Does the redundancy effect exist in electronic slideshow assisted lecturing?

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1. Introduction

Electronic slideshows (e.g., PowerPoint) permit the presentation of multiple formats of information including texts, graphics, pictures, animation, and audio materials, terminating the age when the visual information can only be delivered with blackboard in traditional lectures. Projector and projection screen have been the most used teaching aids in normal classroom settings and their advantages were presented in many perspectives, such as being convenient for poor speakers, reducing complicated messages and elevating style over substances (Wright, 2009). However, limited studies focused on exploring whether using electronic slideshows in teaching could indeed be beneficial for the student learning and how the electronic slideshows should be used for benefiting the student learning.
The processes involved in learning multiple sources of information associated with multimedia presentations are discussed by cognitive load theory (e.g., Kalyuga, 2012; Sweller, Ayres, & Kalyuga, 2011), which may relate to the effects of using electronic slideshows on learning as well as to the design principles for developing slideshow materials. Cognitive load theory (CLT) is an instructional design theory developed based on contemporary knowledge of human cognitive architecture that involves interrelated working memory and long-term memory components when processing instructional information and constructing new knowledge (Sweller, 2010, 2011, 2012; Sweller et al., 2011; Van Merrienboer & Sweller, 2005). Cognitive load can be defined as the working memory resources that are used to achieve the goals of a learning task (Kalyuga, 2009).

There are two main types of cognitive load. Intrinsic cognitive load is determined by the complexity of learning elements in the subject domain that need to be processed for achieving specific instructional goals and by the learners with specific levels of prior knowledge. Extrinsic cognitive load refers to the efforts required for processing unnecessary information and performing other cognitive activities that are irrelevant to achieving instructional goals due to poor instructional design (Kalyuga, 2012; Sweller, 2010). Being focused on the critical role of processing limitations of working memory in both capacity and duration, CLT suggests that any successful instructional design should control the total cognitive load within the working memory capacity. In recent years, instructional design principles based on CLT have been widely applied in designing digital teaching materials used in various technology-rich learning environments, such as mobile learning (e.g., Liu, Lin, Tsai, & Paas, 2012; Liu, Lin, & Paas, 2013; Liu, Lin, & Paas, 2014), computer assisted language learning (e.g., Liu, Fan, & Paas, 2014; Liu & Lin, 2011) and animations (e.g., De Koning, Tabbers, Rikers, & Paas, 2009, 2010, 2011). These principles are expected to be also used to direct the design of learning materials in the electronic slideshow assisted lecturing.

With the assistance of electronic slideshows, the instructional information can be delivered through both auditory and visual sensory modalities. In many cases, both modalities are used to present the same textual information simultaneously, possibly due to two reasons: (1) it is easy for teachers to copy and paste the instructional materials on the screen and just to read it aloud to the students during lectures, and (2) it is believed that presenting the same information in both modalities accommodates individual differences of students who may choose to listen or to read (Kalyuga, 2012). Such a presentation format is widely used in normal classroom, however, violates the instructional design principle suggested by CLT, resulting in a redundancy effect. The redundancy effect is one of the cognitive load effects that has been demonstrated in many studies (e.g., Chandler & Sweller, 1991; Kalyuga, Chandler, & Sweller, 2004). It occurs when two or more of the presented sources of information could be understood separately on their own without the need of referring to other sources of information (Chandler & Sweller, 1991; Sweller, Van Merrienboer, & Paas, 1998). In this situation, presenting multiple sources of information that just re-describe each other may unnecessarily waste limited working memory resources on processing redundant information and thus impede learning. Some studies have demonstrated redundancy effects by using text-and-audio presentations. For example, Mayer, Heiser, and Lonn (2001) showed that the students who learned with text-and-audio presentations of science-related information performed worse than the students who learned with text or audio-presentations. Using technical, text-based instructions without diagrams (Experiment 3), Kalyuga et al. (2004) also obtained this effect. Learning was facilitated when instructions were presented in spoken form alone rather than both spoken and written forms concurrently. The study of Jamet and Le Bohec (2007) found that the verbal redundancy effect occurred irrespectively whether the redundant written sentences that were accompanied by the identical spoken information were presented sequentially or together.

However, the redundancy effect has not always been demonstrated. Some studies in fact found a reverse redundancy effect. For example, Moreno and Mayer (2002) demonstrated that when no visual diagrams were involved, concurrent presentations of the same spoken and visual text resulted in better learning than spoken-only text. According to Kalyuga (2010), the length of instructional segments may be a significant factor in determining whether redundancy or reverse redundancy effect would occur. In Kalyuga et al.’s (2004) study demonstrating a redundancy effect, the text was presented to participants continuously as a single large chunk of around 350 words without breaks. In contrast, the text used in Moreno and Mayer (2002) study was presented in several consecutive small segments with appropriate breaks between them. Such breaks may have allowed the learners to consolidate their partial mental models constructed from each segment of the text before moving to the next one, thus decreasing the cognitive load and resulting in a reverse redundancy effect.

Although the redundancy effect as a result of presenting the same information in two different modalities have been demonstrated in many empirical studies, most of the studies were conducted in well-controlled laboratory settings or carried out with the participants individually. Both these environments are quite different from the normal classroom in real educational settings. Electronic slideshow assisted lecturing in a normal classroom has two main typical features. First, the information is usually segmented into several sections rather than presented continuously due to the low resolution and limited space typical to the commonly used electronic slideshows. Second, the classmates sitting around may potentially create some sources of interference. In this situation, an important question related to successful use of electronic slideshows in a normal classroom is whether the characteristics of such slideshows would influence the occurrence of the redundancy effect or, in other words, whether the redundancy effect observed in the experimental environments could also be applicable in normal classrooms.

The current study aimed at exploring this question by examining the occurrence of the redundancy effect in a real, normal classroom environment when presenting multiple formats of information with the assistance of electronic slideshows. The hypothesis tested in the current study was based on the conditions for producing the audiovisual redundancy effect and the features of electronic slideshow assisted lecturing in normal classrooms. Redundancy effect occurs when learners simultaneously process similar information from different sources and this information is characterized by
sufficiently high levels of element interactivity. Element interactivity refers to the degree to which a concept or procedure can or cannot be understood when its elements are processed in isolation. Information with high levels of element interactivity consists of heavily interdependent elements that cannot be learned in isolation (Sweller, 2010). Therefore, whether the information can actually be understood separately without the need for integrating the two sources and whether the element interactivity associated with the information is sufficient to exceed working memory limitation become the critical factors in determining the presence or absence of the redundancy effect. If the redundancy effect applies to the electronic slideshow assisted lecturing, learning with on-screen displayed text accompanied by narration should result in worse performance and higher cognitive load than learning with either on-screen text only or narration only.

However, the above results could be expected only for the learning in strictly controlled learning environment where no interference will affect the learning with only one source and for textual materials involving high levels of element interactivity (i.e. high intrinsic cognitive load). For the normal classroom involving dozens of students, unavoidable interferences from the behaviors produced by classmates and teacher may distract students from learning. The information could potentially be missed if it presented only in one source. Therefore, contrary to the redundancy effect, it is expected that presenting the information in both modalities could be beneficial even when one source cannot be understood without reference to the other source. Likewise, for the textual materials that are segmented in relatively simple fragments with low levels of element interactivity that are easy to understand, a reverse redundancy effect could be also observed. If the text shown on the electronic slideshows in a realistic classroom lecturing situation is thoroughly segmented to avoid high levels of element interactivity, the simultaneous presentation of written text and narration could complement each other, and learning with written text and narration could be expected to result in better performance and have lower cognitive load than learning with written text only.

In fact, conducting an experiment to test the above hypothesis in a normal classroom is very challenging due to difficulties in controlling the confounded variables. Using a virtual classroom that simulates normal classroom is a potential method to overcome this challenge (Rizzo, Parsons, Kenny, & Buckwalter, 2012). A virtual classroom could be constructed with the virtual reality technology that can simulate physical presence in places in the “real world” or imagined worlds. The virtual classroom with high vividness has been applied for training professional skills such as clinical assessment in neuropsychology (e.g., Rizzo et al., 2000, 2006). Blascovich et al. (2002) indicated that using virtual environment (e.g., a virtual classroom) as an empirical study platform to conduct research could offer some benefits. Firstly, the trade-off between realism and control of the ecological factors can be solved and the validity of the findings can be largely improved. Secondly, the perfect replications of studies are possible. Thirdly, participants’ responses to the treatment or their learning processes can be easily recorded.

Virtual classrooms have already been used in many studies, for example, in the studies assessing children with attention deficit/hyperactivity disorder (ADHD) (e.g., Diaz-Orueta et al., 2014; Rizzo et al., 2006, 2012). These studies indicated that virtual classrooms could bring higher ecological validity of the results than other assessment instruments (Diaz-Orueta et al., 2014). Based on the empirical studies with virtual classrooms, it is believed that examining the redundancy effect in electronic slideshow assisted lecturing with the use of the virtual classroom as an empirical study platform could bring the results that are similar to those found in the normal classrooms.

2. Method

2.1. Participants and design

One hundred and twenty undergraduates and graduated students (75 males, 45 females) with an average age of 23.41 (SD: 4.14) from northern Taiwan participated in this experiment. The majors of the participants were diverse, including Engineering, Literature, Physics, Chemistry, Management, and so on. They all had no prior exposure to a virtual classroom environment.

A between-subject experimental design was used to explore the redundancy effect in electronic slideshow assisted lecturing. Different experimental conditions associated with presentation formats represented a between-subject factor. There were three experimental conditions in the current study: an audio only condition in which the information was only narrated by the virtual teacher without any text presented on the slides; a visual only condition in which the information was only presented in written form without assistance of any spoken explanations; and an audio-visual condition in which the same textual information was presented to the learners in both written (presented on the slides) and spoken (narrated by the teacher) forms simultaneously. The information presented to all three conditions during the experiment was identical except different formats of delivery. The participants were randomly assigned to the three experimental conditions, 40 in each group.

2.2. Experimental environment

The current experiment was conducted in the virtual classroom environment, which was developed by the research team of the current study based on a head-mounted display (HMD) VR system of Unity 4.2.3 (Unity Technologies, http://unity3d.com/unity). A normal university classroom was chosen as the model for building the virtual classroom, in which all devices (e.g., laptop, projection screen) and furniture (e.g., desks, chairs, windows, etc.) were replicated from the real model classroom. Specifically, a female virtual teacher and 23 virtual students were included in the virtual classroom, with the teacher standing at the left front of the classroom and the students sitting on their seats. Directly in front of the students was a
projector screen hanging on the wall. Like the real model classroom, textbooks and pens were set up on the students’ desks. The scenes outside were also constructed according to the model real classroom, the natural scene including trees, blue sky and white cloud being outside of the left window of the virtual classroom and a passage of the building being outside of the right window.

All actions of the virtual teacher and students were designed referring to real situations in the normal classroom. Specifically, the gestures that the virtual teacher made when delivering her lecture could be often seen in a normal classroom. Likewise, the virtual students also behaved according to what they usually do in a normal classroom, such as raising and lowering their heads, shaking their heads, taking notes. The participant was located at the 4th middle row seat in the virtual classroom and four virtual students (classmates) were sitting around him. Fig. 1(a & b) represents a screenshot of the virtual classroom and the place at which the participant is located.

The vividness of this virtual classroom had been examined before the experiment with twenty undergraduates and graduated students who then did not participate in the formal experiment. The measurement was adopted from Witmer and Singer Presence Questionnaire compelled to measure a person’s immersive tendencies (Witmer & Singer, 1998), composing of 10-item Likert type seven-point rating scales (from very very low to very very high). The participants were asked to rate the sense of reality on the scales for different items (such as virtual students, classroom environment, etc.) existed in the virtual classroom, the highest score for each item being 7 points and the lowest score being 1 point. The mean of the 10-item ratings was 5.6 (SD = 1.21) indicating that the vividness of the virtual classroom was at a satisfactory level.

2.3. Experimental material

The experimental material used in the current experiment was composed of two short stories adapted from the Logical Memory test in Wechsler Memory Scale – Third Edition (WMS-III) (Wechsler, 1997), which is a test designed to measure auditory immediate memory in adults and older adolescents. This material was selected because it did not require any additional information (e.g., visuals) for understanding and participants’ prior knowledge had little effect on recalling and
comprehending the stories. Fig. 2 provides the examples for each of the three presentation formats (experimental conditions). In the audio-only condition, the stories were narrated by the virtual teacher and there was nothing on the screen. In the visual-only condition, the text was presented on the screen slide by slide without spoken information assisting. In the audio-visual condition, the stories were narrated by the virtual teacher and the corresponding text was also presented on the screen at the same time. Story A used the following scenario: “Ms. Chan is an undergraduate who are interested in on line shopping. One day, she received a coupon from an on line shopping store and she wanted to use the coupon to buy a gift for her mother with better price. She took some strategies to achieve her purpose ...”. Story B was developed following this scenario: “Ms. Cheng is a clothes store manager. On a very bad weather day, she had a traffic accident when she was on the way to replenish her products. Some parts of her car were broken and she was injured in this accident ...”. Both stories were presented in participants’ native language —

**Fig. 2.** The examples of presentation formats for three experimental conditions. (a) Condition 1: Audio only presentation. (b) Condition 2: Visual only presentation. (c) Condition 3: Audio-visual presentation.
Chinese, a total 161 Chinese characters for story A and 160 characters for story B. For the conditions with visual presentation format (visual-only & audio-visual conditions), each story was segmented to be presented on three slides, 46, 36, and 79 Chinese characters respectively for story A and 42, 45, and 73 for story B. The time used for presenting the materials was equalized in different conditions according to the length of audio-only presentation (48 s and 50 s for the two stories respectively), which fell into the normal rate of speech tempo in teaching.

2.4. Measurements

The measurements used in the current study includes a working memory span test, a recall test, a comprehension test, and corresponding subjective ratings of cognitive load associated with the recall and comprehension tests.

2.4.1. Working memory span test

Working memory span test was conducted before the experiment in order to make sure that the participants’ working memory capacity in different conditions are equivalent. As is common in working memory span literature, the digit span test of Wechsler Adult Intelligence Scale-Third Edition (WAIS-III) (Axelrod, Fichtenberg, & Millis, 2006; Suhr, Tranel, Wefel, & Barrash, 1997) was administered. This test includes two parts - forward digit span test (16 items) and backward digit span test (14 items). When administering working memory test, the experimenter read aloud a total of 30 groups of numbers and then asked the participants to quickly repeat them, 16 groups to be repeated in the same order as they were presented (forward digit span test) and 14 groups to be repeated in the reverse order (backward digit span test). An item was considered repeated correctly (with one point allocated) if the output completely matched the presentation. The highest possible score for the test was, therefore, 30 points and the lowest possible score was 0 point. Once more than two groups of numbers in the test were wrongly repeated, the test was stopped irrespective whether it was the forward or the backward digital span test. The digit span test from Wechsler Adult Intelligence Scale-Third Edition (WAIS-III) had been used by a number of empirical studies and were approved a high reliability (Axelrod et al., 2006; Suhr et al., 1997).

2.4.2. Recall test

Recall test was used to measure how much the participants’ could remember about stories. The scoring method was also adopted from the Logical Memory test in Wechsler Memory Scale – Third Edition (WMS-III): One point was given when the specific keywords associated with the stories were said aloud. There were 25 keywords for story A and 27 keywords for story B in total; the highest possible recall test score was therefore 25 for story A and 27 for story B. Kuder-Richardson formula 20 (KR-20) for reliability on the recall test after stories A and B indicated acceptable reliability coefficients of 0.71 and 0.73 respectively.

2.4.3. Comprehension test

Comprehension test was used to investigate how much the students could understand the information provided in the stories after learning. Five-item short questions were developed for testing the comprehension of story A, only one key point being involved in the correct answer of each question. The questions were answered orally. One mark was given for a correct-answered key point and therefore, the full mark of the comprehension test for story A was 5. To answer these questions, participants should be able to actively operate on the information kept in working memory. For example, when responding to Question 5 for story A “How much did Ms. Chang pay for the vacuum bottle?”, participants should select the relevant information regarding the price of this vacuum and the value of the coupon from their working memory, and then do the necessary calculations. Comprehension test for story B included seven short questions, with one to three key points being involved in the correct answer of each question. The total number of key points in the answers for the comprehension test questions for story B was 12, and the highest possible score for story B was therefore 12 points. The internal consistency reliability coefficient (KR-20) of the comprehension test was 0.68 for story A and 0.74 for story B.

2.4.4. Cognitive load rating scales

Cognitive load subjective rating scales were used to measure participants’ perceived cognitive load in responding to the recall test and comprehension test. The rating scale referring to the cognitive load yielded during cognitive activities, originally designed by Paas and Van Merriënboer (1994), was separately used for each story in the present study. For each story, participants were asked “How much effort did you spend on recalling the contents of the story?” immediately after the recall test and “How much effort did you spend on correctly answering the items?” immediately after the comprehension test. Each item was presented as the Likert type nine-point scale, with 1 being very very very low and 9 being very very very high. Accordingly, the highest level of cognitive load corresponded to 9 points and the lowest level was 1.

2.5. Procedures

The whole experiment included three phases: pre-experimental phase, intervention and test phase for story A, and intervention and test phase for story B (see Fig. 3, for a schematic representation of the procedure). The procedure was identical for all participants except different presentation formats used during intervention phase in different experimental conditions. All participants participated in each phase individually.
2.5.1. Pre-experimental phase

Before conducting the experiment, a working memory span test was firstly administered to measure the participants’ working memory capacity in different conditions. The average time spent on completing the working memory span test was 7 min. After the working memory span test, the participants were required to make preparations for the experiment, including inputting their demographic information, wearing the Head Mounted Displays (HMDs) with the assistance of experimenters, looking at the screen in the virtual classroom for calibration, and accommodating themselves to the experimental environment. The experimenters needed to calibrate the equipment for eliminating the participants’ novelty feeling, making sure that the participants feel comfortable with the environment. The average time spent on the experiment preparation was about 5 min.

2.5.2. Intervention and test phase for story A

After taking a working memory span test and making preparation for the experiment, the participants were given the specific type of presentation that corresponded to the experimental condition they had been assigned to. The participants in the audio only presentation condition were asked to listen to the narration of the learning materials of story A. The participants in the visual only presentation condition were asked to read the texts of story A shown on the screen slide by slide. The participants in the audio-visual presentation condition were asked to read the stories shown on the screen and simultaneously listen to the narration of the stories. Before the story started, the participants had been advised to do their best to remember and to comprehend the story. They were not allowed to control the presentation pace just like in most situations in the normal classroom. The story A in all the conditions was shown only once and the participants were not allowed to read or hear the story again.
The tests for story A immediately followed the presentation of this story. Both tests were answered orally. The first recall test was implemented immediately after the story A had ended. After the participants had completed the recall test for story A, they were asked to rate their effort in performing this test on a computer. The participants were then asked to take the comprehension test for story A followed by rating the mental effort involved in performing this test.

2.5.3. Intervention and test phase for story B
The same procedure related to the intervention and the tests (recall and the comprehension tests) was conducted again for story B.

3. Results

The independent variable in this study was the experimental condition (presentation format), while dependent variables included participants’ performance on the recall and the comprehension tests, and the associated self-ratings of cognitive load. Participants’ performance (number recall accuracy scores) on working memory span test was analyzed first to investigate any difference between experimental groups in working memory capacity before the experiment. Statistical significance for all tests was set at 0.05 level except when especially indicated. Partial \( \eta^2 \) was used as the effect size index. Accordingly, 0.01, 0.06 and 0.14 are considered as the \( \eta^2 \) values for small, medium and large effect sizes.

3.1. Working memory span test

A one-way analysis of variance (ANOVA) for the number recall accuracy scores during working memory span test was conducted. Table 1 shows the means and standard deviations for working memory span test performance for the three experiment conditions. No significant difference between the three conditions was found, \( F(2, 117) = 2.67, Mse = 12.44, p < .05, \eta^2_p = 0.06 \), indicating that the participants in different experimental groups were equal in their working memory capacity and the individual differences in this capacity could not cause any difference between the groups in the following learning activities. Based on these results, it was decided not to use the working memory span test scores in any other analyses of the present study.

3.2. Test performance and cognitive load during the recall test

One-way analyses of variance (ANOVAs) were separately carried out for the recall test results (keywords accuracy scores) following story A and story B and corresponding cognitive load self-ratings. Table 2 provides the means and standard deviations for the three experimental conditions for stories A and B.

For the recall test for story A, the result revealed a significant effect of experimental condition for both test performance, \( F(2, 117) = 3.70, Mse = 12.44, p < .05, \eta^2_p = 0.06 \), and cognitive load self-rating, \( F(2, 117) = 7.25, Mse = 2.93, p < .01, \eta^2_p = 0.11 \). The LSD post-hoc analysis results showed that the audio-visual condition significantly outperformed audio only condition with higher recall accuracy scores and lower cognitive load self-ratings. However, when comparing with visual only condition, this advantage of the audio-visual condition only existed for the recall accuracy scores; there was no difference between these groups for cognitive load self-ratings. Also, both the visual only and audio-visual conditions reported a significant lower cognitive load than the audio only condition in the recall test for Story A, although no significant difference was found between these two conditions for the test scores. For the recall test for story B, the results also showed a significant effect of experimental condition for both recall accuracy scores, \( F(2, 117) = 4.27, Mse = 17.60, p < .05, \eta^2_p = 0.07 \), and cognitive load self-

<table>
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<tr>
<th>Variable</th>
<th>Audio only ((n = 40))</th>
<th>Visual only ((n = 40))</th>
<th>Audio-visual ((n = 40))</th>
</tr>
</thead>
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<tr>
<td></td>
<td>( M )</td>
<td>SD</td>
<td>( M )</td>
</tr>
<tr>
<td>Working memory span</td>
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<td>3.97</td>
<td>23.55</td>
</tr>
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</table>

Table 1

The means and standard deviations for keywords recall accuracy score and cognitive load subjective ratings during recall test.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Audio only ((n = 40))</th>
<th>Visual only ((n = 40))</th>
<th>Audio-visual ((n = 40))</th>
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<td>SD</td>
<td>( M )</td>
</tr>
<tr>
<td>Story A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recall performance (0–25)</td>
<td>12.93</td>
<td>3.53</td>
<td>12.73</td>
</tr>
<tr>
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<td>5.83</td>
<td>1.63</td>
<td>4.78</td>
</tr>
<tr>
<td>Story B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recall performance (0–27)</td>
<td>13.43</td>
<td>4.45</td>
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<tr>
<td>Cognitive load in recall test (1–9)</td>
<td>5.68</td>
<td>1.46</td>
<td>4.75</td>
</tr>
</tbody>
</table>
ratings, $F(2, 117) = 8.49$, $Mse = 3.41$, $p < .001$, $\eta^2_{p} = 0.13$. The LSD post-hoc analysis results revealed a perfectly consistent picture with the results of story A: audio-visual condition showed significantly higher recall accuracy scores and lower cognitive load self-ratings than the audio only condition, but it outperformed visual only condition only on recall accuracy scores.

3.3. Test performance and cognitive load during the comprehension test

Similar analyses to those used for recall test data were performed with question scores and cognitive load self-ratings for comprehension test. Table 3 shows the corresponding means and standard deviations for the three experiment conditions for both stories A and B.

For the comprehension test for story A, ANOVA showed a significant effect of experimental condition for both short question scores, $F(2, 117) = 4.58$, $Mse = 1.23$, $p < .05$, $\eta^2_{p} = 0.07$, and cognitive load self-ratings, $F(2, 117) = 8.19$, $Mse = 3.76$, $p < .001$, $\eta^2_{p} = 0.12$. The LSD post-hoc analysis results revealed that the audio-visual condition performed significantly better than the other two conditions (audio only and visual only conditions) with a higher short question scores and lower cognitive load self-ratings.

The comprehension test for story B also indicated results consistent with those for story A, revealing a significant difference between experiment conditions for both test scores, $F(2, 117) = 4.18$, $Mse = 4.56$, $p < .05$, $\eta^2_{p} = 0.07$, and cognitive load self-ratings, $F(2, 117) = 6.27$, $Mse = 2.58$, $p < .01$, $\eta^2_{p} = 0.10$. The LSD post-hoc analysis results showed that the audio-visual condition had significantly higher short question scores and lower cognitive load self-ratings than the audio only and the visual only conditions.

4. Discussion

The overall goal of the present study was to investigate whether redundancy effect also exists in electronic slideshow assisted lecturing. The aim was achieved by comparing the recall and comprehension of two stories under three presentation formats. The general pattern of results obtained in this experiment using a virtual classroom simulating real normal classroom as an experimental study platform is in accordance with those of Moreno and Mayer (2002). A reverse audiovisual redundancy effect was obtained for most dependent variables thus supporting the hypotheses formulated for real normal classroom environments in which the simultaneous presentation of written text and narration could complement each other with written on-screen text providing an easy-to-follow back-up for narrated textual information. As a result, learning with written text and narration resulted in better performance with lower cognitive load than learning with written or narrated text only.

There could be two possible reasons for the reverse redundancy effect in the present study. One could be related to the interferences replicated from the real classroom that might result in students missing some of the essential information delivered by only one source. In the current experiment, the virtual classroom replicated a real, normal classroom involving twenty-three students. The behaviors of the virtual students and teacher were also replicated according to what they usually do in a normal classroom, such as raising and lowering their heads, shaking their heads, taking notes. The existence of the classmates and teacher as well as their behaviors provided the potential sources of interference to the participants sitting among them. For the experimental conditions with only one presentation format, once the students were distracted from attending the single source of information, no other source could be used to retrieve the missed information for understanding. Especially for the audio only condition in which the information was only narrated by the teacher without any other source for reference, students required close attention in order to understand the fleeting spoken messages. On the one hand, concentration was needed for receiving the complete, clear audio information in sensory memory; any interference might result in the omission of parts of the incoming information. On the other hand, students needed to encode and process the information in working memory for understanding within very limited time according to the speaker pace. If the processing of one sentence from the teacher was interrupted or delayed by any interference, the students could have difficulties with perceiving and processing the next sentence.

Most importantly, as auditory information is transitory in nature, it might impose overwhelming cognitive load on learners in the audio only condition. They would need to keep the recent information in their working memory and integrate

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<tbody>
<tr>
<td></td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
</tr>
<tr>
<td>Story A</td>
<td></td>
<td></td>
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<td>Comprehension performance (0–5)</td>
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<td>Cognitive load in comprehension test (1–9)</td>
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<td>1.69</td>
<td>5.73</td>
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<tr>
<td>Story B</td>
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<td></td>
<td></td>
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<tr>
<td>Comprehension performance (0–12)</td>
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</table>
it with newly received information for understanding, resulting in a transient information effect (Leahy & Sweller, 2011). Cognitive load associated with processing auditory information in a learning environment with potential interference might significantly increase and inhibit learning. The higher ratings of cognitive load in the audio only condition, as well as it’s lower performance scores in the recall test proved the assumption about the influence of potential interference in real classroom on learning with only audio presentations. For the visual only condition, although the on-screen text was theoretically accessible for returned inspections if more understanding was needed, in the current experiment, the presentation time for this information was consistent with the audio presentation pace and therefore, the students had no much time to read and process the on-screen information over and over. Similar to the audio only format, if the students lost some information due to interference or cognitive overload, no stable back-up source was provided for reference.

In contrast, for the audio-visual condition, both formats were presented simultaneously and supplementary to each other. If the students lost some audio information because of inference or transience, they could retrieve what they had lost from visually presented information and achieve understanding. Similarly, if they were distracted from reading the on-screen information due to interference, the narrations from teacher could re-concentrate their minds on incoming information. In the learning environment close to a real classroom involving some natural, unavoidable interference, the two sources provided more readily available information for processing. Their complementary effect decreased the heavy cognitive demands when receiving, retrieving, and integrating the incoming information under interference conditions, and thus benefited learning.

One of the limitations of the present study was that the degree of the interference that existed in the current experiment was not directly examined and it might be weak for the interference sources only from the existence and behaviors of classmates and teacher (e.g., a stronger degree of interference could be triggered by auditory sources). However, the reverse redundancy effect was robust even with such potentially weaker interference sources. The lower test performance scores associated with higher self-rated cognitive load in both recall and comprehension tests, and the intentionally implemented features of real classroom interferences in contrast to the laboratory settings provided evidence for the above explanations of the reverse redundancy effect in the present study. Future studies should involve more focused investigation of interference in the virtual classroom, for example, by doing qualitative surveys to learn whether the difficulties reported by the students following the presentation with only one format come from interference. Future work can also learn more about the effect of interference on the redundancy effects by manually controlling the degree of interference. Specifically, it can be explored whether the redundancy effect found in the laboratory settings could disappear and eventually reverse with the increased levels of interference. Also, the influence of auditory interference sources needs to be investigated in our future studies related to virtual/normal classroom environments.

Another possible reason for the reverse redundancy effect in the present study could be related to the segmented presentation of information with decreased levels of element interactivity used in this experiment. Cognitive load theory suggested that any cognitive load effect could only be obtained when intrinsic cognitive load is sufficiently high (Sweller, 2010; Sweller & Chandler, 1994). When the element interactivity associated with intrinsic load is low, the total cognitive load may be still below working memory capacity, and therefore, the manner in which the material is presented may not be important. In the current study, the materials were mostly based on common everyday language that was relatively low in element interactivity (i.e. imposed low intrinsic cognitive load) by its nature. Therefore, especially when segmented, these materials were easy to understand in spoken form, and providing some visual back-up for factual information was expectedly beneficial for learners. Sweller and Chandler (1994) found that when instructing students to use computer work-processing packages for complex computer-aided design/manufacture (CAD/CAM) programs, for materials that were characterized by low levels of element interactivity and, consequently, low intrinsic cognitive load, the formats of presentation that resulted in a high extraneous cognitive load, would not be a critical factor for learning. However, in the present study, inspection of means revealed that average of only 50.8% for accuracy scores was associated with an average of 5.18 (out of 9) for cognitive load self-ratings during tests, thus indicating that the learning materials (stories A & B) were not so effortless for the students that they could be remembered and understood regardless of presentation formats, even if the cognitive load associated with element interactivity of the two stories might have been decreased by segmenting them into small parts.

In addition, it should be noted that the segmented presentation of information was not an intentional instructional method to reduce cognitive load as those used in the Moreno and Mayer (2002)’s study (Experiment 1), but only because of the limited size of the screen. The information presented in each segment of Moreno and Mayer (2002) was no longer than short sentences including only 9 to 26 words, however, the information presented in each segment of the present study contained on average more than 50 (the range of 36–79) Chinese characters (a character usually stands for a word). Participants in the present study perceived significantly more information at one time than participants in the Moreno and Mayer (2002). According to the laboratory-based study of Kalyuga et al. (2004), such relatively longer pieces of text would normally overload learner working memory resulting in a standard redundancy effect. Under these conditions, interference might be a more plausible and significant factor resulting in a reverse redundancy effect in the present study.

Both possible reasons for the reverse redundancy effect (interference in the real classroom and presentation of segmented information) were tested in one experiment, constituting another limitation in the present study. Although the results indicate that the classroom interference is more likely to be responsible for the reverse redundancy effect, future research studies need to experimentally separate these factors to find out which one is precisely responsible for the absence of redundancy effect in a learning environment close to real classroom.
5. Conclusion

The present study examined the redundancy effect in electronic slideshow assisted classroom environment using virtual classroom technology. Classroom interference and segmented presentation as two important characteristics of a real classroom that were different from the laboratory experimental settings were hypothesized to be two possible factors in determining the presence or absence of the redundancy effect. Using a cognitive load approach, the presentation formats with spoken narration or written text were compared with the presentation format that used both these forms. The results demonstrated a reverse redundancy effect in the simulated real classroom conditions. The presentation of on-screen textual information accompanied by spoken narrations outperformed the presentation with either of these two sources. Inspection of the means indicated that classroom interference was a more plausible explanation for the reverse redundancy effect. Under conditions of classroom interference, both sources could provide more back-up for factual information and thus benefit learning. The results of this research may have general implications for using electronic slideshows. In the real classroom, interference may inhibit learning from only one source, and it could be more beneficial to present information in both spoken and written forms.

In summary, the virtual classroom that is constructed with virtual reality technology has been successfully used for the assessment and rehabilitation of students with attention deficits (e.g., Díaz-Orueta et al., 2013; Rizzo et al., 2006, 2012). Different from the use of the virtual classroom in special education, this study showed potential value of applying the virtual classroom as the research platform to investigate cognitive load factors. The use of the virtual classroom may also successfully bridge the gap between research studies in laboratory and real classroom conditions. As the first study in exploring cognitive load issues in the virtual classroom, this study used simple verbal material rather than more sophisticated multimedia presentations as the experimental materials. The multimedia materials which are widely used in the real classrooms will be selected as learning materials in our future studies (with measures of transfer and long-term recall performance used in posttests).

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