas (see Table 3 and Fig. 2). Such a result actually signals that learners rely more on written information when reading science texts containing both written and graphical forms of information.

## CONCLUSION

Eye movement investigations cannot only map learners' cognitive activities but also provide practitioners with more process data to further improve the effectiveness and efficiency of science education. The study results show that the effects of scientific epistemic beliefs and gender on science reading differ with regard to the processing of different components of science texts. In addition, significant interactions are found between the effects of the two learner traits. Since science is a field encompassing different subjects that utilize various symbols, inscriptions, and graphics, more process studies are needed to add to our understanding of the science learning process. In addition, because the study involved a limited number of students and the discussion about reading is focused on the online process, our understanding about the roles of gender and scientific epistemic beliefs in mediating science reading is imperfect. It is recommended that future studies should involve the analysis of reading comprehension so that how SEBs and gender are affecting the online and offline reading behaviors can be substantially studied.

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## APPENDIX—TWO-WAY ANOVA TABLES

### TABLE 5

Test of between-subject effect (AFD) for gender and beliefs in authority source on AOI2 (data)

| *Source* | *Type III sum of squares* | *df* | *Mean square* | *F* | *Sig.* |
|---|---|---|---|---|---|
| Corrected model | 0.007[a] | 3 | 0.002 | 2.574 | 0.086 |
| Intercept | 2.095 | 1 | 2.095 | 2232.082 | 0.000 |
| Gender | 6.512E-5 | 1 | 6.512E-5 | 0.069 | 0.795 |
| Authority | 3.054E-5 | 1 | 3.054E-5 | 0.033 | 0.859 |
| Gender × authority | 0.007 | 1 | 0.007 | 7.483* | 0.014 |
| Error | 0.017 | 18 | 0.001 | | |
| Total | 2.208 | 22 | | | |
| Corrected total | 0.024 | 21 | | | |

*$p < 0.05$

[a] $R^2 = 00.300$ (adjusted $R^2 = 00.184$)

### TABLE 6

Test of between-subject effect (AFD) for gender and beliefs in authority source on AOI4 (Scientific Explanation)

| *Source* | *Type III sum of squares* | *df* | *Mean square* | *F* | *Sig.* |
|---|---|---|---|---|---|
| Corrected model | 0.010[a] | 3 | 0.003 | 3.419 | 0.040 |
| Intercept | 1.827 | 1 | 1.827 | 1963.842 | 0.000 |
| Gender | 0.006 | 1 | 0.006 | 6.159* | 0.023 |
| Authority | 9.464E-5 | 1 | 9.464E-5 | 0.102 | 0.753 |
| Gender × authority | 0.004 | 1 | 0.004 | 4.532* | 0.047 |
| Error | 0.017 | 18 | 0.001 | | |
| Total | 1.944 | 22 | | | |
| Corrected total | 0.026 | 21 | | | |

*$p < 0.05$

[a] $R^2 = 00.363$ (adjusted $R^2 = 00.257$)

**TABLE 7**

Test of between-subject effect (AFD) for gender and beliefs in authority source on AOI3 (prior investigation)

| *Source* | *Type III sum of squares* | *df* | *Mean square* | *F* | *Sig.* |
|---|---|---|---|---|---|
| Corrected model | 0.005[a] | 3 | 0.002 | 1.668 | 0.207 |
| Intercept | 2.108 | 1 | 2.108 | 2308.292 | 0.000 |
| Gender | 0.000 | 1 | 0.000 | 0.266 | 0.612 |
| Certainty | 0.000 | 1 | 0.000 | 0.514 | 0.482 |
| Gender × certainty | 0.004 | 1 | 0.004 | 4.364* | 0.050 |
| Error | 0.017 | 19 | 0.001 | | |
| Total | 2.236 | 23 | | | |
| Corrected total | 0.022 | 22 | | | |

*$p < 0.05$

[a] $R^2 = 00.208$ (adjusted $R^2 = 00.084$)

**TABLE 8**

Test of between-subject effect (TTZ) for gender and beliefs in authority source on AOI3 (prior investigation)

| *Source* | *Type III sum of squares* | *df* | *Mean square* | *F* | *Sig.* |
|---|---|---|---|---|---|
| Corrected model | 142.782[a] | 3 | 47.594 | 2.923 | 0.062 |
| Intercept | 1396.938 | 1 | 1396.938 | 85.790 | 0.000 |
| Gender | 32.777 | 1 | 32.777 | 2.013 | 0.173 |
| Authority | 1.597 | 1 | 1.597 | 0.098 | 0.758 |
| Gender × authority | 113.285 | 1 | 113.285 | 6.957* | 0.017 |
| Error | 293.098 | 18 | 16.283 | | |
| Total | 1984.272 | 22 | | | |
| Corrected total | 435.880 | 21 | | | |

*$p < 0.05$

[a] $R^2 = 0.328$ (adjusted $R^2 = 0.215$)

TABLE 9

Test of between-subject effect (TTZ) for gender and beliefs in authority source on AOI2 (Data)

| *Source* | *Type III sum of squares* | *df* | *Mean square* | *F* | *Sig.* |
|---|---|---|---|---|---|
| Corrected model | 154.193[a] | 3 | 51.398 | 2.045 | 0.142 |
| Intercept | 2852.923 | 1 | 2852.923 | 113.535 | 0.000 |
| Gender | 0.129 | 1 | 0.129 | 0.005 | 0.944 |
| Justification | 1.991 | 1 | 1.991 | 0.079 | 0.781 |
| Gender × justification | 145.619 | 1 | 145.619 | 5.795* | 0.026 |
| Error | 477.434 | 19 | 25.128 | | |
| Total | 3981.100 | 23 | | | |
| Corrected total | 631.627 | 22 | | | |

*$p < 0.05$
[a] $R^2 = 0.244$ (adjusted $R^2 = 0.125$)

TABLE 10

Test of between-subject effect (PTFD) for gender and beliefs in authority source on AOI13 (data)

| *Source* | *Type III sum of squares* | *df* | *Mean square* | *F* | *Sig.* |
|---|---|---|---|---|---|
| Corrected model | 39.345[a] | 3 | 13.115 | 2.823 | 0.068 |
| Intercept | 413.453 | 1 | 413.453 | 88.986 | 0.000 |
| Gender | 3.104 | 1 | 3.104 | 0.668 | 0.424 |
| Authority | 2.424 | 1 | 2.424 | 0.522 | 0.479 |
| Gender × authority | 32.161 | 1 | 32.161 | 6.922* | 0.017 |
| Error | 83.633 | 18 | 4.646 | | |
| Total | 528.766 | 22 | | | |
| Corrected total | 122.978 | 21 | | | |

*$p < 0.05$
[a] $R^2 = 0.320$ (adjusted $R^2 = 0.207$)

**TABLE 11**

Test of between-subject effect (PTFD) for gender and beliefs in authority source on AOI1 (fact)

| *Source* | *Type III sum of squares* | *df* | *Mean square* | *F* | *Sig.* |
|---|---|---|---|---|---|
| Corrected model | 300.000[a] | 3 | 100.000 | 6.072 | 0.004 |
| Intercept | 8317.046 | 1 | 8317.046 | 505.024 | 0.000 |
| Gender | 78.997 | 1 | 78.997 | 4.797 | 0.041 |
| Certainty | 1.200 | 1 | 1.200 | 0.073 | 0.790 |
| Gender × certainty | 216.852 | 1 | 216.852 | 13.168** | 0.002 |
| Error | 312.904 | 19 | 16.469 | | |
| Total | 10,338.620 | 23 | | | |
| Corrected total | 612.904 | 22 | | | |

**$p < 0.01$

[a] $R^2 = 0.489$ (adjusted $R^2 = 0.409$)

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