Education Tech Research Dev (2020) 68:2305–2320
https://doi.org/10.1007/s11423-020-09775-4

RESEARCH ARTICLE

Does learner expertise matter when designing emotional multimedia for learners of primary school mathematics?

Thomas K. F. Chiu[1] · Morris Siu-yung Jong[1] · Ida A. C. Mok[2]

Published online: 27 April 2020

Abstract

Recent research on multimedia learning has considered the integration of cognitive and affective aspects of media processing. The literature suggests that learners' emotions influence the effectiveness of multimedia learning, which is explained by the cognitive-affective theory of learning with media (CATLM). A multimedia design that changes learners' emotional status can facilitate or suppress learning. Individual difference, which suggests that learners with different expertise levels respond differently to an emotional design, is an assumption of CATLM. However, how learner expertise influences the effectiveness of emotional designs remains unclear. This study investigated the effects of learner expertise (novice vs advanced) and an emotional design incorporating a face-like shape and warm colours (with vs without) on developing skills in remembering and understanding in mathematics learning. The novice group comprised younger learners who had no prior knowledge of the topic; the advanced group comprised older learners who had studied the topic previously. We randomly allocated 122 primary school students to four experimental groups to see how they learned geometrical patterns from videos with different designs. These results showed that (1) the emotional design group performed better in remembering, and (2) the emotional design benefited the advanced group, but not the novice group, in understanding. A plausible explanation is that the benefits of the emotional design do not outweigh its drawback in the novice group when developing understanding. Further analysis revealed that learner expertise and learning outcomes influence the designs' effects. Our findings suggested that using emotional design can effectively facilitate lower-order thinking skills such as remembering, identifying and procedural skills, and drawing students interests and motivation may not lead to better learning outcomes.

Keywords Cognitive load theory · Learner expertise · Emotional design · Multimedia learning · Mathematics learning

✉ Thomas K. F. Chiu
Thomas.kf.chiu@gmail.com

Extended author information available on the last page of the article

Introduction

To expand previous research on multimedia learning, which has taken a predominantly cognitive perspective, recent studies have focused on the influence of affective processes such as emotions and motivations (Chiu and Hew 2018; Park et al. 2015a, b; Plass and Kalyuga 2019; Um et al. 2012). Such studies have aimed to integrate affective variables into cognitive processing theories of multimedia learning (Park et al. 2014). Appealing and interesting design elements in multimedia learning can evoke a positive emotional status in learners (Heidig et al. 2015), which alters working memory capacities (Knörzer et al. 2016; Plass and Kalyuga 2019; Schneider et al. 2016). Whether this positive emotional status can facilitate cognitive processing in multimedia environments for better learning outcomes has been critically discussed in multimedia learning research. Some studies suggest that appealing design elements facilitate learning through the creation of an enjoyable experience (Knörzer et al. 2016; Mayer and Estella 2014). However, some researchers believe that additional design elements result in an additional cognitive load that impairs learning (e.g. the coherence principle; Mayer 2009) or may merely be 'seductive details', elements added to instructional materials that are interesting to learners but not directly relevant to the instructional goal (Harp and Mayer 1997; Rey 2012). These discussions relate to Moreno's cognitive-affective theory of learning with media (CATLM) (Moreno 2005, 2006, 2007, 2009). This theory adds the idea of affective mediation, i.e., that motivational factors influencing the learner's cognitive engagement may mediate learning, to expand Mayer's cognitive theory of multimedia learning (CTML) (Mayer 2009). Learners must be motivated to learn or to use self-regulation to allocate sufficient cognitive resources to learning tasks. Appealing and interesting design elements that may impose an extraneous load may play motivational and emotional roles in multimedia learning (Leutner 2014; Park et al. 2011). However, the role of emotions in multimedia learning remains unclear (Heidig et al. 2015; Knörzer et al. 2016; Leutner 2014; Mayer and Estrella 2014; Park et al. 2015a, b). When it comes to designing learning experiences, we need more relevant studies to understand how emotional multimedia materials affect learning outcomes.

When designing multimedia learning environments, it has been shown that positive emotion should be optimised to enhance learning processes (Chiu 2018, 2019; Ng and Chiu 2017). The next question is whether certain design elements can evoke positive emotions and eventually foster learning. An emotional design should change intrinsic design elements, such as shapes and colours, rather than adding extra elements (Heidig et al. 2015; Plass et al. 2014; Um et al. 2012). Studies have shown that warm colours and round shapes in multimedia designs can facilitate learning outcomes by inducing positive emotions (Mayer and Estrella 2014; Plass and Kalyuga 2019; Plass et al. 2014; Um et al. 2012). However, these studies did not take learner expertise into account or assess how learner background influences the effectiveness of multimedia designs (Chiu and Mok 2017; Chiu and Hew 2018; Kalyuga 2007, 2014; Kalyuga et al. 2012). Therefore, the present study looked at the impact of emotional design (with vs without) and learner expertise (novice vs advanced) on the learning outcomes of remembering and understanding in multimedia learning for a primary school mathematics topic. The results of our experiment can inform practitioners about when and how to use emotional design.

The remainder of the paper is organised as follows. We first present the theoretical framework of this study and outline previous studies on emotional design in multimedia learning. We then describe the purpose and methodology of the study. Next, we present the results of our analyses, followed by a discussion of the results and our conclusions.

Theoretical framework

We use Sweller's (2010) cognitive load theory (CLT), Moreno's (2005, 2006, 2007, 2009) CATLM and Kalyuga's (2014) expertise reversal effect to construct a theoretical framework to explain findings presented in the literature on multimedia learning.

Cognitive load theory and cognitive-affective theory of learning with media

Cognitive load theory, developed by Sweller (2010), is based on human brain architecture and describes two types of memory, working and long term. This theory assumes that the limitations of working memory critically influence the effectiveness of instructional designs and suggests three types of cognitive load: extraneous, intrinsic and germane. Different types of cognitive load consume cognitive resources during learning processes in different ways. 'Extraneous load' refers to the load placed on working memory by processing unnecessary information; 'intrinsic load' refers to working memory demands imposed by processing essential information to achieve specific learning goals; and 'germane load' reflects the cognitive effort invested in comprehending the essential information in the working memory.

Based on CLT, Mayer's formulation of CTML was developed by looking closely at the basic foundation of working memory in multimedia learning environments. CTML assumes that the human information processing system includes dual channels for visual and verbal processing (the dual-channels assumption). Both CLT and CTML suggest that learner motivation affects cognitive load or processing. Moreno (2005, 2006, 2007, 2009) further expanded CTML by including affective aspects such as emotions and motivations, and proposed CATLM, which suggests that motivational factors affect the cognitive engagement of learners and therefore mediate multimedia learning.

Cognitive-affective theory of learning with media explains how cognitive and affective processes work in multimedia learning environments. The theory incorporates seven assumptions: (i) verbal and non-verbal information processing are independent, (ii) working memory is limited and processes all of the organised information, while long-term memory is relatively large and stores the information, (iii) dual coding enhances learning, (iv) active processing of information is necessary for meaningful learning (Moreno 2005, 2006, 2007, 2009), (v) motivational factors mediate learning by adjusting cognitive engagement (Pintrich 2003), (vi) metacognitive factors mediate learning by regulating affective and cognitive processes, and (vii) learner expertise in specific media may affect learning results (Kalyuga 2007, 2014; Moreno 2004). The CATLM model is shown in Fig. 1.

Recent research on multimedia learning has focused on understanding how affective aspects, particularly in emotional design, influence cognitive processing (Heidig et al. 2015; Park et al. 2015a, b; Schneider et al. 2016; Um et al. 2012). As learner expertise can influence the effectiveness of multimedia designs (Chiu 2018, 2019; Chiu and Mok 2017; Kalyuga 2007, 2014; Kalyuga et al. 2012), we believe that causal relationships exist between learner expertise and emotional design. The following three sections discuss previous research into how emotion, emotional design and learner expertise affect multimedia learning.

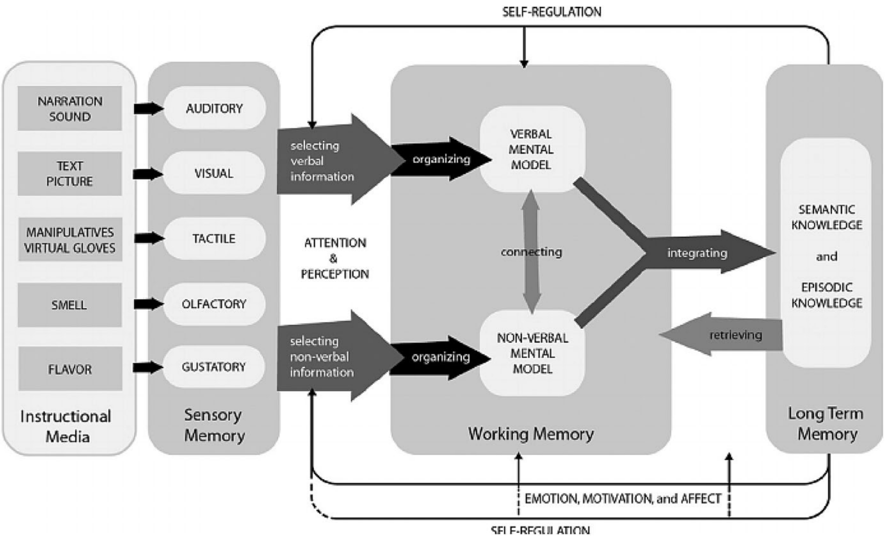


Fig. 1 Cognitive-Affective Theory of Learning with Media (CATLM)

Emotions in multimedia learning

How do emotions affect multimedia learning?

Emotions have crucial effects on different types of cognitive processes. For example, a positive emotional state can enhance recall by serving as an effective retrieval cue for long-term memory (Isen et al. 1987; Isen et al. 1978). This is reflected in the fifth assumption of CATLM, which suggests that learner emotional status affects multimedia learning. Emotions influence learning via both beneficial and detrimental effects on cognitive processes (Knörzer et al. 2016; Isen et al. 1987; Plass and Kalyuga 2019), which can be explained by the effects of extraneous load, motivation, attention and processing styles (Knörzer et al. 2016). The experiment described in this paper was designed based on the assumptions that learner emotions affect extraneous load and motivation.

In relation to extraneous load, it is assumed that both positive and negative emotions consume working memory, impairing learning compared to a neutral emotional state. In a non-neutral emotional state, the cognitive components of emotion demand additional cognition in the working memory (Knörzer et al. 2016). Thus, in terms of CLT, emotions result in an extraneous cognitive load, as they do not facilitate cognitive processes that are related to germane load. This argument is supported by some empirical studies (Ellis et al. 1984; Oaksford et al. 1996). Ellis et al. (1984) showed that induced positive and negative emotions impair information processing. Oaksford et al. (1996) found that emotions complicate deductive reasoning processes. Here, the extraneous load assumption assumes that positive and negative emotions complicate, and do not contribute to, the learning process.

In contrast, the motivation assumption suggests that both positive and negative emotions facilitate learning via fostering learner motivation. Studies have shown that positive and negative emotions can enhance both intrinsic motivation (Mayer and Estrella 2014; Park et al., 2015a, b; Pekrun et al. 2002) and extrinsic motivation (Pekrun et al. 2002), leading to better cognitive processing and learning (Pekrun 2006; Isen et al. 1987). Positive emotions associated with the cognitive process foster many different learning outcomes, such as creative and divergent thinking (Isen et al. 1987), problem solving skills and recall (Isen et al. 1987; Mayer and Estrella 2014).

Emotions can be induced by external mood and emotional design (Um et al. 2012). External mood induction is not discussed in this paper as it is not relevant to our study. Emotional design induction concerns learning processes, and is supported by the core affect model (Russell 2003). This model suggests that the appearance of a graphic can change emotional status and affect learning. A graphic's appearance can have either facilitating or suppressing effects on learning, which can be explained by the effects of extraneous load (Sweller 2010; the coherence principle in Mayer 2009) and motivation (Moreno 2009; Knörzer et al. 2016; the generative process in Mayer 2009).

Emotional design in multimedia learning

Can an emotional design be a decorative picture? Does an emotional design complicate learning by producing unnecessary cognitive load during multimedia learning?

Most studies of multimedia learning suggest that images and pictures should be directly related to the learning content (the coherent principle; Mayer 2009) to facilitate learning; therefore, the inclusion of pictures that are merely decorative is not recommended. However, emotional design (of which decorative pictures may be a part) uses different visual design features with the aim of invoking learner emotion to facilitate multimedia learning (Mayer and Estrella 2014; Park et al. 2015a, b). Although the design features are decorations that do not contain content directly related to the learning (i.e., theoretically, they are irrelevant to the learning task and may even hinder learning), they might motivate learners to give more effort to processing multimedia information. Whether an emotional design will impede or promote learning performances depends on its specific design features.

Researchers have investigated the question of which design features can effectively enhance multimedia learning. Schneider et al. (2016) reported that learning-context related decorative pictures (e.g., students in a lecture hall) enhanced both retention and transfer skills with medium effect sizes, compared to leisure-related context pictures (e.g., students in a cafeteria). A plausible explanation is that a stronger arousal perception was created by the students in the learning-context related decorative pictures group. Plass et al. (2014) found that the tones of colours used in teaching and learning materials, such as warm colours and neutral colours, and the inclusion of 'face-like shapes' in the design, can affect the nature of emotion and learning. Their study demonstrated that using round face-like shapes and warm colours can facilitate comprehension skills, while using round face-like shapes and neutral colours can facilitate transfer skills. They also found that round face-like shapes can evoke positive emotions among learners. Mayer and Estrella (2014) used emotional design principles including personification and visual appeal to redraw all of the key elements in a lesson using round and symmetrical faces with expressive eyes. Students learning with the redrawn pictures exerted more effort during multimedia learning and this led to better retention and transfer skills.

According to CATLM, students' short-term memory can be enhanced by capturing their attention. Emotional designs that are more likely to draw students' attention therefore help learners remember and understand the learning concepts and knowledge better and for longer (Knörzer et al. 2016).

Learner expertise in multimedia learning

Does learner expertise affect the effectiveness of emotional design in multimedia learning?

In addition to emotional status, learner expertise is a mediator of multimedia learning. Learner expertise influences the effectiveness of multimedia instruction because learners with different expertise levels will respond differently to a given multimedia design (Chiu 2018, 2019; Chiu and Mok 2017; Kalyuga 2007, 2014; Kalyuga et al. 2012). The literature suggests that multimedia designs that are beneficial for novice learners may be detrimental for advanced learners. This phenomenon is referred to as the expertise reversal effect (Kalyuga 2007). Advanced learners find the designs redundant or useless, which places an extraneous cognitive load on them, leading to a reduction in cognitive capacity available for learning processes. Empirical studies have shown that a multimedia design that benefits novices will complicate advanced learners' development of understanding (Chiu and Mok 2017; Leslie et al. 2012; Rey and Fischer 2013; Spanjers et al. 2011), possibly due to a heavier cognitive load when developing understanding. Other studies have shown that ill- or less-structured multimedia presentations benefit advanced learners more than novice learners (Nievelstein et al. 2013).

Experimental approaches to assessing the effects of learner expertise, i.e., experience and prior knowledge, have included incorporating additional design features, such as presenting aids audibly and/or visually, and controlling the pace of learning (the segmenting principle). Many experimental studies suggest that learner expertise has an impact on remembering and understanding in multimedia learning (Chiu 2016; Chiu and Mok 2017; Kalyuga 2007, 2014; Kalyuga et al. 2012; Leslie et al. 2012; Rey and Fischer 2013; Spanjers et al. 2011). For example, a design that presented and described steps to learn on screen worked better for weaker students than for stronger students (Kalyuga et al. 2012); images and pictures helped younger (less experienced) children learn science, but not older (more experienced) children (Leslie et al. 2012); continuous animations were more effective than segmented animations for more knowledgeable learners (Spanjers et al. 2011); and when developing statistical skills, expository examples and illustrations should be removed for stronger undergraduate students (Rey and Fischer 2013). These results suggest that additional design elements that help weaker learners understand the images and words presented could complicate the learning of more able students. The designs provided more informative environments that eased weaker learners' cognitive processing by selecting relevant images and words. In contrast, stronger learners found that the extra information in the environments was redundant or useless. The additional designs thus became a burden and required additional, and unnecessary, cognitive processing (Kalyuga 2014). This extra processing resulted in less cognitive capacity for other kinds of processing. This was a crucial effect for stronger learners (Kalyuga 2014). Moreover, most of the studies indicated that incorporating additional design elements in multimedia learning was effective for all learners on remembering, but less effective for stronger learners on understanding (Chiu and Mok 2017; Leslie et al. 2012; Rey and Fischer 2013; Spanjers et al. 2011). These findings suggest that learners with different expertise levels have different responses to emotional designs. Such designs may only benefit a specific learner group, such as novices.

Method

The present study

Previous research suggests that the effectiveness of emotional designs is linked to a learner's expertise and affect; however, no detailed studies in this area have been conducted. Accordingly, the findings of this study make a significant contribution to theories of multimedia learning. This paper describes an experimental study that investigated how learner expertise (novices with no prior knowledge vs advanced learners who are more knowledgeable/have studied the related topics previously) affects an emotional design on mathematics learning in multimedia environments, and attempts to understand how the design influences cognitive capacities available for learning. In the experiment, a 2 × 2 between subjects factorial design with the factors learner expertise (novice (N) vs advanced (A)) and emotional design (with an emotional design (ED) vs. without (ND)) was used to achieve the research goals. We hypothesized that the emotional design would (H1) help the learners develop better remembering (Moreno 2006, 2006, 2007, 2009); (H2) place an extraneous cognitive load on the learners, and have a greater facilitating effect on novice learners in developing understanding as a result of the expertise reversal effect (Kalyuga 2007, 2014) and the individual assumptions for multimedia learning (Chiu and Mok, 2017; Mayer 2009; Kalyuga 2007, 2014); and (H3) make learning materials more fun (Plass et al. 2014).

Participants and procedure

Our research team first obtained ethical clearance from the university and the consent of all participants. The study had a pilot phase and a main study phase. In the pilot phase, we conducted an experimental study with two groups of a total of 30 lower primary school students to examine the effectiveness of an emotional design that incorporated face-like shapes and warm colours. The results showed that the emotional design significantly promoted the participants' positive emotions.

Experimental studies related to learner expertise or expertise reversal effects have used different approaches to measure learners' expertise levels in different educational sectors, such as school year, in lower primary children (see experiment 1 in Leahy and Sweller 2005; Leslie et al. 2012); academic tests in upper primary and secondary children (Chiu and Mok 2017; Kalyuga et al. 2013); and self-reported questionnaires in university students (Oksa et al. 2010; Rey and Fischer 2013).

In our main study, the participants were lower primary school students. We believe that students' school year is closely related to their learner expertise. We therefore purposefully invited 70 Primary 1 students (approximately 5 years old and in their first year of K12 schooling) and 68 Primary 3 students (approximately 7 years old and in their third year of K12 schooling) from a Hong Kong school to participate in the experiment. Eleven of them disagreed to participate in the experiment or were absent in the experiment day. The Primary 1 students had not been taught the principles and concepts of patterns as a curriculum unit and were classified as novice learners. The Primary 3 students had some prior knowledge of the content of the instructional materials presented because they had previously studied patterns as a unit of work, and were classified as advanced learners. We expected that the Primary 1 group would be less knowledgeable than the Primary 3 group, which was verified by the result of a paper-based pre-test with 10 multiple-choice questions.

We administered the pre-test to the participants 3 days before the experiment and used the results to remove the outliners (two Primary 1 and one Primary 3 students) whose z-scores were higher than 3 or lower than -3. Then, we randomly divided the students into the four experimental conditions. One Primary 1 and one Primary 3 student did not complete the experiment so the composition of the four groups was as follows: 32 novices learning with the emotional design (NED), 30 novices learning with a non-emotional design (NND), 29 advanced students learning with the emotional design (AED), and 31 advanced students learning with a non-emotional design (AND).

We began the experiment by briefing the groups about our purpose and the desired learning outcomes in four classrooms at the same time. The students were then shown the corresponding 5-min videos and were given 20 min to complete the post-test and questionnaire. The students were all thanked at the end of the experiment.

Learning instruments and materials

The learning instruments, post-test and questionnaire were written in Cantonese. The learning materials were 5-min videos about understanding geometrical patterns. In the emotional design groups, face-like shapes and warm colours were added in the design (Fig. 2). The post-test, which was in the form of multiple-choice questions with three answers, assessed remembering and understanding (Fig. 3). The questions were the same as those used in our previous experiments (Chiu and Mok 2017) and were modified from those used in Chiu (2016, 2018), Chiu and Mok (2017), and Chiu and Churchill (2015a, 2015b). The validity tests of the questions remembering and understanding yielded all p values less than 0.05 and Pearson coefficients higher than 0.65; the reliability tests of the questions remembering and understanding yielded cronbach's alpha of 0.81 and 0.85 respectively. The remembering learning outcomes were measured by means of recall questions the same as those presented in the videos for the

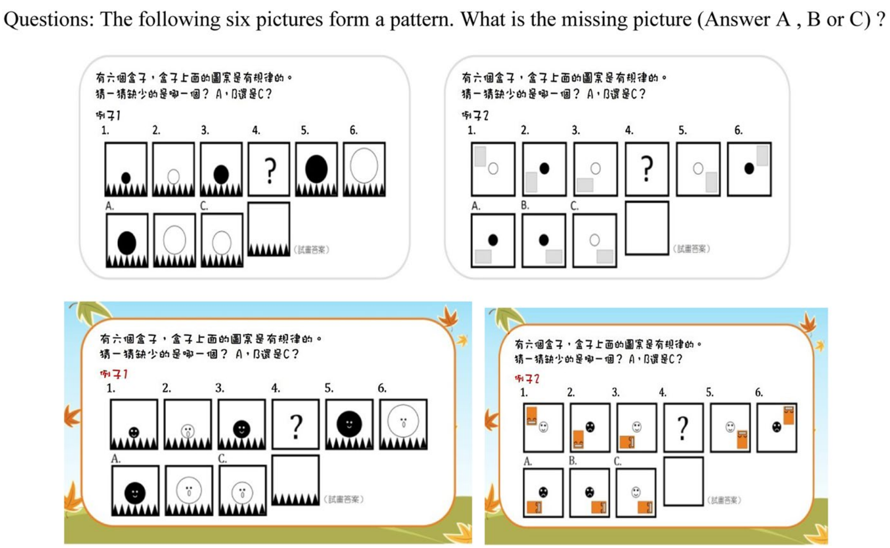
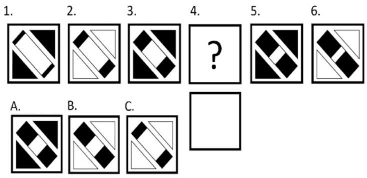


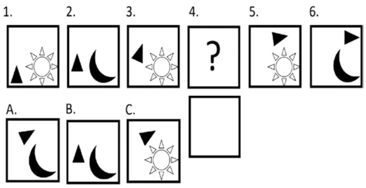
Fig. 2 The screenshots of the videos in the control and experimental group

下列各題有六個盒子，盒子上面的圖案是有規律的。
(In the following, there are six boxes and they form a pattern.)
猜一猜缺少的是哪一個？A，B 還是 C？（將適當的英文字母圈出來。)
(Please write down the missing picture in the box with “?” A, B or C? Please circle the right one.)

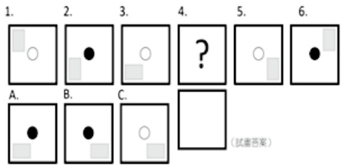
Understanding test: the questions are not presented to them before.
Question 1



Question 2



Remembering test: the questions are as same as the questions used in the video.
Question 1



Question 2

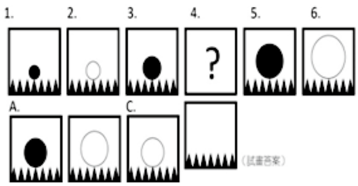


Fig. 3 Sample questions in remembering and understanding tests

non-emotional design groups; the questions which measured understanding were new. Each measure had 10 questions and each scored 1 point. The questionnaire included a 5-scale Likert question measuring intrinsic motivation with the statement ‘I find the learning material fun’. This question was used in the study by Plass et al. (2014).

Table 1 Descriptive statistics for four experimental groups

Variable	NED (n=32)		NND (n=30)		AED (n=29)		AND (n=31)	
	M	SD	M	SD	M	SD	M	SD
Remembering	9.10	.82	7.37	.85	9.03	.87	6.84	1.03
Understanding	7.75	1.39	6.93	1.05	7.00	1.00	8.29	1.21
Intrinsic motivation	3.16	.95	3.63	.85	3.07	.80	3.39	.72

Table 2 Summary of the main and interaction effects

Variable	Main effect of learner expertise	Main effect of emotional design	Interaction effect
Remembering	No	Yes	No
Understanding	No	No	Yes
Intrinsic motivation	No	Yes	No

Results

To analyse the post-test data, we used SPSS 21 to conduct 2×2 univariate analyses of variance (ANOVAs) (emotional design: with vs without face-like shape and warm colour)×(learner expertise: novice vs advanced) with remembering, understanding and intrinsic motivation as dependent variables. All dependent variables met the assumption of homogeneity of variance, with all p values > 0.05 in Levene's tests. Means and standard deviations for the scores of both groups are shown in Table 1; the main and interaction effects are summarised in Table 2.

For remembering, ANOVA revealed a main effect of emotional design, $F(1, 118) = 145.79$, $p < 0.001$, partial $\eta^2 = 0.56$, indicating that the with emotional design group (M = 9.07, SD = 0.84) performed significantly better than the without group (M = 7.09, SD = 0.98). There was no main effect of learner expertise, $F(1, 118) = 3.26$, $p = 0.07$, partial $\eta^2 = 0.03$; nor was there an effect of emotional design by learner expertise, $F(1, 118) = 2.08$, $p = 0.15$, partial $\eta^2 = 0.02$.

For understanding, univariate ANOVAs showed that there were no significant effects of emotional design, $F(1, 118) = 1.23$, $p = 0.27$, partial $\eta^2 = 0.01$ or learner expertise, $F(1, 118) = 2.02$, $p = 0.158$, partial $\eta^2 = 0.02$. A significant interaction effect was found, $F(1, 119) = 5.52$, $p = 0.020$, partial $\eta^2 = 0.04$. A significant simple effect was found for the novices who learned better with the emotional design, $F(1, 60) = 6.75$, $p = 0.01$, partial $\eta^2 = 0.101$; a significant simple effect was found for the advanced group who learned better without the emotional design, $F(1, 58) = 19.99$, $p = < 0.001$, partial $\eta^2 = 0.26$. A significant simple effect was found for the non-emotional design, such that the advanced students learned better than the novice group, $F(1, 59) = 21.72$, $p < 0.001$, partial $\eta^2 = 0.27$; a significant simple effect was found for the emotional design, such that the novices learned better than the advanced students, $F(1, 59) = 5.74$, $p = 0.02$, partial $\eta^2 = 0.654$.

For intrinsic motivation, a univariate ANOVA found no main effect of learner expertise, $F(1, 118) = 1.21$, $p = 0.27$, partial $\eta^2 = 0.01$, but an effect was found for emotional design, $F(1, 118) = 6.90$, $p = 0.01$, partial $\eta^2 = 0.06$. No significant interaction effect was found, $F(1, 118) = 0.28$, $p = 0.60$, partial $\eta^2 = 0.002$.

Discussions, conclusions and limitations

The experiment reported in this paper was designed to investigate the effect of an emotional multimedia design incorporating face-like shapes and warm colours on the remembering and understanding skills of students with different expertise levels. This study aimed to investigate how different expertise levels influence the effectiveness of an emotional design on mathematics learning in multimedia environments, and sought to understand the facilitating, neutralising or suppressing effects of the design. Consequently, this paper presents three empirical implications and makes two theoretical contributions and two practical suggestions.

Empirical implications

The findings of the experiment confirmed our three hypotheses described earlier in this paper and have three major empirical implications. First, the emotional design had significant effects on developing remembering (H1). This result supports those of related empirical studies, such as those by Plass et al. (2014), Mayer and Estrella (2014), and Chiu and Mok (2017), which indicate that aspects of multimedia design can enhance the development of remembering. This phenomenon may arise because an emotional design creates a fun environment in which learners are inclined to invest more effort in learning. Such a design is more likely to facilitate the development of lower-order thinking skills.

Second, the design benefited the novice group, but not the advanced group on developing understanding (H2). This suggests that the emotional design complicated learning for the advanced group. The learning task for understanding (higher-order thinking skills) involved heavier cognitive processing (Chiu and Mok 2017). A plausible explanation in terms of CATLM is that the design encourages novice learners to make more effort in learning; however, the extraneous cognitive load placed on the learners consumes so much cognitive capacity that the available capacity is not sufficient for generative learning processes (germane load) (Chiu and Mok 2017). However, the advanced group has enough capacity to process the information. Therefore, the design was purely 'decorative' for the advanced group and should not be included (see Mayer's (2009) coherent principle). In other words, for the advanced group the benefits of emotional design do not outweigh its drawbacks and consume too many cognitive resources. Although the results of this study have implications, the *p* value of the emotional design group was close to 0.5, i.e., the effect size was low. This may suggest that there was no significant difference between the novice and advanced groups in developing understanding skills when the emotional design was used.

Finally, the emotional design introduced more fun (and thus intrinsic motivation) to the learning process (H3). This result is in line with earlier studies that encourage the use of emotional designs in learning (see Mayer and Estrella 2014; Chiu and Mok 2017; Plass et al. 2014). However, these results suggest that an emotional design may not benefit advanced learners' development of understanding as the design consumes working memory capacity compared to a neutral emotional state, see Kalyugas' expertise reversal effect (Kalyuga 2007, 2014) and Mayers' redundant principal (Mayer 2009).

Theoretical contributions

The results contribute to CATLM by showing how an emotional design in multimedia learning affects cognitive processes through emotion, motivation and attention. Most earlier relevant studies have not taken learner expertise or thinking skills into account when studying emotional designs (see Park et al. 2015a, b, Plass et al. 2014; Knörzer et al. 2016; Schneider et al. 2016; Um et al. 2012). The authors of these studies advocated that an appropriate emotional design can facilitate cognitive processing during learning even though it may place an extraneous cognitive load on the learners because the learners would invest more effort in their cognitive processing to integrate their prior knowledge from long-term memory and organised knowledge from the multimedia presentations into new knowledge.

This study has added two new factors to the theory: learner expertise and thinking skills. The emotional design increased the level of intrinsic motivation; however, the effect varied between learners with different expertise levels. The findings show that a design can be purely decorative for some learners. Its facilitating effects on cognitive processing may not overcome the difficulties caused by the additional extraneous cognitive load, which results in neutralising or suppressing effects. Even though learners' cognitive processes were facilitated through positive emotion and a higher level of motivation, the effects on cognitive processing were minimal. Consequently, this study supports the individual difference assumption, and further suggests that multimedia materials that stimulate and elicit emotion have varying effects on different learners. The answer to the question of whether emotions and attention can facilitate cognitive processing will differ according to learner expertise and learning outcomes.

Practical suggestions

We offer two practical suggestions for mathematics teachers and one practical suggestion for instructional designers. The first suggestion for mathematics teachers is that it is more effective to use face-like shapes and warm colours for all learners in developing lower-order mathematics thinking skills such as remembering, identifying and procedural skills. We recommended that human-like pictures are included in multimedia presentations when the mathematics learning tasks are not too complicated. The other suggestion is that teachers should be very careful when they design mathematics learning activities that aim to draw students' interests and foster their motivation, because such 'fun' activities may not lead to better learning outcomes.

Our findings expand upon to the design principals for emotional design and learner expertise in multimedia learning, such as those of Plass et al. (2014), Mayer and Estrella (2014); Kalyuga (2014) and Mayer (2009). A single multimedia learning design cannot effectively cater for learners with different expertise levels (Chiu 2016, 2018; Kalyuga 2007, 2009, 2014; Mayer 2009). The results of this study further suggest that a single emotional multimedia design can also have different effects on developing different thinking skills. Emotional designs that have promising facilitating effects on a thinking skill of a given order may suppress learning in thinking skills of a different order. We encourage instructional designers to use learner expertise and learning outcomes, particularly in terms of thinking skills of different orders, to determine whether to include emotional design in multimedia presentations offered to learners.

Limitations and future directions

Learners are required to allocate sufficient cognitive resources to multimedia presentations to develop better learning outcomes (Chiu 2016, 2018; Chiu and Churchill 2015a, 2015b; Chiu and Mok 2017; Park et al. 2015a, b). This study appears to support the use of emotional designs to motivate students to make more effort in learning; however, some of the p values are close to 0.05. We believe that more experiments are needed to support and extend the current findings to understand how learner expertise and learning outcomes influence the effectiveness of emotional design in multimedia learning. To further understand what and how emotional designs benefit learners, the results of the present experiment could also be extended by additional studies on different emotional designs, mood/emotion induction designs, or in other subject domains. In conclusion, future research on adaptive learning environments should focus on cognitive processing, and interactions among learner prerequisites, emotions and multimedia presentations.

Acknowledgements We thank the participating schools and the University of Hong Kong for the support of this work through a research fund (Grant No. 200007704/058199/10000/400/01)

Funding This study was funded by Faculty of Education, The University of Hong Kong: 200007704/085199/10000/400/01.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

Chiu, T.K.F. (2016). Prior knowledge and mathematics order thinking skill in multimedia learning. In *Proceedings of The International Conference of Learning Sciences*. Singapore:Elsevier.

Chiu, T.K.F. (2018) Learner expertise and emotional designs in Mathematics Learning. In *Proceedings the International Conference of Learning Sciences*. London:International Society of the Learning Sciences, Inc.[ISLS]

Chiu, T. K. F. (2019). *Does an Emotional Multimedia Design Work for Everyone in Mathematics Learning? AERA Annual Meeting (Mathematics Education Section)*. Toronto: Canada.

Chiu, T. K. F., & Churchill, D. (2015a). Design of learning objects for concept learning: Effects of multimedia learning principles and an instructional approach. *Interactive Learning Environment, 1*, 1–16. https://doi.org/10.1080/10494820.2015.1006237.

Chiu, T. K. F., & Churchill, D. (2015b). Exploring the characteristics of an optimal design of digital materials for concept learning in mathematics: Multimedia learning and variation theory. *Computers & Education, 82*, 280–329. https://doi.org/10.1016/j.compedu.2014.12.

Chiu, T. K., & Hew, T. K. (2018). Factors influencing peer learning and performance in MOOC asynchronous online discussion forum. *Australasian Journal of Educational Technology*. https://doi.org/10.14742/ajet.3240.

Chiu, T. K., & Mok, I. A. (2017). Learner expertise and mathematics different order thinking skills in multimedia learning. *Computers & Education, 107*, 147–164.

Ellis, H. C., Thomas, R. L., & Rodriguez, I. A. (1984). Emotional mood states and memory: Elaborative encoding, semantics processing, and cognitive effort. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10*(3), 470–482.

Harp, S. F., & Mayer, R. E. (1997). The role of interest in learning from scientific text and illustrations: On the distinction between emotional interest and cognitive interest. *Journal of Educational Psychology, 89*(1), 92–102. https://doi.org/10.1037//0022-0663.89.1.92.

Heidig, S., Müller, J., & Reichelt, M. (2015). Emotional design in multimedia learning: Differentiation on relevant design features and their effects on emotions and learning. *Computers in Human Behavior, 44*, 81–95. https://doi.org/10.1016/j.chb.2014.11.009.

Isen, A. M., Daubman, K. A., & Nowicki, G. P. (1987). Positive affect facilitates creative problem solving. *Journal of Personality and Social Psychology, 52*(6), 1122–1131.

Isen, A. M., Shalker, T. E., Clark, M., & Karp, L. (1978). Affect, accessibility of material in memory, and behavior: A cognitive loop? *Journal of Personality and Social Psychology, 36*(1), 1–12.

Kalyuga, S. (2007). Expertise reversal effect and its implications for learner-tailored instruction. *Educational Psychology Review, 19*(4), 509–539. https://doi.org/10.1007/s10648-007-9054-3.

Kalyuga, S., Law, Y. K., & Lee, C. H. (2013). Expertise reversal effect in reading Chinese texts with added causal words. *Instructional Science, 41*(3), 481–497.

Kalyuga, S. (2014). The expertise reversal principle in multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 576–597). New York, NY: Cambridge University Press.

Kalyuga, S., Rikers, R., & Plaas, F. (2012). Educational implications of expertise reversal effects in learning and performance of complex cognitive and sensorimotor skills. *Educational Psychology Review, 24*(2), 313–337.

Knörzer, L., Brünken, R., & Park, B. (2016). Facilitators or suppressors: Effects of experimentally induced emotions on multimedia learning. *Learning and Instruction, 44*, 97–107.

Leahy, W., & Sweller, J. (2005). Interactions among the imagination, expertise reversal, and element interactivity effects. *Journal of Experimental Psychology: Applied, 11*(4), 266–276.

Leslie, K. C., Low, R., Jin, P., & Sweller, J. (2012). Redundancy and expertise reversal effects when using educational technology to learn primary school science. *Educational Technology Research and Development, 60*(1), 1–13. https://doi.org/10.1007/s11423-011-9199-0.

Leutner, D. (2014). Motivation and emotion as mediators in multimedia learning. *Learning and Instruction, 29*, 174–175. https://doi.org/10.1016/j.learninstruc.2013.05.004.

Mayer, R. E. (2009). *Multimedia learning*. New York, NY: Cambridge Press.

Mayer, R. E., & Estrella, G. (2014). Benefits of emotional design in multimedia instruction. *Learning and Instruction, 33*, 12–18. https://doi.org/10.1016/j.learninstruc.2014.02.004.

Moreno, R. (2004). Decreasing cognitive load for novice students: Effects of explanatory versus corrective feedback in discovery-based multimedia. *Instructional Science, 32*(1), 99–113.

Moreno, R. (2006). Does the modality principle hold for different media? A test of the method-affects-learning hypothesis. *Journal of Computer Assisted Learning, 22*, 149–158.

Moreno, R. (2007). Optimizing learning from animations by minimizing cognitive load: Cognitive and affective consequences of signalling and segmentation methods. *Applied Cognitive Psychology, 21*, 765–781.

Moreno, R. (2009). Learning from animated classroom exemplars: The case for guiding student teachers' observations with metacognitive prompts. *Journal of Educational Research and Evaluation, 15*, 487–501.

Moreno, R. (2005). Instructional technology: promise and pitfalls. In L. Pytlik Zillig, M. Bodvarsson, & R. Bruning (Eds.), *Technology-based education: Bringing researchers and practitioners together* (pp. 1–19). Greenwich, CT: Information Age Publishing.

Ng, K. H., & Chiu, T. K. (2017). Emotional multimedia design for developing mathematical problem-solving skills. *New ecology for educationCommunication x learning* (pp. 131–141). Singapore: Springer.

Nievelstein, F., Van Gog, T., Van Dijck, G., & Boshuizen, H. P. (2013). The worked example and expertise reversal effect in less structured tasks: Learning to reason about legal cases. *Contemporary Educational Psychology, 38*(2), 118–125.

Oaksford, M., Morris, F., Grainger, B., & Williams, J. M. G. (1996). Mood, reasoning, and central executive processes. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*(2), 476–492.

Oksa, A., Kalyuga, S., & Chandler, P. (2010). Expertise reversal effect in using explanatory notes for readers of Shakespearean text. *Instructional Science, 38*(3), 217–236.

Park, B., Moreno, R., Seufert, T., & Brünken, R. (2011). Does cognitive load moderate the seductive details effect? A multimedia study. *Computers in Human Behavior, 27*(1), 5–10. https://doi.org/10.1016/j.chb.2010.05.006.

Park, B., Plass, J. L., & Brünken, R. (2014). Cognitive and affective processes in multimedia learning. *Learning and Instruction, 29*, 125–127. https://doi.org/10.1016/j.learninstruc.2013.05.005.

Park, B., Flowerday, T., & Brünken, R. (2015a). Cognitive and affective effects of seductive details in multimedia learning. *Computers in Human Behavior, 44*, 267–278. https://doi.org/10.1016/j.chb.2014.10.061.

Park, B., Knörzer, L., Plass, J. L., & Brünken, R. (2015b). Emotional design and positive emotions in multimedia learning: An eyetracking study on the use of anthropomorphisms. *Computers & Education, 86*, 30–42. https://doi.org/10.1016/j.compedu.2015.02.016.
Pekrun, R. (2006). The control-value theory of achievement emotions: Assumptions, corollaries, and implications for educational research and practice. *Educational Psychology Review, 18*(4), 315–341.
Pekrun, R., Goetz, T., Titz, W., & Perry, R. P. (2002). Positive emotions in education. In E. Frydenberg (Ed.), *Beyond coping: Meeting goals, visions, and challenges* (pp. 149–173). New York, NY: Oxford University Press. https://doi.org/10.1093/med:psych/9780198508144.003.0008.
Pintrich, P. R. (2003). A motivational science perspective on the role of student motivation in learning and teaching contexts. *Journal of Educational Psychology, 95*(4), 667–686.
Plass, J. L., Heidig, S., Hayward, E. O., Homer, B. D., & Um, E. (2014). Emotional design in multimedia learning: Effects of shape and color on affect and learning. *Learning and Instruction, 29*, 128–140. https://doi.org/10.1016/j.learninstruc.2013.02.006.
Plass, J. L., & Kalyuga, S. (2019). Four ways of considering emotion in cognitive load theory. *Educational Psychology Review, 31*, 339–359.
Rey, G. D. (2012). A review of research and a meta-analysis of the seductive detail effect. *Educational Research Review, 7*(3), 216–237. https://doi.org/10.1016/j.edurev.2012.05.003.
Rey, G. D., & Fischer, A. (2013). The expertise reversal effect concerning instructional explanations. *Instructional Science, 41*(2), 407–429. https://doi.org/10.1007/s11251-012-9237-2.
Russell, J. A. (2003). Core affect and the psychological construction of emotion. *Psychological Review, 110*(1), 145–172.
Schneider, S., Nebel, S., & Rey, G. D. (2016). Decorative pictures and emotional design in multimedia learning. *Learning and Instruction, 44*, 65–73.
Spanjers, I. A. E., Wouters, P., Van Gog, T., & Van Merrienboer, J. J. G. (2011). An expertise reversal effect of segmentation in learning from animated worked-out examples. *Computers in Human Behavior, 27*(1), 46–52. https://doi.org/10.1016/j.chb.2010.05.011.
Sweller, J. (2010). Element interactivity and intrinsic, extraneous, and germane cognitive load. *Educational Psychology Review, 22*(2), 123–138. https://doi.org/10.1007/s10648-010-9128-5.
Um, E., Plass, J. L., Hayward, E. O., & Homer, B. D. (2012). Emotional design in multimedia learning. *Journal of Educational Psychology, 104*(2), 485–498. https://doi.org/10.1037/a0026609.

Thomas K.F. Chiu is an assistant professor in the Department of Curriculum and Instruction at the Faculty of Education at The Chinese University of Hong Kong. His research interests include Mathematics, Technology and STEM education, Learning Technology, and Teacher Education.

Morris Siu-yung Jong is an associate professor in the Department of Curriculum and Instruction, and Director of Centre for Learning Sciences and Technologies at the Faculty of Education at The Chinese University of Hong Kong. His research interests include learning sciences, gamification, educational VR, context-aware mobile learning, as well as teacher facilitation in technology-enhanced learning environments.

Ida A.C. Mok is an associate professor and associate dean at the Faculty of Education at The University of Hong Kong. Her research interests include Mathematics Education, Teacher Education, Teaching and Learning, Comparative Studies in Mathematics Education and Qualitative Research.

Affiliations

Thomas K. F. Chiu[1] · **Morris Siu-yung Jong**[1] · **Ida A. C. Mok**[2]

Morris Siu-yung Jong
mjong@cuhk.edu.hk

Ida A. C. Mok
iacmok@hku.hk

1 Department of Curriculum and Instruction, Faculty of Education, The Chinese University of Hong Kong, Shatin, Hong Kong, China

2 Faculty of Education, The University of Hong Kong, Pokfulam road, Hong Kong, China