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A Study of Applying Cognitive Load Theory to Science Education Websites

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Abstract— This study employed three units, "Air and Combustion," "Heat Effects on Substances," and "Healthy Diet" from the Science Education Website set up by the Ministry of Education (Tainan, Taiwan) to assist students' learning. This multifunctional website offers teaching resources, interesting experiments, inquiry experiments, virtual animations, multi-assessments, and supplementary materials, all of which are highly interactive and simulative. Cognitive Load Theory was adopted in this study to investigate the influences on learning achievement under distinct multimedia combinations and learner-controlled modes. The sampled subjects in this study were six classes of fifth graders (n=192). Our findings were: (1) Learner-controlled modes were significantly influential; (2) Multimedia combination forms also had obvious influences on learning effects, with the "animation + narration" group identified as performing evidently better than the "animation + subtitles" group. That is, even though the animated subject matter was broken down under the Segmentation Principle, multimedia combination forms still had an influence on learning achievement, indicating that the modality effect always exists. In conclusion, inappropriate A/V combinations may interfere with learning, and more functions and information input do not guarantee better learning effects.

Index Term — cognitive load theory, multi-media combination modules, learner-controlled modules, learning effect

I. INTRODUCTION

Nowadays, almost all schools are devoting themselves to integrating information into teaching activities and experiments in all subject areas; yet, seldom do they notice the potential problems related to cognitive load. Cognitive Load Theory (CLT) was first proposed in the early 1980s and developed rapidly in the 1990s as it gained increasing attention from researchers (Paas, Renkl, & Sweller, 2003). In recent years, there have been new cross-field applications and studies, for example in biology, neuron research, and the cognitive sciences of the human brain (Sweller, 2009; Gog, Paas, Marcus, Ayres, & Sweller, 2009; Kirschner, Paas, & Kirschner, 2009; Gerjets, Scheiter, & Cierniak, 2009). In addition, CLT has been connected with the application of self-adjustment and exploring learning approaches in educational psychology (van Merriënboer & Sluijsmans, 2009; Renkl, Hilbert, & Schworm, 2009).

CLT holds that teaching designs should take into careful consideration human cognitive structures and the possible limits which exist when pursuing efficiency (Paas, Renkl, & Sweller, 2003). It further reveals different sources of load in working memory (Brunken, Plass, & Leutner, 2003; Paas, Renkl, & Sweller, 2003; Sweller, 1999; Sweller, van Merrienboer, & Paas, 1998), including the complexity of the subject matter (intrinsic cognitive load), teaching designs (extraneous cognitive load), and the total efforts (germane cognitive load) made when learning. Germane cognitive load will appear when extra or excessive information such as exegeses or reviews are given to students. If inappropriate teaching designs are employed, additional extraneous cognitive load will result and lead to a decline in learning. The cognitive capacity limit of learners will be exceeded if the given information is strange, excessive, or if it brings intrinsic cognitive load due to the complexity of the teaching materials (Sweller, Chandler, & Cooper, 1990). Thus, proper material presentation can not only diminish extraneous cognitive load but can also help learners concentrate on the subtleties of the subject matter, integration, and building up schemas (Brüken, Plass, & Leutner, 2003). The correlations among three kinds of cognitive load are shown in Fig. 1.

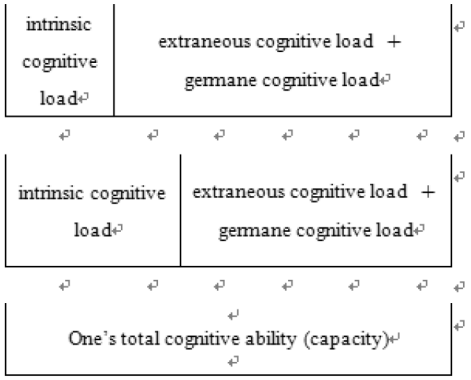

Fig. 1 Correlations among three kinds of cognitive load

There are many literatures bearing researches about how multimedia combinations and their presentation ways affect learners, and how much cognitive load and achievement have been made during the learning process. Most literatures reveal that combinations of multimedia e-materials create modality effect (Mayer, 2001; Penny, 1989; Sweller, 2003b; Tindall-Ford, Chandler & Sweller, 1997); namely, if different information processing channels (i.e. animation + narration) are triggered to receive the information presented via multimedia, the learning effects

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will be better than the ones from single processing channel (i.e. subtitles).

Related researches about information processing have confirmed that students can obtain better achievement from animation/auditory text than the one from animation/visual text (Chen Huei-fang, Fan Yi-wun, 2000; Wong Jia-hong, 2001; Tindall-Ford, Chandler & Sweller, 1997; Moreno & Mayer, 1999) since the former adopts dual information processing channels while the latter utilizes only single channel. Therefore, that the forms of multimedia e-material combinations bring influences onto learning effects, and inappropriate multimedia combinations or unnecessary information may put extra cognitive load on learners has been regarded as an evident fact in related studies. In short, dual-channel information presentation is better than single-channel information presentation for achieving better teaching/learning effects.

At presence, due to the improvement of both hard and soft wares for computers, the e-materials are not only presented in a form of multimedia, but also at a faster speed, which enriches the e-teaching materials and powers them to step into the area of animation. However, studies of Mayer and Moreno (2003) point out that if the content of multimedia is presented in a too fast speed, the total amount of information will overpass the cognitive capacity of learners, which may cause a decline of learning effects as there is not enough time for learners to make deep comprehension over the content presented. The research results of Mayer and Chandler (2001) point out that to weaken negative impacts brought by the abundant information from multimedia, content segmenting and learner-controlled schedules are more reliable for creating better achievement than a nonstop information input might be able to. In addition, Mayer and Moreno (2003) proposed segmentation principles for multimedia designs, indicating that dividing the content into small units of info-input and providing learners with self-controlled schedules are more likely to enable learners to effectively allocate and dominate cognitive resources; thus, better learning effects may be obtained. This idea is called Segment Effect (Mayer & Moreno, 2003). However, what is the correlation may be between the modality effect from different media combinations and the functions of learner-control? This is exactly one of the t motives for this study.

Furthermore, do the teaching materials produced with Mayer and Moreno's (2003) segmenting principle and learner-controlled functions (i.e. replay, pause, page-flipping) simultaneously influence learning effects? So far, no further researches have been found depicted in related literatures. This is the other motive for this study.

Based on the abovementioned research background and motives, the major goal of this study is to explore and test (a) whether the modality effect will be eliminated when the content of multimedia animation teaching materials are divided into several segments according to the segmentation principle after the learners are fully instructed to control (active-control mode, passive-control mode) the timing to get to the next segment; (b) to what extent learner-controlled functions have an influence on learning achievement.

II. METHODOLOGY

The material and methods applied to this study include the research methodology, the operation of the Science Education and Learning Web, and experimental research.

A. Research Method

Via a quasi-experimental research method, this study manipulated two independent variables, (a) learner-controlled playing modes (control mode A and B), and (b) multi-media combination forms (animation + subtitles, animation + narration, and animation + subtitles + narration), to probe the influences on the dependent variables and the students' learning achievement. The research structure is shown as the flow chart in Fig. 2.

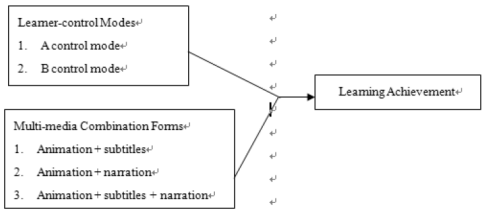

Fig.2. Flowchart of the Research Structure

B. Functions of the Science Education and Learning Web

This website is one of the six major learning webs/science education and learning webs set up by the Ministry of Education in Taiwan. The teaching experiment in this study utilized three instructional units in the said web, namely "Air and Combustion", "Heat Effects on Substances", and "Healthy Diet". All three of these units are considered to have expert validity and content validity as they have received reliable assessment from many science educators and experienced teachers in elementary schools.

C. Forms of multimedia combination

The forms of multimedia combination in this study comprised "animation + subtitles," "animation + subtitles + narration," and "animation + narration." In this study, the instructional animation was divided into several segments depending on the contents. In the form of "animation + subtitles," the subtitles appeared at the bottom of the screen to match the animation (Fig. 3 ~ Fig 5); in the form of "animation + narration," the animation was presented with descriptive narration; in the form of "animation + subtitles + narration," the animation appeared together with narrated subtitles.

Fig. 3 Instructional screen of Air and Combustion

Fig. 4 Instructional screen of Heat Effects on Substances

Fig. 5 Instructional screen of Healthy Diet

D. Learner-controlled Modes

Segments of the instructional animation included "control mode A" with the function of flipping pages (Fig 6) and "control mode B" with only the function of going to the next page (Fig 7).

Fig. 6 Control mode A with the function of flipping pages

Fig. 7 Control mode B with only the function of going to the next page

E. The Experiment

E.1 Experiment Design

The dependent variables in this study are "learner-controlled modes" (control mode A and control mode B) and "multimedia combination modes" (animation + subtitles, animation + subtitles + narration, and animation+narration). To avoid creating deviation in the experiment due to the differences in the sample, repeated-measurement was used for the selected three units: "Air and Combustion", "Heat Effects on Substances", and "Healthy Diet". Every subject in each experiment group was given instructions about the subject matter using all three multi-media combination modes. Each multi-media combination mode delivered instructions only for one of the three units; therefore, this study used a 2×3 dual-factor-mixture experimental design.

E.2 Subjects selected for the experiment

Six classes (A, B, C, D, E, and F) of fifth graders were sampled as the subjects for the experiment, which summed to 250 students. The final number of the samples was 192 after deducting students under extra learning aids and absent ones. All six classes comprise students with normal academic performances. All of these student have basic ability to operate computers and surf the internet since they have had one computer class a week for three years. Researchers of this study randomly assigned classes A, B, and C to be the A control-mode team and classes D, E, and F to be the B control mode team, and then randomly divided each class into three small groups. The first small group from each class (A1, B1, and C1) was then tagged as Group 1 of the A control mode team comprising 32 students. Likewise, as the formation continued, six groups came out of two teams. Thus, we had three pairs of groups; each pair comprised one group from each team. Subject matters contained in three multimedia combination forms were assigned to each pair, respectively. The groupings and topic allocation are shown in Table 1 and Table 2.

TABLE I Grouping for the Experiment

		Multi-media Combination Form (MMCF)		
		animation + subtitles (A+S)	animation + subtitles + narration (A+S+N)	animation + narration (A+N)
Learner-control Mode (LCM)	A control Mode (AC) N1=96	Group1 (A1、B1、C1)	Group 2 (A2、B2、C2)	Group 3 (A3、B3、C3)
	B control Mode (BC) N2=96	Group 4 (D1、E1、F1)	Group 5 (D2、E2、F2)	Group 6 (D3、E3、F3)

TABLE II Allocation of Instruction Units (I.U.) and Multimedia Combination Forms

I.U.		1			2			3		
MMCF / Class		A+S	A+S+N	A+N	A+S	A+S+N	A+N	A+S	A+S+N	A+N
AC Mode	A	A1	A2	A3	A3	A1	A2	A2	A3	A1
	B	B1	B2	B3	B3	B1	B2	B2	B3	B1
	C	C1	C2	C3	C3	C1	C2	C2	C3	C1
BC Mode	D	D1	D2	D3	D3	D1	D2	D2	D3	D1
	E	E1	E2	E3	E3	E1	E2	E2	E3	E1
	F	F1	F2	F3	F3	F1	F2	F2	F3	F1

E.3 Assessment Tools for Learning Achievement

Every unit finished with an assessment to evaluate the students' learning achievement. The test questions were set by the researchers and science advisers from elementary schools in New Tainan City. All twelve questions were in multiple choice forms to test both memory and comprehension, with six questions testing memory and six for comprehension. Every question was awarded one point when correctly answered. Four steps were taken to generate the assessment tools.

(a) Question Planning

Twenty questions were drafted by the researchers according to the subject matter for each of the three units mentioned above.

(b) Pretest

After completing the question planning, a pretest was administered with 68 fifth graders from two classes from a different elementary school in New Tainan City. The results were then analyzed.

(c) Question Choosing

After the analysis, twelve questions with discernment of over .25 and a difficulty degree of between .40~.80 were reserved as the formal questions for each unit. One of the questions is shown hereunder:

( ) 12. The so-called "acid-rain" is actually the rain contains acid. Its pH value should be less than: (①7.0② 6.5③5.6④4.0).

(d) Analysis for Reliability and Validity

The reserved questions with internal consistency, that is with Kuder-Richardson reliability of .826, and an average difficulty degree of .618 were identified and confirmed by experienced science teachers to assure that the test result of each unit was representative.

III DISCUSSION

A. The Influence of "Learner-controlled Mode" on Learning Achievement

In Table 3 are the mean values and standard deviations of learning achievement from the two groups of learners applying AC mode and BC mode and receiving instructions from three kinds of multimedia combinations. What is shown in Table 4 is the summarized result of the variable-analysis over the learner-control modes and multimedia combination forms.

The analytic result in Table 4 indicates that the cross-effect ($F= .59$, $p=.551 > .05$) on the learning achievement from "learner-controlled modes" and "multimedia combination forms" did not reach a significant level; thus a major-effect examination was executed, whose summarized analysis are shown in Table 5, among which the major effect of "learner-controlled modes" was at a significant level ($F=3.112$, $p=.046< .05$), indicating it has evident influence on learning achievement. When examining it together with the data in Table 3, one can find that control mode A was more effective than control mode B for learning.

The learners in both groups controlled the learning schedules in which the instructional multimedia animations had been divided into several segments according to segmentation principles. However, since the A control mode was equipped with the function of flipping pages, which gave the learners greater choice of access, formation, and information integration, the learning effects it created were superior to those generated by the B control mode which only provided the function of going to the next page.

B. The Influence of "Multi-media Combination Form" on Learning Achievement

In Tables 6, the data indicate that the major effects of learning achievement resulting from the different multi-media combination forms differed significantly. The performance of the animation + narration group was evidently better than that of the animation + subtitles group. However, no differences in learning achievement were apparent between the animation + subtitles + narration group and the animation + narration group. This phenomenon suggests that in a learning plot constructed via segmented multimedia animation, the learning effects gained from dual channels (visual and audio) are better than those from a single channel (visual), though each instructional segment brought less intrinsic cognitive load. This is evidence of the modality effect in this case.

TABLE III Mean Values and Standard Deviations of the Learning Achievement from Different LCMs and MMCFs

LCMs	Groups		
	A+S	A+S+N	A+N
ACM	8.10 (2.76)	8.22 (2.54)	8.48 (3.26)
BCM	6.91 (2.53)	7.50 (2.14)	7.59 (2.71)

TABLE IV Summarized Result of the Variable-analysis over the Learner-control Modes and Multimedia Combination Forms

Variable Sources		*SS*	*df*	*MS*	*F*	*p*
LCM (A)	SSa	125.62	1	125.62	10.00**	.002
MMCF (B)	SSb	27.98	2	13.99	3.11*	.046
A×B	SSab	5.38	2	2.69	.59	.551
Deviations	SSs/a	2385.87	190	12.55		
Deviations	SSbs/a	1711.97	380	4.50		

*p<0.05 **p<0.01 ***p<0.001

TABLE V Summarized Variable-analysis of the Major Effects of the Mixed Design

Major Effects	*SS*	*df*	*MS*	*F*	*p*
Learner-control Modes	27.98	2	13.99	3.11	.046*
Deviation	1717.35	382	4.49		
Multi-media combination Forms					
ACM vs. BCM	41.87	1	41.87	10.00	.002*
Deviation	795.29	190	4.18		

*p<0.05

TABLE VI Post-comparisons (Learning Effects) of the Variable-analysis of the Major Effects of the Mixed Design

		Mean Difference (I-J)	Standard Deviation	Significance (a)	Post Hoc
Comparing Method	A+S vs. A+S+N	-.35	.18	.059	(A+S) < (A+N)
	A+S vs. A+N	-.53*	.23	.023	
	A+S+N vs. A+N	-.18	.23	.428	

*p<0.05

IV CONCLUSIONS

A. The influences of "Learner-controlled Mode" on Learning Achievement

Results of the experiment suggest that the cross-effects resulting from "learner-controlled modes" and "multimedia combination forms" on the learning achievement of the students were not significant. Yet, the "learner-controlled mode" alone was significantly influential on learning, and the learning effects via the "active-control mode" were explicitly superior to those via the "passive-control mode." In addition, the "multi-media combination forms" had evident influences on learning achievement. It was revealed that whichever learner-controlled mode was adopted, the outcome was always that the animation + narration group's performance in learning was better than that of the animation + subtitles group. That is, even if the animated subject matter had been divided into small segments, the multimedia combination forms still had an influence on learning achievement. Clearly, the modality effect remains.

B. The influence of "Multimedia Combination Form" on Learning Achievement

This study also indicates that in the situation of playing animations segment by segment, those animations described with simultaneous narration and subtitles did not have an obvious influence on learning, suggesting the redundancy effect. The researchers believe the reason was that when animations, subtitles, and narration were presented at the same time, the amount of information may have been too much for the visual system to process, so the learners may have chosen to temporarily ignore the subtitles and focus on the animations and narration only. According to Mayer's (2001) Multimedia Cognition Theory models, the integration of animation (image model) and narration (word model) is the key for comprehension; animation and narration are processed by different senses, meaning that not only can the material be processed without causing overload for a single sense, but that it is also capable of promoting the effectiveness of info-integration. Therefore, learners are most likely to watch the animation and listen to the narration without necessarily concerning themselves with the connections between the subtitles and animations. So, even though learners may read the subtitles very shortly afterwards, it does not have much influence on the learning effects since the key integration of image and word models has been completed through the simultaneous presentation of animation and narration. This result reasonably explains why the animation + subtitles + narration mode does not have a great effect on learning achievement.

From the learning achievement results we found that after the animations were divided into small segments according to segmentation principles, both the "learner-control modes" and the "multi-media combination forms" had an influence on learning achievement. Moreover, describing the animations via subtitles had the least effect, while presenting animations with matching narration was the most effective in terms of promoting learning effects. This shows that inappropriate audio-video combinations may interfere with learning effects, suggesting that more functions and information do not always bring better learning achievement.

This study as well found that under the situation of playing animations segment by segment, animations described with narration and subtitles simultaneously did not cause obvious influences on learning, suggesting a

disappearing of redundancy effect. The researchers believe the reason was that when animations, subtitles, and narration were presented at the same time, the information amount may be too much for the visual system to process, yet learners can choose to temporarily ignore the subtitles and focus on animations and narration only. The conclusion was also proved from eye-movement data. That's why the students in animation + subtitles + narration and animation + narration groups spent the same time and all of them enhance the understanding. According to the models from Mayer (2001)'s Multimedia Cognition Theory, the integration of animation (image model) and narration (word model) is the key for comprehension; animation and narration belong to different senses, which can not only be processed without causing over-load for a single sense but also be capable of promoting the effectiveness of info-integration. Therefore, learners are most likely to watch the animation and meanwhile listen to the narration without necessarily concerning with the connections between the subtitles and animations. So, even though learners may read the subtitle very short after, it does not do much influence upon learning effects since the key integration of image and word models has been completed through the simultaneous presentation of animations and narrations. This result reasonably explains why the animation + subtitles + narration mode does not cause much affection for learning achievement.

The researchers of this study designed animated teaching materials according to Mayer (2001)' s segmentation principles first, and then measured the learning effects to investigate how different multimedia teaching materials affected learning. Results of this study can be pedagogically referential indicators and tools to observe learning effects for current teaching programs and for future researchers to take into account when designing multi-media instructions for a science education web or organizing teaching materials practiced in classrooms. This is what makes this study different from the former ones.

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