EFFECTS OF SEGMENTED ANIMATED GRAPHICS AMONG STUDENTS OF DIFFERENT SPATIAL ABILITY LEVELS: A COGNITIVE LOAD PERSPECTIVE

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ABSTRACT
This study investigated the effects of segmented animated graphics utilized to facilitate learning of electrolysis of aqueous solution. A total of 171 Secondary Four chemistry students with two different spatial ability levels were randomly assigned to one of the experimental conditions: (a) text with multiple static graphics (MSG), (b) text with continuous animated graphics (CAG) and (c) text with segmented animated graphics (SAG). Analysis of ANCOVA was conducted by using students' pretest scores as a covariate. The results showed that the SAG is more effective than the CAG and the MSG for improving learning across all levels of spatial ability. Low spatial ability students using the SAG mode performed significantly better as compared to low spatial ability students using the CAG and the MSG mode. The SAG mode seemingly compensates for low spatial ability students' insufficient visualization skills and limited cognitive capacities by offering them an external representation which simplifies information processing and saves valuable cognitive capacities for essential cognitive tasks.

INTRODUCTION

Multimedia has emerged as one of the main interests of researchers these days. The term "multimedia" refers to the use of text and graphics to convey certain information via computer. Static graphics, for instance, have long been widely used for promoting better comprehension of textual information (Levin, Anglin, & Carney, 1987), better retrieval and transfer of knowledge (Mayer, 1989). With the rapid advancement in technologies, static graphics have been evolved into animated graphics. Researchers in chemical education found that animated graphics can enhance learners' understanding of chemistry conceptions (Williamson & Abraham, 1995), provide scaffolding and facilitate "conceptual change" (Othman Talib, Matthews, & Secombe, 2005).

Static Graphics versus Animated Graphics

Do animated graphics offer more benefits than static graphics? This question has been debated for years and yet the results remain inconclusive and inconsistent. Some research studies reported an overwhelming result in favour of animated graphics (e.g., Rieber, 1990; Thompson & Riding, 1990), while some found no advantages of animated graphics over static graphics (e.g., Hegarty, Kriz & Cate, 2003; Mayer, Hegarty, Mayer, & Campbell, 2005; Boucheix & Schneider, 2009). Tversky, Morrison and Betrancourt (2002) even argued that positive impact of animated graphics found in some studies may be due to the lack of informational equivalence between animated and static graphics conditions.

Given the motion and trajectory attributes of animated graphics (Klein, 1987), animated graphics would make the invisible and touchable visually explicit, offering learners more relevant external representation that helps them accurately encode the changes into their memory system (Rieber, 1990). In effect, the construction of "runnable" mental model is facilitated (Mayer, 1989). On the other hand, animated graphics does not always lead to an accurate mental model (Hegarty, 2004), but sometimes even carry potential for misunderstandings, misinterpretations, and misconceptions. This is particularly true when the learners are not familiar with the content (Ruiz, Cook, & Levinson, 2009). Novices tend to perceive the animated features literally (Falvo, 2008).

Animated graphics are still preferable because it makes the transition more concrete whereby learners can directly visualize the changes that otherwise have to be mentally simulated from static graphics. In other words, animated graphics reduces processing demands by replacing "cognitive processes such as abstraction, imagination or creativity that some learners are short of" (Barak, Ashkar, & Dori, 2011, p. 840). By contrast, understanding static graphics may impose high cognitive demands because learners have to mentally infer the information and concurrently construct a mental model.

However, learning from animated graphics is still particularly problematic for novices (Mayer, 2005). Overconsumption of limited cognitive resources to understand content-rich and fast-paced animated graphics may induce cognitive overload (Hoffler & Leutner, 2007). Less working memory capacity is then available for necessary cognitive activities to make sense of the learning content (Mayer & Moreno, 2003).

Segmented Animated Graphics and Learning

Many authors found evidence that segmenting an animated graphics into meaningful chunks could better fit the human cognitive architecture and yields better learning performance (e.g., Fong, 2000; Moreno, 2007; Ahmad Zamzuri & Ahmad Rizal Madar, 2010; Fong & Lily, 2010).

Segmented animated graphics compensates for the inevitable working memory limitations by providing pause between each segment and learner-control features to move from segment to segment (Ahmad Zamzuri & Ahmad Rizal Madar, 2010). The pause between segments yields extra time for cognitive processes of selecting, organizing and integrating information (Mayer, 2005) which can hardly be done when a display continuously changes (Lowe, 2004). In terms of the cognitive load perspective, segmented animated graphics could prevent learners from overusing the limited working memory resources, thus optimizing their information-processing abilities for other learning tasks (Moreno, 2007). This situation might overcome the negative learning outcomes of animated graphics caused by the threat of extraneous cognitive overload as pointed out by Hoffler and Leutner (2007).

Thus, the present study attempted to investigate if segmented animated graphics are effective in enhancing learning of electrolysis among chemistry students, particularly those who are unable to visualize the underlying sub-microscopic processes.

Spatial Ability and Learning

A considerable body of research studies on chemical education has been dedicated to the investigation of role of spatial ability. Empirical works have frequently demonstrated that spatial ability is a factor in the success of students in chemistry tasks (Bodner & McMillen, 1986; Pribyl & Bodner, 1987). Most of the correlational studies of visuo-spatial skills and chemistry have reported that high spatial students, as compared to low spatial students, are more capable of understanding and performing chemistry tasks. In few studies conducted by Bodner and his colleagues, chemistry students with high spatial ability were better able to solve given compound-naming task, structure-drawing task, synthesis-writing task and reaction-completing task (Pribyl & Bodner, 1985), to identify crystal structures and solve stoichiometry problems (Bodner & McMillen, 1986), to solve molecular geometry and crystal structure test questions (Carter, LaRussa & Bodner, 1987).

The significant difference in the performance of high spatial ability and low spatial ability students in chemistry tasks suggests a difference in the quality of internal representations that they are able to construct (Hegarty & Waller, 2004; Mohler, 2008). That is, high spatial ability students are capable of constructing a more appropriate corresponding mental representation from what they visually perceive. This will eventually help them to spatially organize and represent the problem (Larkin & Simon, 1987), enable them to make inferences explicitly, and search for information easily (Wu & Shah, 2004), which in turn, lead to greater success in chemistry understanding and problem solving.

Another explanation is contributed by Miyake and Shah (1999) that individuals with higher spatial ability may possess more spatial working memory resources than those with lower spatial ability. On the other hand, low spatial learners do not possess sufficient cognitive spaces for spatial information, inhibiting development of mental representations, thus yielding an unsatisfactory learning performance.

The present piece of work addresses the very few studies conducted concerning cognitive off-loading effects of segmented animated on learning performance of low spatial learners. Thus, this research attempted to examine if segmented animated graphics can help low spatial learners to reduce the consumption of working memory space that could be useful for other learning tasks.

RESEARCH QUESTIONS

This study investigated the effects of three graphical presentation modes – (a) text with multiple static graphics (MSG), (b) text with continuous animated graphics (CAG) and (c) text with segmented animated graphics (SAG) on learning electrolysis among students with different spatial ability levels – high spatial (HS) and low spatial (LS). The study sought to address the following questions:

1. Are there significant differences in performance among students in the SAG, CAG and MSG groups?
2. Are there significant differences in performance among students of high spatial ability (HS) and low spatial ability (LS)?
3. Are there significant differences in performance among low spatial students in the SAG, CAG and MSG

groups?

RESEARCH METHODOLOGY

In order to answer the research questions, an experiment was conducted according to a 3x2 factorial quasi-experimental design including the between groups factor – modes of graphical presentation (SAG, CAG and MSG) and the within groups factor – levels of spatial ability (HS and LS).

Research Sample

The samples were randomly selected from two different urban secondary schools that were facilitated with computer laboratories. A total of 171 Secondary Four chemistry students from five intact classes were participated in the experiment. None of these students had specific prior knowledge about electrolysis of aqueous solutions.

Treatment Conditions

There were three treatment groups – SAG, CAG and MSG in this study. Students in these treatment groups were exposed to exactly the same learning content, but the sub-microscopic processes of electrolysis were displayed in different graphical presentation modes as follows:

- MSG group (see Figure 1): A series of static graphics accompanied by relevant motion cues and text were presented simultaneously to explain the electrolysis process. For example, when explaining the movement of ions, the arrows and explanatory text were closely placed next to the static graphics. To proceed from frame to frame, the students clicked on the 'Next' button.

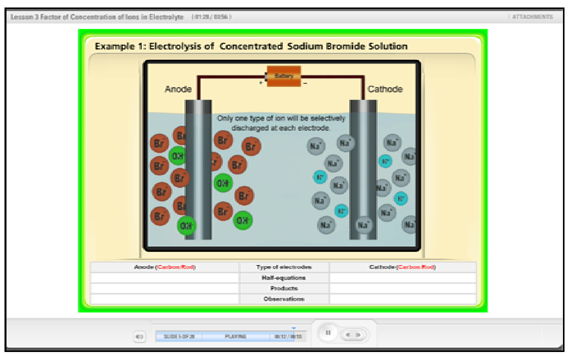

Figure 1. Screenshot of the MSG Mode

- CAG group (see Figure 2): Animated graphics were presented to demonstrate the whole molecular process of electrolysis continuously from the beginning to the end. Explanatory text, as similar to that of MSG group, was provided along with the animated graphics. For example, when explaining the movement of ions, the changes in position of ions over time came directly with the corresponding explanatory text.

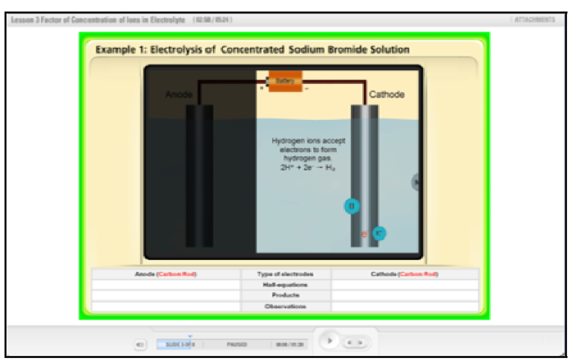

Figure 2. Screenshot of the CAG mode in motion (taken at 0.53s/0.64s)

- SAG group (see Figure 3 and Figure 4): The treatment that was given to this group is similar to that of CAG group, except that animated graphics was presented in a segmented instead of continuous manner. To proceed to the next segment, the students clicked on the 'Next' button.

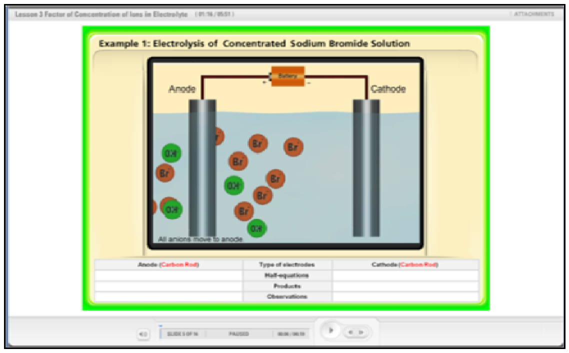

Figure 3. Screenshot of one segment of the SAG mode in motion (taken at 0.05s/0.13s)

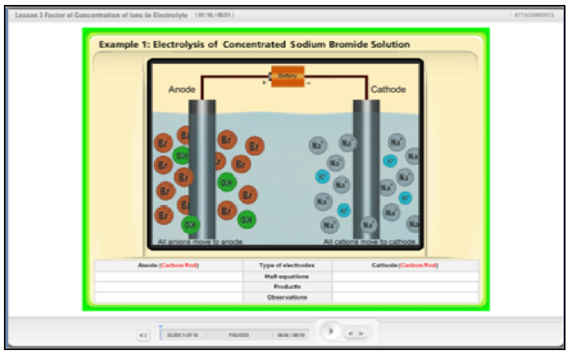

Figure 4. Screenshot of one segment of the SAG mode in motion (taken at 0.11s/0.13s)

Instruments

Two main instruments were used in this study, as follows:

- Electrolysis Performance Test: Learning was measured with a test consisting of fifteen multiple-choice questions, three structural questions and one essay-type questions. All these test items were written at lower and higher levels of Bloom's revised taxonomy (i.e., remembering, understanding, applying, analyzing and creating). The Cronbach Alpha analysis yielded a coefficient of 0.82 showing that the test instrument was reliable.
- Purdue Visualization of Rotation Test (ROT): This questionnaire was adopted from Bodner and Guay (1997), to examine students' spatial ability level. It consists of twenty test items that to be answered by the students within a time limit of ten minutes.

Research Procedure

Prior to the treatment, students' prior knowledge and spatial ability levels were measured with pretest and the ROT Test, respectively in their classes. Before the arrival of the students, the researcher and assistants installed one of the three versions of learning courseware into each computer in the computer laboratory. Students were brought to the laboratory and randomly assigned to any one of the three treatment groups – MSG, CAG and SAG. Students were free to choose their seating places in the laboratory, whereby each of them had one personal computer with pre-installed courseware. Throughout the study, students must be seated at the same place that was selected on the first day.

The treatment session involves two phases – introduction and learning. During the first lesson, students were introduced to the interfaces and functions of the various icons for 30 minutes, under the guidance of research assistants. Students learnt how to use the learning courseware and how to navigate the content. This was important to eliminate the potential effects of novelty. Students then started to learn the electrolysis concepts from the learning courseware. Students interacted with the contents three times a week (40 minutes per session). Chemistry teachers were given explicit instruction and they acted as facilitators for the whole session. The duration of the treatment was one week.

Following the treatment, students were given the posttest to measure their performance after the treatment. The results were recorded for further statistical analysis.

RESEARCH FINDINGS

In order to ascertain the equivalence between groups in term of prior knowledge, one-way analysis of variance (ANOVA) was conducted. There was no significant difference at the $p < 0.05$ significance level, as $F(2, 168) = 0.200$, $p = 0.819$, showing that the three treatment groups were homogeneous in terms of prior knowledge of the topic 'Electrolysis of Aqueous Solutions'.

To examine the appropriateness of pretest as a covariate in the later analysis of covariance (ANCOVA), a further investigation of the relationship between the pretest and the posttest was conducted using Pearson product-moment correlation. The result yielded a correlation coefficient of 0.755 ($p < 0.05$), indicating a strong correlation between the two variables. Thus, despite the three treatment groups were statistically homogeneous, this strong correlation signified the appropriateness of using pretest score as covariate. This was done to eliminate extraneous variations from the posttest score, thereby increasing measurement precision.

Performance of Students with Different Spatial Abilities in Various Treatment Groups

With the pretest score as covariate, the posttest scores were subjected to analysis of covariance (ANCOVA) to compare the effects of SAG, CAG and MSG modes on students' learning of electrolysis. The results, as in Table 1, showed a significant difference in the performance of students among the three treatment groups, $F(2, 167) = 88.197$, $p = 0.000$. As expected, the students using SAG mode performed significantly better than students using the CAG mode and the MSG mode, whereas those using the CAG mode performed significantly better than students using the MSG mode.

Table 1: ANCOVA Results for Posttest Scores by Treatment Groups with Pretest Score as Covariate

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	5163.807[a]	3	1721.269	210.100	0.000	0.791
Intercept	1023.137	1	1023.137	124.885	0.000	0.428
Pretest	3599.361	1	3599.361	439.341	0.000	0.725
Groups	**1445.138**	**2**	**722.569**	**88.197**	**0.000**	**0.514**
Error	1368.169	167	8.193			
Total	38008.000	171				
Corrected Total	6531.977	170				

[a]R Squared =0 .791 (Adjusted R Squared = 0.787)

Table 2: Mean performance (and SD) on the two spatial ability levels as a function of condition

	Treatment Conditions			
	SAG (n = 53)	CAG(n = 56)	MSG (n = 62)	Total (N = 207)
LS (n = 83)	14.04 (4.442)	9.76 (4.419)	6.94 (3.224)	10.10 (6.199)
HS (n = 88)	22.04 (4.574)	14.65 (3.629)	14.68 (4.650)	16.84 (5.429)
Total (N = 207)	17.96 (6.019)	12.46 (4.659)	10.81 (5.566)	

ANCOVA was also employed to find out whether the difference in performance of the HS and the LS students as shown in Table 2 are significant. After controlling for the pretest scores, the performance of HS and LS students were differed significantly, $F(1, 168) = 14.709$, $p = 0.000$. That is, the HS students performed significantly better than the LS students.

Using ANCOVA, the performance of LS students in SAG, CAG and MSG groups were also compared. The result, $F (2, 79) = 66.592$, $p = 0.000$, revealed a significant difference between the posttest scores of LS students across the three treatment groups. As expected, the LS students using SAG mode performed significantly better than LS students using CAG mode and MSG mode, whereas LS students using CAG mode performed significantly better than LS students using MSG mode.

DISCUSSION

Significantly better performance of SAG group provides evidence supporting the cognitive benefits of segmented animation, in accordance with cognitive theory of multimedia learning and cognitive load theory. This result concurs with study by a number of multimedia studies (e.g., Fong, 2000; Moreno, 2007; Ahmad Zamzuri & Ahmad Rizal Madar, 2010; Fong & Lily, 2010) reporting the greater effects of segmented animated graphics on facilitating conceptual understanding and knowledge transfer. The SAG mode with pause seemingly allows students to process the continuous flow of information chunk by chunk without perceptual and conceptual overload, hence optimizing their cognitive capacities for information processing (Fong & Lily, 2010). In other words, learners have sufficient time to organize the selected information from one segment into coherent mental models and integrate them with existing schemas effectively before moving to the next segment (Mayer, 2005). Construction of internal representation is thus facilitated, resulting in better comprehension. Furthermore, the SAG mode provides the students a minimal control of the learning space, stimulating them to invest cognitive resources for germane load. According to Paas, Renkl and Sweller (2003), with a substantial amount of germane load, knowledge elements being processed by working memory are most effectively stored in the long-term memory. Learners' ability to retrieve knowledge and transfer into application is thus maximized.

In a closer comparison of static and animated graphics, the finding implies that the CAG mode could reduce the students' processing demands by providing them with an explicit and dynamic external representation (Rieber & Kini, 1991). On the contrary, when interacting with the MSG mode, learners need to expend more efforts for germane load, such as inferring transition between frames and subsequently combining them into smooth event (Betrancourt, Dillenbourg & Clavien, 2008). Despite that a certain amount of germane load being added over intrinsic load is expected to maximize learning (Paas et al., 2003), but since memory capacity is limited, these so-called "good" processes may overload working memory and so inhibit learning (de Jong, 2010).

While presenting electrolysis process as a sequence of discrete parts via the SAG and MSG mode which is believed to be more congruent with learners' mental representations (Hegarty et al., 2003), the SAG group was likely to significantly outperform the MSG group. Perhaps, because of its two perceptual attributes beyond the MSG mode – motion and trajectory (Klein, 1987), the SAG mode offers learners a more relevant external representation, allowing learners to easily develop accurate mental models, thus saving more cognitive capacities for deeper learning of the knowledge domain.

The study also highlighted that there was a correlation between spatial ability and electrolysis learning process, that is, HS students significantly performed better than LS students. This could be a consequence of inadequate and irrelevant visual details being encoded in their mental representations (Hegarty & Waller, 2004) or limited cognitive capacities that are available for essential processing (Miyake & Shah, 1999) or both. Nevertheless, the learning of electrolysis among the LS students was most significantly promoted when they interacted with the SAG mode, as compared to the CAG and the MSG mode. The SAG mode seemingly compensates for their insufficient visualization skills and limited cognitive capacity by offering them an external representation which simplifies information processing on the one hand and devotes valuable cognitive capacities to essential cognitive tasks at the other hand (Moreno, 2007).

IMPLICATIONS OF THE RESEARCH STUDY

The information provided from the findings of this study has several theoretical implications. Firstly, the significant positive effect of the SAG mode over the CAG and MSG modes supported the so-called segmenting principle by Mayer's (2005). Secondly, the finding reinforces Sweller's cognitive load theory that segmenting an animated graphics could avoid additional cognitive activities that are unnecessary for comprehending the domain concepts or knowledge. The third theoretical implication of this study lies in the contribution of its findings to the growing body of knowledge. The significant differences of post scores among students using the SAG, CAG and MSG modes implied that segmented animated graphics can be most effective at promoting learning of abstract chemical processes especially for low spatial learners.

Furthermore, the study demonstrated that the integration of segmented animated graphics by chemistry educators within science lesson for secondary school students is practicable. Chunking an animated graphics can be done easily using some freely available tools in the market (e.g., Camtasia Studio 7.0 trial version, Window Movie Maker).

RECOMMENDATION FOR FUTURE RESEARCH

This study raised several interesting issues that are worthy of further research. First, future studies should investigate the robustness of the current findings by testing student performance under delayed conditions. Second, it would be particularly interesting to examine learners' engagement in the different treatment groups by using qualitative method, such as observations or interviews. Third, since this study involved only novice chemistry learners, further study that focuses on experienced learners is deemed interesting. Finally, the interaction effects of different graphical presentations can be extended to other learners' characteristics, such as locus of control, anxiety levels and field dependency. Fifth, further study focusing on the segment length, display speed, level of learners' control and pause between segments is indeed needed.

CONCLUSIONS

This study found that learning from segmented animated graphics is significantly better than learning from continuous animated graphics and multiple static graphics. Presenting an animated graphics chunk by chunk seemingly saves cognitive capacities for deeper cognitive processes. Segmented animated graphics is particularly helpful for low spatial learners who possess insufficient cognitive abilities for spatially related learning tasks. Segmenting an animated graphics seemingly allows low spatials to learn chunk by chunk, minimizing cognitive demands, optimizing their cognitive abilities for information processing and thus resulting in better learning. It is suggested that instructional designers should take into consideration the segmenting principle when using animated graphics to present learning materials, particularly among low spatial learners.

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