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The Effects of Chemical Element Symbols in Identifying 2D Chemical Structural Formulas

Abstract

This study aims to explore the effect of chemical element symbols in students' identification of 2D chemical structural formulas. A chemical conceptual questionnaire, event-related potential experiments and interviews were administered to fifty university students in this study. The results revealed that high achieving students performed different brain activities and strategies to identify 2D figures (without chemical elements symbols inside) and 2D chemical structural formulas. However, low achieving students ignored the existence of chemical element symbols and performed similar brain activities and strategies when identifying 2D figures and chemical structural formulas. This paper discusses implications for new education.

Keywords: *chemical element symbols, chemical structural formulas, event-related potentials (ERPs)*

1. Introduction

Chemistry is a difficult subject for students because of the abstract concepts, unobservable objects, and unfamiliar specific terms used by the chemistry community (Gilbert & Treagust, 2009; Tsaparlis, Kolioulis, & Pappa, 2010). One of the most important and difficult topics in chemistry is that of chemical structures (Korakakis et al., 2009; Mayer, 2001). Learning about chemical structures must start with identifying chemical structural formulas. Unfortunately, many students fail to identify 2D chemical structural formulas (Huang & Liu, 2012).

The possible reason why students cannot identify 2D chemical structural formulas successfully could be a lack of both cognitive ability, such as mental rotation, and knowledge of chemical structures (Huang & Liu, 2012; Mayer, 2001). Huang and Liu (2012) mentioned that some of students' difficulties in identifying 2D chemical structural formulas are due to their inappropriate strategies of mental rotation. In their results, they found that the students of low achievement in identifying chemical structural formulas always used the same strategies to identify 2D geometric figures and chemical structural formulas. Thus, we wanted to find out the meaning of chemical element symbols to those students. Do they recognize these chemical element symbols in these 2D representations?

Answers to the research questions are not easy to measure simply using questionnaires and interviews. Wang, Chiew and Zhong (2010) suggested that many cognitive processes are difficult to explain verbally and many students do not even recognize what kind of cognitive ability they are applying in problem solving tasks. Hence, they suggested that this kind of research must combine neurophysiological methods with questionnaires and interviews (Wang, Chiew, & Zhong, 2010).

Huang and Liu (2012) combined event-related potentials (ERPs), a kind of neurophysiological methods, with questionnaires and interviews to provide physiological evidence to explain the effects of mental rotation in identifying 2D figures and chemical structural formulas successfully. Therefore, in this study, we also combined ERPs, a questionnaire and an interview to explore the effects of chemical element symbols when students identified 2D figures and chemical structural formulas. According to the principle of ERPs, humans show similar trends of brain wave when responding to the same task (Lai et al., 2010). The details will be discussed in the next section.

2. Theoretical Framework

When a visual system delivers signals from the physical world to the brain, the neuronal networks of the brain integrate the new information with personal experiences and establish new information structures (Moè, 2009). It means students' scientific knowledge and their response to scientific explanations are often influenced by their prior experiences in daily life (Frailich et al., 2009). The notion of constructivism demonstrates that each individual learner constructs his/her knowledge by making sense of the world and prior experiences, and by integrating new information with his/her existing cognitive structures (Frailich et al., 2009). However, many of the ideas generated by what students experience in daily life are significantly different from those of scientific explanations (Gilbert & Treagust, 2009). In terms of chemical structural formulas, many teachers and textbooks use balls and sticks for illustration (Stevens, Delgado, & Krajcik, 2010). Unfortunately, based on the model of balls and sticks, many students believe that a chemical bond is a real physical entity (Boo, 1998) and ignore the meaning of chemical elements .

Students use their daily life experiences about balls and sticks to develop a conceptual understanding of atoms and chemical bonds (Stevens et al., 2010). The identification of figures by students predisposes them to apply the same strategies in identifying chemical structural formulas (Stieff, 2007). Therefore, this study hypothesized that chemical element symbols are meaningless for the students of low achievement in identifying chemical structural formulas.

This study adopted the ERP technology to provide physiological data for explaining the effects of chemical element symbols when students identified 2D figures and chemical structural formulas. ERP is a procedure used to collect data on the electrical activity of the brain through the skull and scalp (Coles & Rugg, 1996). The procedure comprises many events that include several experimental trails. When participants recognize or apply the specific cognitive abilities, such as recognition, identification or mental rotation, in response to events, the corresponding electrical activities of brain are induced (Huang & Liu, 2012). The averages of these corresponding electrical activities are integrated as specific ERPs components (Coles & Rugg, 1995). In this study, the main set of specific ERPs components was the N250 component.

The N250 component occurs with a latency between 220–250 ms after stimulus onset (Figure 1) and it is always found in occipito-temporal electrode sites including TP7, TP8, T5, and T6 (Figure 2) (Caharel et al., 2009). Research has found out that a larger amplitude of the N250 component of ERPs will be induced when the participants identify different contents of two similar figures consisting of the same contours but different internal elements. (He, Liu, Guo, & Zhao, 2011). For example, the N250 component has been referenced in studies on the recognition of faces, letters and the contents of plausible models, and it has been defined as an individual repetition effect (Duñabeitia, Molinaro & Garreiras, 2011; He et al., 2011). To sum up, the students who have a greater recognition of chemical element symbols within chemical structural formulas will reveal a larger N250 amplitude than those who do not recognize the differences between 2D figures and chemical structural formulas well.

Figure 1. N250 components in ERPs analysis

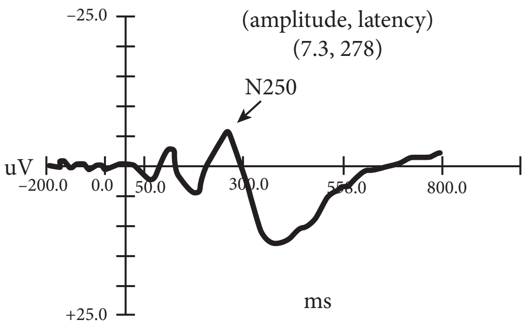
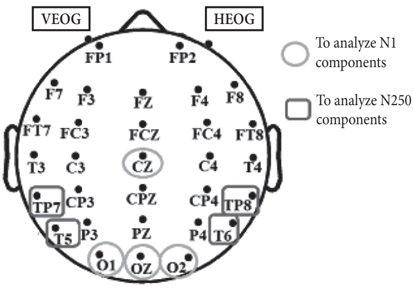


Figure 2. The locations of electrodes in brain map



3. Methodology

Research Population and Instrument

This study was conducted at an urban university in Taiwan. Fifty university students majoring in chemistry (n=50, 31 males, 19 females; mean age ± S.D. = 20.9 ± 2.0 years) participated in the study.

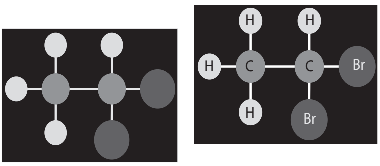
A questionnaire, developed by the authors and based on previous research (Chiu & Fu, 1993; Frailich et al., 2009), was administered to the participants. The questionnaire (perfect score = 100) included ten questions (perfect score for each question = 10). These questions were used for understanding the students' learning performance related to chemical structure. The questionnaire was constructed using the Delphi method and was determined by reaching consistency. The expert panel consisted of two science educators, two science teachers, one chemist and two psychologists. Then, the constructed questionnaire was tested by thirty university students to validate the content, reaching the Cronbach's α value of .935.

The participants completed the test within 50 minutes without conversing with others. After the test, one science teacher graded the questionnaires, and the other science teacher confirmed the grading. Based on the scores of the questionnaire, the students with upper and lower 27% of total scores (Kelly, 1939) were grouped into the high score (HSG, n=9; mean age ± S.D. = 20.7 ± 2.7 years) and low score (LSG, n=9; mean age ± S.D. = 20.4 ± 1.9 years) groups respectively. All the participants were healthy, without a history of neurological or psychiatric disorders, and all gave voluntary consent to participate in the ERPs experiments. This study conformed to The Code of Ethics of the World Medical Association (Declaration of Helsinki) and was approved by the ethics committee of the National Kaohsiung Normal University.

ERPs Experiments

Based on the research questions, this study designed two types of ERPs experiments, which included 2D geometric figures (2D figures) and 2D chemical structural formulas. 2D figures were presented by a shape similar to 2D chemical structural formulas, but without any chemical element symbols inside (Figure 3). Each experiment included a short guideline and 62 trials. A pair of matched (n=31) or unmatched (n=31) figures was presented in each trial, and the participants were asked to respond by recognizing whether the pair of figures was matched or not by pressing the appropriate buttons (matched: press ○; mismatched: press ×).

Figure 3. Examples of experimental tasks (Huang & Liu, 2012)

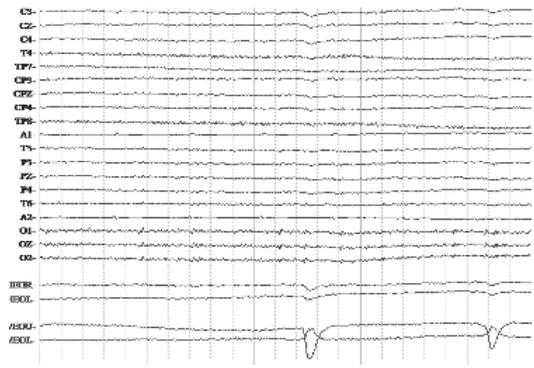


A guideline message appeared on the screen for 10000 ms before each experiment. Then, the sequence of each trial began with a red fixation point that was presented at the centre of the screen that remained in view for 100 ms. The red fixation point could help participants to refresh their memory from previous trials and to pay attention to the centre of the screen. Furthermore, the target slide of a trial was presented for either 4000 ms or until the participants pressed a response button.

Data Collection

All the electroencephalogram (EEG) signals (Figure 4) from the participants were collected when they were manipulating the experiments.

Figure 4. An example of EEG signals



The EEG was amplified (band pass, 0.01–40Hz) by the SynAmps/SCAN 4.4 hardware and software (NeuroScan, Inc., Herndon, VA); using the commercial electro-cap (Electro-Cap International, Eaton, OH) which was placed at 32 scalp locations based on the 10–20 international system. The noise signals collected could be filtered out automatically. The electrode impedance was kept below 5 kΩ. The averaging epoch was 1024 ms, including 200 ms of pre-stimulus baseline.

EEG channels were continuously digitalized at a rate of 1000 Hz by a SynAmpTM amplifier. The signal was analogue filtered (0.1–200 Hz), and digitally filtered in the range 0.1–30 Hz.

Data Analysis

The correct scores and the ERPs data were collected for analysis. The score for correct response in each trail was one point, and the total score was 62 points. Because each participant needed to perform the same experiment twice, the highest possible score was 124 points. For the ERPs data, the N250 amplitudes were obtained from the TP7, TP8, T5 and T6 electrodes (Caharel et al., 2009). The extracted data were analyzed by *t*-test (SPSS version 6.0).

Interviews

After the students completed the ERPs experiments, semi-structured interviews were conducted to investigate their explanations and understanding of the chemical representations. Explanations from both the HSG and LSG student groups were coded as object explanations, partial explanations, and scientific explanations.

The interview for each student lasted 40 minutes. The interview data were used to triangulate the findings of the ERPs data and the scores of the questionnaire.

4. Results and Discussion

Behavioral data

The results in Table 1 show that there was no statistical difference between the HSG and LSG students in their response scores for identifying 2D figures. In contrast, the scores of the HSG students were significantly higher than those of the LSG students for identifying 2D chemical structural formulas. These results suggested that there were no differences of cognitive ability in identifying geometric figures between the high and low achieving students, but the high achieving students did perform better in identifying 2D chemical structural formulas than the low achieving students.

Table 1. *t*-test analysis of the response scores between and within HSG and LSG

Variable	Experiment	Group	Mean ± S.D.	*t*	Cohen's *d*
Scores	2D	HSG	124.0 ± 0	1.5	0.707
		LSG	123.8 ± 0.4		
	2Dchem	HSG	118.9 ± 3.9	10.7***	5.059
		LSG	93.0 ± 6.1		

* *P*<.05; ** *P*<.01; *** *P*<.001; 2D: 2D figures; 2Dchem: 2D chemical structures.

The low achieving students often performed similar brain activities and strategies to identify 2D chemical structural formulas and 2D figures

The results of *t*-test on the N250 amplitude of the HSG and LSG students (Table 2) showed that there were no statistical differences between the HSG and LSG students in the N250 amplitude induced by the identification of 2D figures. However, the N250 amplitude of the HSG students was significantly larger than that of the LSG students when identifying 2D chemical structural formulas.

He et al. (2011) found out that when the participants recognized the differences between two similar figures which consisted of the same contours but with different elements inside, the larger amplitude of N250 component from brain activities was induced. In other words, the results of this study indicate that the HSG and LSG students exercised similar brain activities to identify 2D figures. However, the HSG students exercised more brain activities than the LSG group in the identification of the internal content of 2D chemical structural formulas. This finding indicated that the meanings of chemical element symbols in 2D chemical structural formulas were different between the HSG and LSG students.

Table 2. Differences in N250 amplitude between the HSG and LSG groups

Variable	Group	Mean ± S.D.	*t*	Cohen's *d*
N250 amplitude (2D figures)	HSG	0.5 ± 0.7	0.1	0.090
	LSG	0.4 ± 1.4		
N250 amplitude (2D chemical structures)	HSG	8.5 ± 3.7	5.4***	2.565
	LSG	0.4 ± 2.5		

*** *P*<.001; 2D: 2D figures; 2Dchem: 2D chemical structures

Further, we collected paired *t*-test data on the N250 amplitude from the HSG and LSG students. The results showed that for the HSG students the N250 amplitude obtained from identifying 2D chemical structural formulas was significantly larger than that from identifying 2D figures (*t*=11.6; *P*<.001; **Cohen's** *d=2.953*). But, for the LSG students, there was no statistical difference in N250 amplitude (*t*=-0.07; *P*=0.944; **Cohen's** *d=-0.020*).

The results of this study indicated that the HSG students could recognize the differences of contents between 2D figures and 2D chemical structural formulas well, but the LSG students could not. The LSG students performed similar brain activities to identify those two representations. This finding implied that the LSG students ignored the meaning of chemical element symbols when they identified the 2D chemical structural formulas. The interview data also supported this implication.

The interview data showed that the HSG students recognized the chemical element symbols well and used some analytical strategies of the chemistry background knowledge to identify 2D chemical structural formulas. In contrast, the LSG students imaged the chemical element symbols as some specific 2D round shapes and used the same strategies to identify 2D figures and chemical structural formulas.

(Students explain how they identify the 2D representation in Figure 5)

HSG 5: I compared the location of specific balls in the left pictures with the right pictures to check the match or mismatch of different 2D figures. But in the 2D chemical struc-

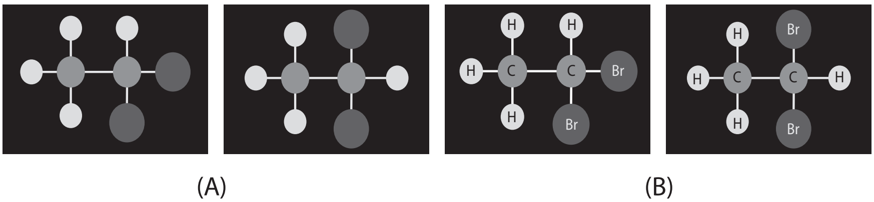
tural formulas, the "Br" atoms were connected to the same "C" atom; therefore I could determine that these two chemical structures are the same.

HSG 9: To recognize 2D figures, I check and compare two specific balls. But in chemical structural formulas, I need to calculate the numbers of "Br" atom first and check the location of "C-Br" single bonds. These two chemical structural formulas are the same because the single bond could rotate, therefore, the spatial structures are the same.

LSG 2: You can image "Br" atoms as specific balls and a single bond as sticks in 2D figures. And you can compare these 2D chemical structural formulas as 2D figures.

LSG 3: I think there are some rules to identify 2D chemical structural formulas and figures, because the chemical bonds are the same as the sticks of objects, I think I can use the same strategies to identify 2D chemical structural formulas.

Figure 5. An example of comparison between A) 2D figures; B) 2D chemical structural formulas



As shown in Figure 5, obvious mistakes occurred if the students determined 2D chemical structural formulas to be the same as 2D figures. The 2D figures in Figure 5 (A) are different, but the 2D chemical structural formulas in Figure 5 (B) are the same. The interview data show that the HSG students applied different strategies when identifying 2D figures compared to identifying 2D chemical structural formulas. The finding agrees with previous studies (Gilbert & Treagust, 2009; Stieff, 2007). In contrast, the LSG students applied similar strategies to identify 2D figures and chemical structural formulas. In other words, the chemical element symbols of 2D chemical structural formulas are meaningless to the LSG students. The LSG students just identified those representations by considering their contours.

5. Conclusion

Previous research by Huang and Liu (2012) indicated that the students of low achievement in identifying chemical structural formulas always used the same strategies to identify 2D geometric figures and chemical structural formulas. The question of this study was that if the low achieving students used the same strategies to identify 2D figures and chemical structural formulas, what was the meaning of chemical element symbols to those students?

The behavioural data and the physiological data from N250 amplitude of ERPs indicated that chemical element symbols were meaningless for the students of low achievement in identifying chemical structural formulas. The physiological data from brain activities and interview data implied that those low achieving students ignored the chemical elements symbols when they identified the 2D chemical structural formulas in their cognitive processing because they had an alternative conception about ball and stick models of chemical bonding. They thought the 2D chemical structural formulas were the same as 2D figures. Based on the findings, this study suggested that science teachers must avoid only introducing the ball and stick models when teaching chemical structural formulas, and they need to emphasize the meaning of chemical element symbols through the use of multiple representations and analytical strategies.

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