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Benefits of emotional design in multimedia instruction

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ABSTRACT

Emotional design of multimedia instruction involves making the essential elements in the lesson's graphics more appealing, such as by rendering them with human-like features and with distinct, appealing colors (Um, Plass, Hayward, & Homer, 2012). College students received an 8-slide multimedia lesson on how a virus causes a cold for 5 min (Experiment 1) or for as long as they wanted (Experiment 2). For the control group, the graphics consisted of simple black-and-white drawings in which the host cell was represented as a large circle, and the virus was represented as a small circle with small spikes on the outside and a rectangle on the inside. For the enhanced group, the graphics were redrawn to render the host cell as a red face with expressive eyes (registering surprise, fear, and sickness at various stages in the process), and the virus as a blue face with fierce eyes and with a green dot at the end of each of the blue tentacles surrounding the virus face. The enhanced group performed better than the control group on a subsequent learning test ($d = 0.69$ in Experiment 1, $d = 0.65$ in Experiment 2) and gave higher effort ratings in Experiment 1 ($d = 0.65$) but not in Experiment 2 ($d = -0.10$). The findings are generally consistent with the cognitive affective theory of learning with media, and point to the importance of incorporating motivation into cognitive theories of multimedia learning.

1. Introduction

1.1. Objective and framework

The goal of the present study is to determine whether using emotional design principles to redesign the graphics in a multimedia lesson will improve student learning outcomes (as measured by performance on a comprehension test). For example, consider a slideshow that explains how a virus causes a cold and contains slides containing black-and-white line drawings along with printed sentences, as exemplified in the top of Fig. 1. In an effort to apply emotional design principles, we could enhance the graphics by rendering the essential characters (e.g., host cell, virus, virus DNA) with human-like characteristics (e.g., faces with expressive eyes) and appealing colors (e.g., red, blue, and yellow), as exemplified in the bottom of Fig. 1 (in the web version).

In this study, we use the term *emotional design* to refer to redesigning the graphics in a multimedia lesson to enhance the level of personification and visual appeal of the essential elements in the lesson. Personification involves rendering essential elements with human-like features such as presenting the host cell as a face with expressive eyes (indicating surprise, for example, when a virus approaches). Visual appeal involves rendering each element in a distinct, appealing color, such as red for the host cell and blue for the virus.

A rationale for implementing emotional design principles in multimedia lessons is that the revised graphics are intended to increase the learner's motivation to make sense of the essential material and thereby prime deeper learning processes that lead to improved learning outcomes. Motivation refers to the learner's cognitive state that initiates, energizes, and maintains goal directed behavior, which in the present study involves exerting effort to make sense of the lesson by engaging in appropriate cognitive processing during learning. Overall, consideration of emotional design features represents an attempt to integrate motivational processes with cognitive theories of multimedia learning.

1.2. Literature review

The concept of emotional design has a long-standing place in human engineering concerning how to design everyday things (Norman, 2004), but until recently has not been scientifically studied in education. Research on the emotional design of graphics in multimedia lessons is in its infancy, with the main evidence coming from research by Plass and colleagues (Plass, Heidig, Hayward, Homer, & Um, 2014; Um, Plass, Hayward, & Homer,

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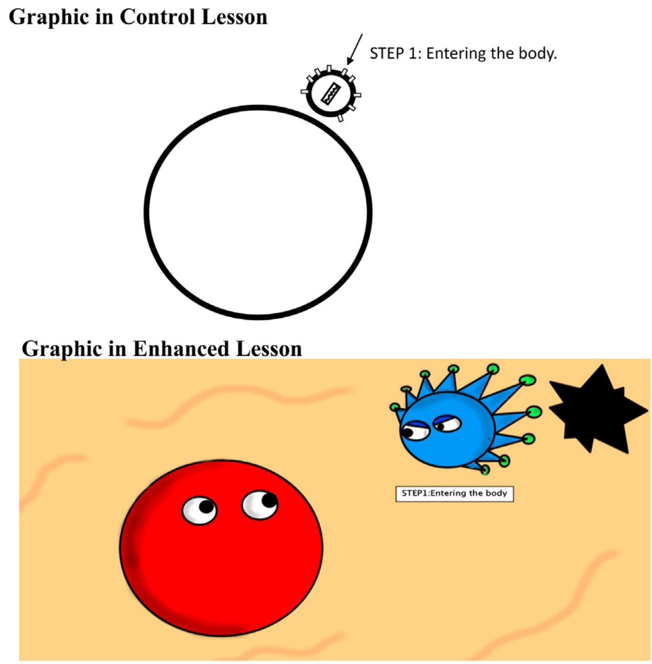

Fig. 1. Graphics from control and enhanced group. Note. In the enhanced lesson, the host cell (on left) is in red, and the virus. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2012). First, Um et al. (2012) implemented emotional design principles in a multimedia lesson on how immunization works by converting the main characters in the illustrations (such as T-Cell, B-cell, and antigens) from gray-tone geometric shapes into little faces with expressive eyes rendered in appealing colors such as purple, blue, and green. In terms of learning outcome tests, students who were given the enhanced lesson performed better that the control group on tests of comprehension ($d = 0.43$). In terms of cognitive load measures, students who received the enhanced lesson reported lower levels of difficulty ($d = 0.42$) and equivalent levels of effort ($d = 0.06$) as compared to the control group.

Plass et al. (2014) replicated the study using the same materials across two experiments, again finding that students given the enhanced lesson performed better on a comprehension test across both experiments ($d = 0.61$ and $d = 0.77$), reported less difficulty in one experiment ($d = 0.49$) but not the other ($d = 0.23$), and reported equivalent effort across both experiments ($d = -0.19$ and $d = 0.08$) as compared to the control group. However, in the Um et al. (2012) study the enhanced group outperformed the control group on a transfer test ($d = 0.80$) whereas no difference was found in the Plass et al. (2014) experiments ($d = 0.01$ and $d = 0.08$).

In contrast to these findings showing the benefits of emotional design in multimedia learning, there is a substantial research base that points to the negative effects of incorporating interesting but irrelevant graphics in a multimedia lesson (Harp & Mayer, 1997, 1998; Mayer, Heiser, & Lonn, 2001; Sung & Mayer, 2012). For example, inserting short color video clips of lighting strikes within a narrated animation explaining how lightning storms develop resulted in poorer transfer test performance ($d = -0.70$; Mayer, Heiser, & Lonn), adding color illustrations showing the results of lightning strikes in a paper-based lesson on how lightning storms develop resulted in poorer transfer test performance across 5 experiments yielding effect sizes greater than $d = -1.0$ (Harp & Mayer, 1997, 1998), and adding interesting but irrelevant graphics to an online lesson on educational technology resulted in poorer comprehension test performance ($d = -0.39$; Sung & Mayer, 2012).

Interesting but irrelevant graphics are a form of *seductive details* (i.e., interesting but irrelevant information added to a lesson) that has been well studied in research on adding seductive text to learning from prose (Garner, Gillingham, & White, 1989), and to some extent in multimedia learning (Mayer, Griffith, Naftaly, & Rothman, 2008). Similarly, adding decorative illustrations (i.e., neutral illustrations that have no instructional role) tends to have no consistent positive effect on learning outcomes (Magner, Schwonke, Aleven, Popescu, & Renkl, 2014; Sung & Mayer, 2012).

An important challenge in applying emotional design principles to redesigning graphics in multimedia lessons is to tap affective processes that prime cognitive processes leading to improvements in learning (as was done in the emotional design research by Plass and colleagues) while not distracting the learner from the essential content of the lesson (as was done in the seductive details research by Mayer and colleagues). The primary difference between interesting illustrations that help learning and those that hurt learning is that in research by Plass and colleagues the interesting graphics concerned the essential content of the lesson whereas in research by Mayer and colleagues the interesting graphics focused the learner's attention on extraneous content. Thus, in applying emotional design principles to the redesign of graphics in multimedia lessons, the focus should be on making the essential elements in the lesson more appealing rather than on adding appealing extraneous graphics.

So far the literature has three studies all from the same research team (i.e., Plass and colleagues) and with the same lesson, showing the benefits of applying emotional design principles to redesigning the graphics in a multimedia lesson on how immunization works. Is a replication of this research needed? According to Shavelson and Towne (2002) scientific research in education is advanced when researchers seek to replicate and extend preliminary findings. The present study seeks to test the emotional design hypothesis using different instructional materials and tests, and in a different lab with different learners. Thus, given the somewhat novel and surprising findings of Plass and colleagues and the importance of appropriately incorporating motivational factors in theories of multimedia learning, we seek to determine the robustness of the benefits of incorporating emotional design in multimedia instruction.

1.3. Theory and predictions

Cognitive theories of multimedia learning, such as Mayer's (2009) cognitive theory of multimedia learning or Sweller's (2005; Sweller, Ayres, & Kalyuga, 2011) cognitive load theory, focus on cognitive processing during learning within a working memory of limited capacity using knowledge activated from a long-term memory with unlimited capacity. Multimedia information from the outside world is assumed to enter through the eyes or ears and register in sensory memory. The learner can attend to some of the fleeting information in sensory memory (which is called the cognitive process of *selecting*), thereby bringing it into working memory. Within working memory, the learner can organize the incoming visual information into a spatial representation and the incoming verbal information into a verbal model (which is called the cognitive process of *organizing*). Finally, the learner can integrate the spatial and verbal representations with each other and with relevant knowledge activated from long-term memory (which is called the cognitive process of *integrating*). According to the cognitive theory of multimedia learning, meaningful learning (e.g., as indicated by test performance) occurs when the learner engages in appropriate selecting, organizing, and integrating during learning. It follows that instructional design should be concerned with priming these cognitive processes during learning, which are represented as arrows in the cognitive theory of multimedia learning (CTML; Mayer, 2009).

The role of motivation is somewhat underspecified in CTML (Mayer, 2011), although the theory distinguishes among three demands on working memory capacity during learning: *extraneous processing, essential processing,* and *generative processing*. Extraneous processing is cognitive processing that does not serve the instructional objective, such as caused by adding interesting but extraneous graphics to a multimedia lesson. Essential processing is cognitive processing aimed at mentally representing the presented material through selecting it, and is caused by the complexity of the material for the learner. Generative processing is cognitive processing aimed at making sense of the represented material through organizing and integrating it with relevant prior knowledge, and is caused by the learner's motivation to learn. In CTML, motivation is the force that instigates and maintains generative processing, which leads to better learning outcomes.

In an effort to better integrate the role of motivation in cognitive theories of multimedia learning, Moreno (2007; Moreno & Mayer, 2007) proposed the cognitive affective theory of learning with media (CATLM). In CATLM arrows from long-term memory point back to the cognitive processes of selecting, organizing, and integrating, indicating the role of motivation and metacognition in initiating, sustaining, and controlling cognitive processing during learning.

Incorporating motivation within CTML or in CATLM suggests the *emotional design hypothesis*, which holds that making essential elements visually appealing initiates and guides cognitive processing during learning by directing attention and maintains cognitive processing during learning by encouraging the learner to understand the main characters better. In short, emotional design of essential elements in the graphics of multimedia lessons can prime and sustain improved cognitive processing during learning (i.e., selecting, organizing, and integrating), which in turn leads to improved learning outcomes. Emotional design can direct the learner's attention towards essential material (i.e., selecting) and encourage learners to get to know the essential material better (i.e., organizing and integrating). However, the emotional design hypothesis applies when essential elements in graphics are redesigned for appeal but not when extraneous features are made appealing.

Based on this analysis we offer two predictions that are tested in the present study:

Hypothesis 1. The major prediction in this study is that students who receive multimedia lessons with graphics based on emotional design principles (enhanced group) should perform better on a learning outcome test (i.e., a comprehension test in which they write explanations) than students who receive the same lesson without emotional design (control group).

Hypothesis 2. A secondary prediction is that the enhanced group will report more effort and less difficulty than the control group, although the use of subjective self-report items to measure these variables provides only a limited and preliminary test.

2. Experiment 1

In Experiment 1 students received the enhanced or control version of the lesson for 5 min and then took retention and transfer tests and completed a questionnaire.

2.1. Method

2.1.1. Participants and design

The participants were 64 college students recruited from the Paid Subject Pool at the University of California, Santa Barbara, who received $10 for their participation. The mean age was 19.5 years, the mean knowledge score based on the participant questionnaire described in the next section was 3.9 out of 12 (which is in the low-to-average range), the average class standing was sophomore, and the proportion of women was 0.76. Thirty students served in the enhanced group and 34 served in the control group.

2.1.2. Participant questionnaire

The paper-based materials consisted of a participant questionnaire, 6 test sheets, and a post-questionnaire, each printed on an 8.5×11 inch sheet of paper. The participant questionnaire solicited information concerning the participant's age, gender, and year in school. The participant questionnaire also asked students to rate their knowledge of biology on a 5-point scale ranging from *very low* (1) to *very high* (5) and to place a check mark next each of the following things that applied to them: "I have participated in science programs or fairs. Biology was my favorite subject in high school. I sometimes watch science documentaries in my free time. I can name most of the cell's organelles from memory. I sometimes find myself on the Internet looking up science related topics. I own (or used to own) a microscope. I took advanced biology classes in high school (AP, IB, Honors, etc.)." A knowledge score was computed by tallying the number of checked items and adding the rating (with 1 for *very low*, 2 for *somewhat low*, 3 for *average*, 4 for *somewhat high*, and 5 for *very high*). Similar knowledge questionnaires have been used in previous research as a way to gage the learner's level of prior knowledge without asking specific questions about the content of lesson (Mayer, 2009). The checklist items are very specific activities, thereby allowing the participant to answer more objectively. The rationale for not including a pretest is that the pretest can create a testing effect in which the act of taking the test is an instructional activity and the pretest can create an adjunct question effect in which pre-questions can direct the learner's selective attention during subsequent instruction.

2.1.3. Posttest questions

The retention sheet contained the following item: "Based on the lesson you just read, please describe how a cold virus attacks the body." A score on this item was obtained by giving one point for each of 19 idea units that the student included regardless of specific wording: (1) virus enters body, (2) through nose or mouth or break in skin, (3) virus searches for host cell, (4) virus usually attacks respiratory or digestive tract, (5) virus attaches to host cell, (6) virus recognizes host cell, (7) virus injects genetic material into host cell, (8) through cell membrane, (9) injected genetic material recruits host cell's enzymes, (10) to copy virus' genetic material, (11) host cell's enzymes produce parts, (12) new parts are packaged into new viruses in the host cell, (13) new viruses break free from host cell, (14) in lyses they destroy the host cell as they leave, (15) in budding they pinch out, (16) new virus can attack other cells, (17) one virus particle reproduces thousands of new copies, (18) viral infections spread quickly through the body, (19) now the person has a cold. Two raters scored the retention tests, with an inter-rater reliability of $r = 0.92$, and disagreements were resolved by consensus.

The five transfer sheets contained the following questions: (1) "Suppose you are exposed to a cold virus from an infected person who sneezes on you, but you do not get sick. Why not?" (2) "If you could, how would you change the human body to minimize the chances of viral infection?" (3) "What would happen to viruses if the cells in our bodies developed thicker membranes?" (4) "What do cell membranes have to do with viral infection? What does DNA have to do with viral infections?" (5) "Why do some kinds of viruses kill their host whereas others do not?" At the bottom of each of the test sheets was the line: "PLEASE KEEP WORKING UNTIL YOU ARE ASKED TO STOP". On each transfer item, students received one point for each relevant answer they expressed regardless of wording. For example, on the "why not" question there were 6 acceptable answers: (1) the virus is prevented from entering the body, (2) the virus is prevented from attached to cell membrane, (3) the virus is not able to inject its genetic material, (4) the virus' genetic code is not copied, (5) the virus cannot break free from the host cell, (6) the virus does not spread after it reproduces. Each student's transfer score was the sum of points across all 5 transfer questions. Two raters scored the transfer tests, with an inter-rater reliability of $r = 0.82$, and disagreements were resolved by consensus.

The total test score was computed by adding the retention and transfer scores. The total score provides an overall measure of comprehension because all items require students to generate explanations corresponding to level 2 ("understand") in Bloom's taxonomy of instructional objectives (Anderson et al., 2001).

2.1.4. Post-questionnaire

The posttest questionnaire sheet contained the following items:

(1) "Please rate how difficult this lesson was for you." on a scale from 1 ("very easy") to 5 ("very difficult").
(2) "Please rate how much effort you exerted in learning this lesson." on a scale from 1 ("very low") to 5 ("very high").
(3) "Please rate how appealing this lesson was for you." on a scale from 1 ("very appealing") to 5 ("very unappealing").
(4) "I would like to learn from more lessons like this." on a scale from 1 ("strongly agree") to 5 ("strongly disagree").
(5) "I enjoyed learning from this lesson." on a scale from 1 ("strongly agree") to 5 ("strongly disagree").

2.1.5. Instructional lessons

The computer-based materials consisted of two PowerPoint lessons that explained how a virus causes a cold—a control version and an enhanced version. The control lesson consisted of 8 slides, with a total of 442 words and 6 graphics, and was adapted from a lesson used by Mayer et al. (2008). The first slide had the heading "How a Cold Virus Attacks the Body" and consisted of 59 words (with no graphic) describing elements in a virus (genetic instructions in the form of DNA and RNA surrounded by a protein coating) and the difference between enveloped viruses and naked viruses. The second slide had the heading, "How is a Virus Different from a Cell?" and consisted of 116 words (with no graphics) stating that a virus does not have all the components needed to survive for long on its own so it needs a host cell to function. The third slide was entitled, "What Are the Steps in Catching a Cold? Step 1: Entering the Body" and consisted of 47 words and one graphic. The words described how a virus enters the body through the nose of mouth or a break in the skin and once inside searches for a host cell to infect. The graphic was a black and white line drawing depicting the host cell as a large circle and the approaching virus as a small circle with some short spikes on the outside and a rectangle on the inside (with the label "STEP 1: Entering the body" placed next to the virus), as shown in the top of Fig. 1. The fourth slide had the heading, "Step 2: Attaching to a Host Cell" and consisted of 49 words and one graphic. The words described how a virus uses its is protein coating to recognize a proper host cell that has a similar coating and attaches to it. The graphic was a black and white line drawing similar to the previous one except the virus' outer wall was touching the host cell's outer wall and the label next to the virus stated, "STEP 2: Attaching to a host cell." The fifth slide was entitled, "Step 3: Injecting Genetic Material into the Host Cell" and consisted of 29 words and one graphic. The words described how a virus injects its genetic instructions through the cell membrane into the host cell. The graphic was the same as the previous one except the rectangle from inside the virus was now inside the host cell along with an arrow showing its path, and a label next to the rectangle stated, "STEP 3: Injecting genetic material into the host cell." The sixth slide was entitled, "Step 4: Copying the Virus's Genetic Code" and consisted of 34 words and one graphic. The words stated that the injected genetic material recruits the host cell's enzymes to copy the virus's parts including genetic instructions. The figure showed the same host cell with an injected rectangle in it as in the previous slide, but also showed an arrow from the injected rectangle to several growing viruses (rendered as circles with rectangles in them) within the host cell, along with a label next to the new viruses stating, "STEP 4: Copying the viruses genetic code." The seventh slide had the heading, "Step 5: Breaking Free from the Host Cell" and consisted of 68 words and one graphic. The words described how the new parts are packaged into new viruses within the host cell and how they break free from the host cell either by pinching out through the cell membrane or by destroying the cell in the process. The graphic was the same as the previous one except there was an arrow from the new viruses inside the host the cell to the same viruses outside but touching the cell membrane, along with the label next the them stating, "STEP 5: Breaking free from the host cell." The eighth slide had the heading, "Step 6: Spreading throughout the Body" and consisted of 40 words and one graphic. The words described how the newly produced viruses become free of the host and can attack other host cells in the body resulting in a person having a cold. The graphic contained the same host cell with new viruses on the outside touching it as in the previous slide along with an arrow pointing away from the cell and a label stating, "STEP 6: Spreading throughout the body."

The enhanced lesson was identical to the control lesson except that each of the six illustrations was redrawn based on emotional design principles, including personification and visual appeal for each key element in the lesson. Personification involved rendering the host cell and virus each as a round and symmetrical face, giving expressive eyes to the host cell that looked worried when the virus approached and sick when under attack, and giving aggressive looking eyes to the virus. Visual appeal involved rendering each character in appealing attention-grabbing colors, such as blue for the virus (with small green circles for the genetic material at the end of each tentacle), red for the host cell, and yellow for the sac in which new blue viruses were created within the host cell. We used these bright and vibrant colors with shadowing in an attempt to attract the learner's attention to the essential elements in the lesson with a positive tone. An example slide is shown in the bottom of Fig. 1. It is imperative that the revised illustrations used in the enhanced group do not add additional content concerning how a virus causes a cold. Therefore, we were careful to make sure key elements (e.g., the virus, host cell, and genetic material) were shown in the same location, same orientation, and same size in corresponding illustrations in the two groups, and that no additional detail relevant to the infection processes was added to the illustrations in the enhanced group.

2.1.6. Apparatus

The apparatus consisted of 5 iMac computers with 21-inch screens.

2.1.7. Procedure

Participants were randomly assigned to treatment group. Up to 3 participants were tested in a session, with each participant seated in an individual cubicle out of sight from other participants. First, the experimenter described the study and participants read and signed an informed consent form. Second, participants completed the participant questionnaire at their own pace. Third, participants viewed the multimedia lesson corresponding to their treatment group—enhanced or control—for 5 min. Fourth, participants were given the retention sheet for 4 min, after which the sheet was collected. Fifth, the participants were given each of the five transfer sheets for 2.5 min per sheet, with one sheet being collected before the next one was handed out. Finally, students completed the post-questionnaire at their own rate. The entire session lasted approximately 30 min. We adhered to ethical principles for conducting research with human subjects.

2.2. Results

2.2.1. Are the groups equivalent on basic characteristics?

A preliminary step is to examine whether the enhanced group and the control group are equivalent on basic characteristics. Appropriate statistical tests (i.e., t-test or chi-square) indicated that the groups did not differ significantly (with $p < .05$) in mean knowledge score, mean age, year in college, or proportion of men and women. We conclude that random assignment procedures were successful in producing groups that did not differ on basic characteristics.

2.2.2. Does adding emotional design features improve student learning outcomes?

The primary purpose of this study is to determine whether adding emotional design features to a multimedia lesson helps student learn better as indicated by learning outcome measures, as predicted by the cognitive affective theory of learning with media (CATLM; Moreno, 2007; Moreno & Mayer, 2007). Table 1 shows the mean and standard deviation for both groups on the total test score, as well as for the retention and transfer sections separately. As summarized in the third column in Table 1, a t-test showed that the enhanced group performed significantly better than the control group on the learning test, $t(62) = 2.67$, $p = .01$, $d = 0.69$. This is the primary empirical contribution of this study.

The learning test is comprised of two kinds of questions—a retention question that asks the learner to explain how a cold virus causes a cold, and several transfer questions that ask the learner to use the information to solve a problem about a new situation such as what would happen if people had thicker cell membranes or why a person might not catch a cold when someone sneezes on them. The first column in Table 1 shows that the enhanced group performed significantly better than the control group on the retention part of the test, $t(62) = 2.56$, $p = .01$, $d = 0.69$. The second column in Table 1 shows that the enhanced group did not perform significantly better than the control group on the transfer part of the test, $t(62) = 1.16$, $p = .25$, $d = 0.29$. Overall, there is moderate-to-strong evidence that redesigning the graphics in a lesson for emotion design improves student learning.

2.2.3. Does adding emotional design features affect ratings of affect, effort, or difficulty?

A secondary issue in this study concerns the effects of emotional design on learners' ratings of affect, effort, or difficulty. Given the limitations of subjective self-report ratings, this issue is addressed in a preliminary manner in this study. According to the CATLM, learners in the enhanced group may provide higher affective ratings than those in the control group. However, the groups did not differ significantly (with alpha at 0.05) on their mean rating for appeal of the lesson ($p = .57$; $M = 2.24$, $SD = 0.89$ for control; $M = 2.10$, $SD = 0.99$ for enhanced), enjoyment of the lesson ($p = .28$; $M = 2.71$, $SD = 0.84$ for control; $M = 2.93$, $SD = 0.83$ for enhanced), or desire for more similar lessons ($p = .91$; $M = 2.79$, $SD = 0.88$ for control; $M = 2.77$, $SD = 0.97$ for enhanced) with higher numbers indicating more positive ratings. Thus, the groups did not differ on their reports of how well they liked the lesson.

According to the CATLM, learners in the enhanced group may produce a higher rating of effort and a lower rating of difficulty than the control group. As predicted, the enhanced group ($M = 3.47$, $SD = 1.02$) reported a higher level of effort during learning than the control group ($M = 2.76$, $SD = 1.17$), $t(62) = 2.57$, $p = .01$, $d = 0.65$. However, the groups did not differ significantly on difficulty rating although the difference was in the predicted direction ($p = .33$, $d = 0.25$).

Overall, students may not be sensitive to their own affective state during learning but there is some preliminary self-report evidence that emotional design may motivate them to exert more effort during learning. More sensitive measures of affective state and effort during learning would be useful in subsequent research.

Table 1
Mean score and standard deviation on retention, transfer, and total score for two groups—Experiment 1.

Group	Retention		Transfer		Total	
	M	*SD*	*M*	*SD*	*M*	*SD*
Enhanced ($n = 30$)	7.42*	1.75	6.60	2.34	14.02*	2.41
Control ($n = 34$)	6.01	2.34	6.00	1.89	12.01	3.43
	$d = 0.69$, $p = .01$		$d = 0.29$, $p = .25$		$d = 0.69$, $p = .01$	

Note. Asterisk (*) indicates enhanced group outperformed control group at $p < .05$.

3. Experiment 2

Experiment 2 was identical to Experiment 1 except students had no time limit during learning. Unlimited time was intended to allow each group the time it needed for learning.

3.1. Method

3.1.1. Participants and design

The participants were 47 college students recruited from the Psychology Subject Pool at the University of California, Santa Barbara, who received course credit for their participation. The mean age was 18.6 years, the mean knowledge score based on the participant questionnaire was 4.9 out of 12 (which is in the low-to-average range), the average class standing was freshman, and the proportion of women was 0.68. Twenty-three students served in the enhanced group and 24 served in the control group.

3.1.2. Materials and procedure

The materials and procedure were identical to Experiment 1 except that students had no time limit for studying the lesson, and their study time was recorded by the experimenter.

3.2. Results

3.2.1. Are the groups equivalent on basic characteristics?

As in Experiment 1, the groups did not differ significantly on age, gender, class standing, and prior knowledge.

3.2.2. Does adding emotional design features improve student learning outcomes?

As in Experiment 1, the primary purpose of this study is to determine whether adding emotional design features to a multimedia lesson improves performance on a learning outcome posttest. Table 2 shows the mean and standard deviation for both groups on the total test score, as well as for the retention and transfer sections separately. As summarized in the third column in Table 2, a t-test showed that the enhanced group performed significantly better than the control group on the learning test, $t(45) = 2.20$, $p = .03$, $d = 0.65$. The first column in Table 2 shows that the enhanced group performed significantly better than the control group on the

Table 2
Mean score and standard deviation on retention, transfer, and total score for two groups—Experiment 2.

Group	Retention		Transfer		Total	
	M	*SD*	*M*	*SD*	*M*	*SD*
Enhanced ($n = 23$)	9.09*	2.02	5.57	2.17	14.66*	3.04
Control ($n = 24$)	7.58	2.10	5.08	1.79	12.66	3.14
	$d = 0.73, p = .02$		$d = 0.25, p = .41$		$d = 0.65, p = .03$	

Note. Asterisk (*) indicates enhanced group outperformed control group at $p < .05$.

retention part of the test, $t(45) = 2.50$, $p = .02$, $d = 0.73$. The second column in Table 2 shows that the enhanced group did not perform significantly better than the control group on the transfer part of the test, $t(45) = 0.83$, $p = .41$. Overall, there is moderate-to-strong evidence that redesigning the graphics in a lesson for emotion design improves student learning as measured by a total score. Thus, the primary empirical contribution of this study is that emotional design improves learning outcomes when there is no limit on study time similar to in Experiment 1 where there was a 5-min limit.

3.2.3. Does adding emotional design features affect study time or ratings of affect, effort, or difficulty?

The differences between the groups in learning outcome performance cannot be attributed to differences in study time because the mean study time for the enhanced group ($M = 167.2$ s, $SD = 44.0$ s) did not differ significantly from the mean study time for the control group ($M = 171.6$ s, $SD = 56.0$ s), $t(45) = -0.30$, $p = .77$. Interestingly, study time did not correlate significantly with total score ($r = 0.17$, $N = 47$, $p = .26$), retention score ($r = 0.17$, $N = 47$, $p = .25$), or transfer score ($r = 0.08$, $N = 47$, $p = .61$), suggesting that differences in test score cannot be explained in terms of differences in study time. However, lack of significant correlations may also be attributable to restricted range.

As in Experiment 1, the groups did not differ significantly (with alpha at 0.05) on their mean rating for appeal of the lesson ($p = .30$; $M = 2.71$, $SD = 1.08$ for control; $M = 2.43$, $SD = 0.66$ for enhanced), enjoyment of the lesson ($p = .23$; $M = 2.47$, $SD = 0.88$ for control; $M = 2.70$, $SD = 0.92$ for enhanced), or desire for more similar lessons ($p = .08$; $M = 2.31$, $SD = 1.02$ for control; $M = 2.70$, $SD = 0.82$ for enhanced), with higher numbers indicating more positive ratings. Unlike Experiment 1 and in contrast to hypothesis 2, the enhanced group ($M = 3.04$, $SD = 0.98$) did not report a higher level of effort during learning than the control group ($M = 3.13$ $SD = 0.85$), $t(45) = 0.31$, $p = .76$. However, consistent with hypothesis 2, the control group reported greater difficulty ($M = 2.83$, $SD = 0.92$) than the enhanced group ($M = 2.30$, $SD = 1.02$), although the difference did not reach statistical significance, $t(45)$ 1.87, $p = .07$, $d = 0.55$. We conclude that students may not be strongly sensitive to their own affective state during learning so subsequent research should use more diagnostic measures of affective state, difficulty, and effort during learning or employ larger sample sizes.

4. Discussion

4.1. Empirical contributions

Overall, the two experiments provide consistent evidence that redesigning multimedia lessons to incorporate emotional design principles significantly improves learning outcomes.

Consistent with hypothesis 1, the primary finding in this study is that redesigning the graphics in a multimedia lesson based on emotional design principles improves student learning as measured by the total score on the posttest ($d = 0.69$ in Experiment 1 and $d = 0.65$ in Experiment 2). Partially consistent with hypothesis 2, the secondary finding is that redesigning the graphics in a lesson based on emotional design principles results in marginally higher ratings of effort during learning in Experiment 1 ($d = 0.65$) but not in Experiment 2 ($d = -0.10$), and in marginally lower levels of perceived difficulty in Experiment 2 ($d = 0.55$) but not in Experiment 1 ($d = 0.25$). Consistent with Shavelson and Towne's (2002, p. 4) principle 5 for scientific research in education ("replicate and extend across studies"), these findings provide an important replication and extension of Um et al.'s (2012) and Plass et al.'s (2014) published work showing the benefits of emotional design in multimedia instruction. Thus, the major empirical contribution of this work is to show that the emotional design effect recently discovered in Plass's lab is robust enough to also be found in a different lab with different materials and participants.

4.2. Theoretical contributions

The results are consistent with the predictions of the cognitive affective theory of learning with media (CATLM) and with an extension of the cognitive theory of multimedia learning (CTML), which asserts that students are more motivated to engage in appropriate cognitive processing during learning when the relevant graphics in a lesson are redesigned to be more appealing. According to this model, emotional design cues cause learners to exert more effort (i.e., motivation) to make sense of the presented material during learning (i.e., generative processing), which in turn leads to better learning outcomes (i.e., mental models) capable of supporting performance on comprehension tests (i.e., posttest performance).

Although the present study is consistent with this account, it does not explicitly pinpoint the mechanisms by which emotional design causes learners to engage in more effort to learn, so future work is needed that examines direct measures of motivation and cognitive processing during learning. In particular, evidence is needed to examine the effects of implementing emotional design principles on measures of student motivation and measures of active cognitive processing during learning, as well as posttest performance as measured in this study. In future research, it is crucial to continue to insure as in this study and Plass's studies that the enhanced illustrations convey the same content information as the control illustrations, so improvements in posttest performance can be attributed to the emotional appeal of the illustrations.

Overall, this research contributes to calls to incorporate affective and motivational factors into cognitive theories of how people from multimedia lessons (Brunken, Plass, & Moreno, 2010; Mayer, 2014; Moreno, 2007; Moreno & Mayer, 2007) by showing that cues intended to motivate learners had a moderate-to-strong effect on posttest performance. Cognitive theories such as the cognitive theory of multimedia learning (CTML) and cognitive load theory (CLT) should be extended to incorporate the idea that emotional design can foster essential and generative processing during learning, leading to better learning of the material.

4.3. Practical contributions

The primary practical contribution is that graphics should be redesigned to be appealing and personified as long as the redesign focuses learners' attention on the relevant aspects of the graphic. In contrast, research on the coherence principle in general and the harmful effects of seductive details in particular (Mayer, 2009) shows that adding appealing but irrelevant graphics can distract learners and lead to detriments in learning. Thus, the emotional design principle is that interesting and personified graphics promote learning when they are relevant rather than irrelevant to the instructional goal.

The active ingredients in the enhanced treatment involve the personification and appeal of the key elements in the lesson—namely, the host cell, the virus, the virus's DNA, and the reproduced viruses. Personification was accomplished by rendering some key elements with faces and expressive eyes whereas increased appeal was accomplished by portraying each key element with distinctive colors and simple shapes. A practical implication for applying the emotional design principle is to identify the key elements in the lesson, develop representations that personify the most important elements such as with faces and facial expressions, and highlight each key element with distinctive and happy colors rendered with simple human-like shapes.

It is useful to consider which kinds of test performance might be aided or hurt by emotional design. Although the ability to explain how a virus causes cold was enhanced in this study, it is possible that emotional design might decrease performance on drawing accurate representations of the elements in the explanation.

4.4. Limitations and future directions

This study can be criticized on the grounds of ecological validity because this was a short-term study involving a 5-min (or shorter) lesson and an immediate 15-min posttest conducted in a lab environment. An important next step is to extend this line of research to more authentic learning environments. The short reading time in Experiment 2—averaging less than 3 min—yields an average reading rate of approximately 156 words per minute, which does not exceed typical adult reading rates of 250–300 words per minute (Crowder & Wagner, 1992) and leaves time for processing of the graphics. However, additional research is needed to determine how much time is necessary to process the presented material in a way that yields strong test performance. Additional research is also needed to determine how emotional design might affect younger populations.

This study used self-ratings of motivation, effort, and difficulty, whereas future research would benefit from more direct measures. This study found significant effects for immediate retention but not for immediate transfer, although the transfer results were in the predicted direction and of small-to-moderate strength. Further research is needed to determine whether the benefits of emotional design can be found on transfer tests and when the tests are delayed, consistent with the idea that deeper learning should persist. Direct measures of motivation and cognitive processing during learning are needed to pinpoint the mechanisms underlying the emotional design effect. Overall, this work is consistent with calls to incorporate affective and motivational factors with cognitive factors to produce a more complete understanding of how people learn from words and pictures.

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