Hindawi
Human Behavior and Emerging Technologies
Volume 2022, Article ID 1235732, 15 pages
https://doi.org/10.1155/2022/1235732

Research Article

Colors and Learner's Gender Evoke Different Emotional and Cognitive Effects in Multimedia Learning

Tze Wei Liew,[1] **Su-Mae Tan**,[2] **Chin Lay Gan**,[1] **and Wei Ming Pang**[1,2]

[1]*Human-Centric Technology Interaction SIG, Faculty of Business, Multimedia University, Jalan Ayer Keroh Lama, Melaka, 75450 Melaka, Malaysia*
[2]*Faculty of Information Science and Technology, Multimedia University, Jalan Ayer Keroh Lama, Melaka, 75450 Melaka, Malaysia*

Correspondence should be addressed to Tze Wei Liew; twliew@mmu.edu.my

Received 17 August 2022; Revised 3 October 2022; Accepted 28 October 2022; Published 8 November 2022

Academic Editor: Zheng Yan

The emotional design principle avers that highly saturated warm colors in multimedia learning presentations can elevate affective-motivational, cognitive, and learning outcomes. While warm and achromatic grayscale color tones have been explored extensively, relatively less research examines the effects of cold colors in multimedia learning. This study explores how color tones (warm, cold, and achromatic grayscale) and learners' gender influence positive emotions, intrinsic motivation, cognitive load, and transfer performance. An online experiment was conducted where learners pursuing IT courses in an Asian university ($n = 204$) engaged with either one of the multimedia learning lessons on distributed denial-of-service attack imbued with (1) a warm color tone, (2) a cold color tone, and (3) an achromatic grayscale color tone. Findings show that the cold color tone was associated with fewer enhanced positive emotion types than the other color tones. Compared to the achromatic grayscale color tone ($M = 2.38$, $SD = 1.88$), significantly higher extraneous cognitive load ratings were observed with the warm color tone ($M = 3.26$, $SD = 1.96$) and the cold color tone ($M = 3.24$, $SD = 2.18$). Following reports by some learners, this could be attributed to the overly vivid and saturated chromatic colors impairing the learners' visual and cognitive processes, causing them to rate the multimedia learning experience with warm and cold color tones as more difficult than with the achromatic grayscale color tone. Male learners in the warm color tone condition ($M = 4.93$, $SD = 3.46$) performed marginally better on the transfer posttest than male learners in the cold color tone condition ($M = 3.49$, $SD = 3.45$) and male learners in the achromatic grayscale color tone condition ($M = 3.44$, $SD = 2.69$). In contrast, female learners in the warm color tone condition ($M = 1.75$, $SD = 1.62$) performed marginally worse than female learners in the cold color tone condition ($M = 3.83$, $SD = 3.92$) and significantly worse than female learners in the achromatic grayscale color tone condition ($M = 3.67$, $SD = 2.50$). Overall, these results show that gender can shape the effects of warm colors on learning—the warm color tone can enhance male learners' but stifle female learners' transfer performance. Moreover, this study aligns with recent studies that colors as an emotional design feature may lead to higher cognitive load ratings. This paper discusses the theoretical and practical implications and submits a future outlook for broadening the research domain.

1. Introduction

The COVID-19 pandemic has precipitated an abrupt shift from conventional physical classrooms to online learning mode [1]. Multimedia learning media, including instructional videos and animations, have become more pervasive due to boosted demands for online learning. A myriad of content authoring tools today, such as Articulate 360, iSpring, Powtoon, and Adobe Captivate, enables instructors to develop multimedia learning videos and animations rapidly and cheaply. While these tools provide limitless choices of color hue, value (lightness or darkness), and chroma (color's purity, intensity, or saturation), instructional designers should not determine multimedia learning colors based on artistic predilections or intuitions. Instead, color choices ought to maximize learning gains, guided by multimedia learning theories that seek to understand how multimedia learning design should conform with learners' cognitive architecture for enhancing affective-motivational, cognitive, and learning outcomes [2, 3].

The emotional design principle is an exciting and emerging research domain applicable to multimedia learning colors [4, 5]. Emotional design refers to the strategy of incorporating multimedia learning aesthetics that can evoke learners' positive emotions and intrinsic motivation to foster learning, often utilizing highly saturated warm colors and anthropomorphic images as emotional design features in multimedia learning environments [6, 7]. Researchers argue that color tones can induce emotional and motivational changes in learners while at the same time retaining the inherent essence or complexity of the instructional information [6]. This concept differs from infusing decorative images that serve purely as aesthetics influencing affective-motivational outcomes but have little or no relevance to the instructional content [8]. Warm colors, including yellow, orange, brown, and red, have longer wavelengths and evoke active, stimulating, and more arousing feelings [9–11]. On the other hand, cold colors comprising green, blue, and violet have shorter wavelengths and are said to evoke comfortable, relaxing, peaceful, and calming emotions [12]. Achromatic colors are characterized by white, gray, and black.

Research has shown that highly saturated warm colors are associated with enhanced pleasure, excitement, and more arousal feelings than cold colors [13, 14]. Nonetheless, the most robust effects have been found between warm colors and achromatic gray colors [15–17]. Emotional design research has often compared highly saturated warm colors against achromatic gray colors, with some findings accentuating the potential of warm colors for enhancing learners' emotional and motivational states [4, 6, 7]. However, less research has been done to explore the effects of cold colors in a multimedia learning environment. Furthermore, research has shown that learners' gender should be accounted for in multimedia learning studies, following evidence that gender robustly affects cognitive and motivational outcomes attributed to gender-related spatial ability, verbal ability, sociocultural norms, subject preferences, situational interest, and perception [18–21]. Relatedly, educational scholars note that learners' gender may influence the emotional design effects of multimedia learning color tones [4, 22]. For instance, Kumar et al. [22] found that a multimedia learning presentation with a dark color tone induced higher motivation and satisfaction in male than female learners, while a multimedia learning presentation with a bright color tone was preferred by female than male learners. Such a research stream builds on color research implying gender differences in color preference, although there are conflicting perspectives. Some studies indicate that females prefer bright and warm colors like yellow and orange while males react more positively to cold and dark colors such as gray and blue [17, 23]. In contrast, other research shows an opposite trend insofar as females favor cold colors more than males while males prefer bright and strong achromatic colors than females [24].

Apart from a few studies [22, 25–27], research is scant on the emotional design effects of cold colors and gender differences in multimedia learning environments. This study addresses the research gap by exploring the confluence of learners' gender and multimedia learning presentations in warm, cold, and achromatic grayscale color tones. Further, the present work involves sample learners from an Asian university, thereby acknowledging the call for emotional design research to account for learner variables such as gender and other cultural context [4]. Overall, the present work is aimed at broadening the emotional design research through a few specifics. First, beyond the emotional design's prototypical comparison of warm versus achromatic grayscale colors, we differentiate the multimedia learning emotional designs into (1) a warm color tone comprising red, orange, and yellow and (2) a cold color tone comprising blue, indigo, and violet, in addition to (3) an achromatic grayscale color tone containing black, white, and gray shades. Second, this study accounts for learners' gender, as there is the initial observation that gender-related preferences, norms, values, and interpretations of colors can modulate the emotional design impact of multimedia learning colors [4, 22]. Similarly, learners' color preferences and expectations may be contextual to specific subject domains, cultural norms, educational backgrounds, and personalities [25–29]. This research involves information technology majors from an Asian university engaging in multimedia learning on how a distributed denial-of-service (DDoS) attack occurs. Hence, this study's findings contribute novel insights into the emotional design effects specific to the learners' cultural and educational profiles and the technical computer-related subject domain. The research questions are formulated as follows:

RQ1: do multimedia learning color tones and learners' gender influence positive emotions?

RQ2: do multimedia learning color tones and learners' gender influence intrinsic motivation?

RQ3: do multimedia learning color tones and learners' gender influence cognitive load (intrinsic, extraneous, and germane) ratings?

RQ4: do multimedia learning color tones and learners' gender influence learning performances?

The next section discusses the theoretical framework and empirical findings surrounding the emotional design effects of colors on affective-motivational, cognitive load, and learning outcomes, drawing on the Cognitive Theory of Multimedia Learning, Cognitive-Affective Theory of Learning with Media, Integrated Cognitive Affective Model of Learning with Multimedia, and Cognitive Load Theory.

2. Theoretical Framework

2.1. Emotional Design. According to the Cognitive Theory of Multimedia Learning, learners process multimedia learning presentation's visual (animation and pictures) and verbal (audio and text) information using two separate channels, one for the visual and the other for the verbal representation [2]. The theory asserts that learners need to select relevant information (S), organize the data into visual and verbal models in the working memory (O), and integrate these models with prior knowledge from the long-term memory to produce meaningful learning (I). The S-O-I model operates under the assumption of limited cognitive resources, drawing on the Cognitive Load Theory positing that people's short-term/working memory can hold about seven plus or minus two information "chunks" at a time [30]. Learning suffers during a cognitive overload, that is, when the overall cognitive demand surpasses the limit of a learner's mental resources. Noteworthy, three load types can be assumed within multimedia learning: (1) intrinsic load to process learning topic-subject information and is impacted by the subject's complexity and learners' prior knowledge; (2) extraneous load to process nonessential information stemming from flawed multimedia learning design, which does not contribute to meaningful learning; and (3) germane load to acquire, construct, and automate knowledge schema that contributes to meaningful learning.

The Cognitive-Affective Theory of Learning with Media, a derivative of the Cognitive Theory of Multimedia Learning, observes that motivational and metacognitive factors mediate learning by augmenting or hampering the learners' cognitive resources devoted to the S-O-I process [31]. The Integrated Cognitive Affective Model Learning with the Multimedia framework extends the abovementioned theories by proposing that converging multimedia learning information into a mental model entails two distinct channels for processing: (1) emotional schemas and (2) visual and verbal information [5, 32]. Thus, emotion and cognition are said to be intertwined and influenced by each other during the S-O-I process. A learner's emotional state is represented by valence (i.e., positive and negative) and activation (i.e., activating and deactivating states). Per the Control-Value Theory of Achievement Emotions, positive and activating emotions like enjoyment can elevate learning and motivation, while deactivating and negative emotions like boredom and hopelessness can hamper learning and motivation [33].

Um et al. [34] postulate two competing perspectives concerning how emotions can affect learning with multimedia learning media. The Emotions as Suppressor implies that emotions can inflict a nonessential load devoted to processing their affective experience and task-irrelevant thoughts, thereby consuming precious cognitive resources [5]. Contrariwise, the Emotions as Facilitator argues that positive and activating emotions enhance motivation and mental effort [33], allow access to more mental resources [35], encourage a more creative thinking style [36], and lead to a deeper comprehension of multimedia learning materials [34].

Leaning on the Emotions as Facilitator viewpoint, the emotional design principle posits that multimedia learning visual and verbal features can be designed to evoke affective and motivational changes in learners to enhance learning performance [4, 32, 34]. Ideally, the emotional design features should conserve the instructional information load by not introducing additional "information chunks" that can complicate the original learning contents [6]. This idea is distinguished from embedding "decorative" or "seductive" pictures or words that can induce emotional and motivational changes in learners but otherwise do not contribute directly to augmenting understanding of the instructional subject [8]. On the other hand, in keeping with this so-called minimalist principle, incorporating highly saturated warm colors in multimedia learning environments has been acknowledged as an effective emotional design strategy because the intrinsic meaning or complexity of the learning contents is less likely to be altered by colors [4, 6, 7, 34, 37].

2.2. Colors as an Emotional Design Feature. The first emotional design study was conducted by Um et al. [34], which imbued a multimedia learning presentation with bright warm colors comprising yellow, orange, and pink and anthropomorphic round shapes, i.e., affixing facial features to visual information. Compared to the neutral multimedia learning design featuring achromatic grayscale colors and square nonanthropomorphic shapes, the pleasant aesthetics induced more positive emotions in learners, enhanced learning performance, and decreased perceived difficulty. Since Um et al.'s [34] seminal work, several studies have examined the effects of highly saturated warm colors, often in conjunction with anthropomorphism and round shapes, as positive emotional designs for multimedia learning [6, 7]. Meta-analyses have indicated that emotional design features, including warm colors and anthropomorphism, generally lead to positive changes in affective-motivational states and perceived effort while decreasing perceived difficulty compared to achromatic grayscale colors with nonanthropomorphic visual representations [6, 7].

However, some studies imply that the emotional design effects may diminish or differ when the color effects are considered separately from anthropomorphism [4, 38]. Plass et al. [4] reproduced and extended Um et al.'s [34] study by isolating the color and anthropomorphism shape effects—it was found that warm colors independently led to enhanced comprehension but did not influence emotions compared to achromatic grayscale colors. Uzun and Yıldırım [38] demonstrated that attention-grabbing, bright, and saturated colors led to higher cognitive effort and retention scores than achromatic grayscale colors. Nevertheless, the study's findings suggest that emotional design featuring pleasing colors alone is generally less robust in enhancing learners' positive emotions than emotional designs converging attractive colors with supplementary aesthetics such as anthropomorphism, expressive faces, and sound.

Few studies manipulated color parameters alone without other emotional design attributes [25, 28, 39]. Wang et al. [28] developed the positive emotional design incorporating both warm and cold colors that follow the natural colors of the visual objects (e.g., ocean, boat, sky, and hut), while the neutral emotional design had achromatic grayscale colors. The study indicated that chromatic colors boosted retention and transfer performance more than achromatic grayscale colors. Interestingly, learners subjected to external positive emotional inducement reported lower perceived difficulty with chromatic colors than with achromatic grayscale colors. Contrariwise, learners subjected to external neutral positive emotional inducement reported lower perceived difficulty with the achromatic grayscale colors version than the chromatic color version. Yang et al. [25] compared two multimedia learning color themes: (1) warm color tone emphasizing red hue and (2) cold color tone emphasizing blue hue. The researchers discovered that the instructional topic's types moderated the learning effects of colors, such that warm color tone was associated with superior learners' transfer scores for Chinese calligraphy but not for the Python programming subject. Emotionwise, the cold color tone was associated with higher negative emotions irrespective of the subjects, but the warm and the cold color tones did not differently impact positive emotions. Peng et al. [39] found that warm colors could facilitate learning performance, visual attention to the learning contents, and willingness to devote mental effort compared to the achromatic black-and-white colors. Nonetheless, the warm colors did not enhance positive emotions but increased perceived learning task difficulty more than achromatic black-and-white colors in the multimedia learning material.

2.3. Warm and Cold Colors in Emotional Design. Positive emotional designs for multimedia learning are associated prototypically with color qualities termed as bright, highly saturated, and warm tones emphasizing yellow, orange, and pink hues [4, 34, 39–42]. The preceding has often contrasted against neutral emotional design colored with achromatic grayscale hues comprising black, white, and gray shades. However, recent emotional design research has extended positive emotional design to integrate cold colors comprising green, blue, and purple alongside warm colors. For instance, positive emotional designs have converged both warm and cold colors to mimic the natural colors of the multimedia learning visual objects, e.g., blue sky, gray cloud, yellow lightning, green tree, and blue ocean water [28, 43–45]. Further, scholars [38, 46] have assigned "appealing" and "attention-grabbing" colors comprising warm and cold color tones, including red, green, and blue, to positive emotional designs. Kumar et al. [22, 26, 27] infused color combinations composed of bright colors of red, blue, and green with bright warm hues of yellow, orange, and brown into the positive emotional design. Interestingly, their studies conceptualized a negative emotional design featuring dark and dull colors of white, brown, and purple.

Although positive emotional designs have merged warm and cold colors, a direct comparison of warm and cold colors' emotional design effects is largely absent in the literature. This poses a research gap as warm and cold colors are theorized to influence emotional and cognitive outcomes differently. Chang and Xu's review [11] observes that warm colors such as red, orange, and yellow are associated with "activating," "stimulating," "arousing," "awakening," "attention-drawing," "exciting," and "lively" feelings, whereas cold (cool) colors such as blue, indigo, and violet tend to induce "restful," "quiet," "calm," "fresh," "peaceful," and "relaxation" experiences. Framed within this study's context, warm colors may be associated with enhanced positive-activating emotions, while cold colors may be related to reduced positive-activating feelings in multimedia learning. If the foregoing is true, to what extent these different learners' emotional states affected by warm and cold colors can influence cognitive and learning factors in a multimedia learning environment is an open inquiry the present research aims to explore.

Visual information imbued with chromatic (including warm and cold colors) than achromatic colors can lead to better cognitive process efficiency insofar as chromatic colors decrease the time for identifying and accessing relevant visual information while facilitating organization and presentation of knowledge schema [11, 47, 48]. This premise underpins, to some extent, the cognitive benefits of "attention-grabbing" chromatic colors over achromatic grayscale colors in emotional design studies [38, 46]. Interestingly, beyond the comparison between chromatic and achromatic colors, there is evidence that warm and cold colors can affect cognitive processes differently [11]. Lindsey et al. [47] observed that warm colors were superior in attracting attention and thus were associated with faster visual search than cold colors. Comparatively, Kuhbandner et al. [49] found that texts in warm colors (yellow and red) were better recalled than texts in cold colors (green and blue). On the other hand, it has been suggested that blue may be associated with better information recall than yellow color, particularly when the colors were applied to a background in multimedia learning slides [50]. Another perspective argues that warm colors (red) activate prevention-focused orientation that benefits detailed-oriented cognitive tasks while cold colors (blue) encourage promotion-focused orientation that benefits creative activities [51, 52].

Different instructional topics may influence the effects of warm and cold colors in multimedia learning. Warm color tone was associated with enhanced learning when applied to Chinese calligraphy, but not for Python programming topic [25]. Plausibly, this could be attributed that learners' preferences and expectations regarding suitable color schemes for certain subject domains—for instance, darker or cold colors (blue-gray combination) might be perceived as more appropriate for technical or engineering-related topics [22, 26, 27]. Relatedly, Wang et al.'s [28] study featured warm and cold colors to evoke visual aesthetics, prompting learners' imagination, perception, and aesthetic appreciation of ancient Chinese poetry. Le et al. [29]'s positive emotional design emphasized the color red, which is linked to positive connotations within the Chinese culture. These observations resonate with Plass et al.'s [4] reasoning that the color effects in multimedia learning are shaped by learners' differences in affective responses to and interpretations of colors contextual to cultural norms and gender profiles.

2.4. Learners' Gender and Emotional Design. Research has accentuated how learners' gender can significantly influence the multimedia learning process in multimedia learning [18, 20, 21]. Often, this premise is based on learners' differences in spatial abilities, i.e., the mental skills to recognize, comprehend, sense, and recall the visual and spatial connections among objects or space [53]. Spatial ability is fundamental for learners engaging with multimedia learning environments to mentally visualize, animate, and manipulate the complex graphical learning information [18, 54]. An existing perspective posits that male learners generally exhibit better spatial abilities than female learners [55, 56]; hence, male learners may benefit more in terms of learning performance than female learners in multimedia learning [18, 20, 21]. Implicatively, learners with higher spatial abilities benefit more from multimedia learning than learners with lower spatial abilities when the presentation features static pictures instead of animated visuals [20, 57, 58].

Concerning colors, some studies imply that females prefer bright and warm colors like yellow and orange, and males respond more positively to cold and dark colors such as gray and blue [17, 23]. On the other hand, others demonstrate that females prefer cold colors more than males while males favor bright and strong achromatic colors more than females [24]. Situated within the emotional design research, Plass et al. [4] highlight that learners' gender can modulate the affective-motivational, cognitive, and learning effects of emotional design features including colors. Kumar et al. [22] found that male learners reported higher preference, satisfaction, and intrinsic motivation with darker colors than females, whereas female learners ascribed more preference to bright warm colors.

3. Method

3.1. Research Design. This research employed a between-subject experimental design involving learners interacting with either one of the three multimedia learning materials differentiated by the color themes: (1) a warm color tone comprising red, orange, and yellow; (2) a cold color tone comprising blue, indigo, and violet; and (3) an achromatic grayscale tone comprising shades of white, black, and gray. We utilized an online survey platform to administer the multimedia learning presentation, survey, and posttest within the experiment.

3.2. Multimedia Learning Presentations in Warm, Cold, and Achromatic Grayscale Colors. We created a 165-second multimedia learning presentation describing the process of a distributed denial-of-service (DDoS) attack. The presentation contained 11 slides with static images denoting servers, malware, botnets, network, computers, and data. We used static rather than animated images because the emotional design effects, particularly for motivation, may be more apparent when multimedia learning materials convey visuals statically than animatedly [7]. The verbal instructional content was presented via spoken narration rather than written, conforming with sound multimedia learning (Cognitive Theory of Multimedia Learning) that optimizes cognitive load while promoting learning performance [2, 3]. We utilized Amazon Alexa's text-to-speech engine (default voice tone) to produce the voice-over to narrate the multimedia learning in English. The multimedia learning content was rated with a Flesch-Kincaid Grade Level of 9.7, which is deemed fit for a college student's comprehension standard. Except for the color tones, all the narration, images, and layout were constant across the three multimedia learning presentations. Following the conceptualization of color associations with affective and cognitive states [11, 25, 27], the emotional design parameter was operationalized through three distinct color themes:

(1) Warm color tone comprising red, orange, and yellow

(2) Cold color tone containing blue, indigo, and violet

(3) Achromatic grayscale tone consisting of shades of white, black, and gray

Figures 1–3 illustrate the sample multimedia learning presentation visuals in warm, cold, and achromatic grayscale color tones, respectively.

4. Instruments

4.1. Prior Knowledge. Learners' prior knowledge of the learning topic was measured by averaging the scores of three items within a ten-point Likert scale survey: (1) How much knowledge about distributed denial of service do you have? (2) How much understanding of distributed denial of service do you have? (3) How much familiarity with distributed denial of service do you have? The scale was reliable ($\alpha > 0.8$).

4.2. Positive Emotions. Conventionally used in emotional design studies [4, 34], the Positive Affect Scale (PAS) measured learners' positive emotions by summing ten items denoting an array of positive feelings on a five-point Likert scale [59]. The scale was reliable ($\alpha > 0.8$).

4.3. Intrinsic Motivation. We assessed learners' intrinsic motivation by totaling the scores of the eight items of the seven-point Likert scale Intrinsic Motivation Scale [36], typically employed in emotional design studies [4, 34]. The scale was reliable ($\alpha > 0.8$).

4.4. Cognitive Load. We measured learners' cognitive load ratings by adopting Leppink's eleven-point Likert scale [60], distinguishing intrinsic load (three items), extraneous load (three items), and germane load (four items). All the subscales were reliable ($\alpha > 0.7$).

4.5. Learning Performance. We assessed learning performance by administering retention and transfer posttests. For the retention test, learners were asked to recall as follows:

(1) The motivations behind a distributed denial-of-service attack—with one mark awarded for each correct response, e.g., monetary, fun, or political factors

(2) The distributed denial-of-service's seven steps—with one mark awarded for each correct step

For the transfer test, learners were required to give as many possible answers to the following scenarios:

(1) How would you make a distributed denial-of-service attack more effective if you were an attacker? For each acceptable answer, one mark was given, e.g., infusing a Trojan virus on an unsecured website or the router

(2) How would you prevent (avoid) a distributed denial-of-service attack if you are a server administrator? For each acceptable answer, one mark was given, e.g., updating antivirus and firewall, promoting security awareness, or routine check-ups

(3) How would you prevent (avoid) the risk of your personal computers or other personal devices getting infected and becoming botnets if you were a computer user? One mark was given for each acceptable answer, e.g., ignoring suspicious emails, activating

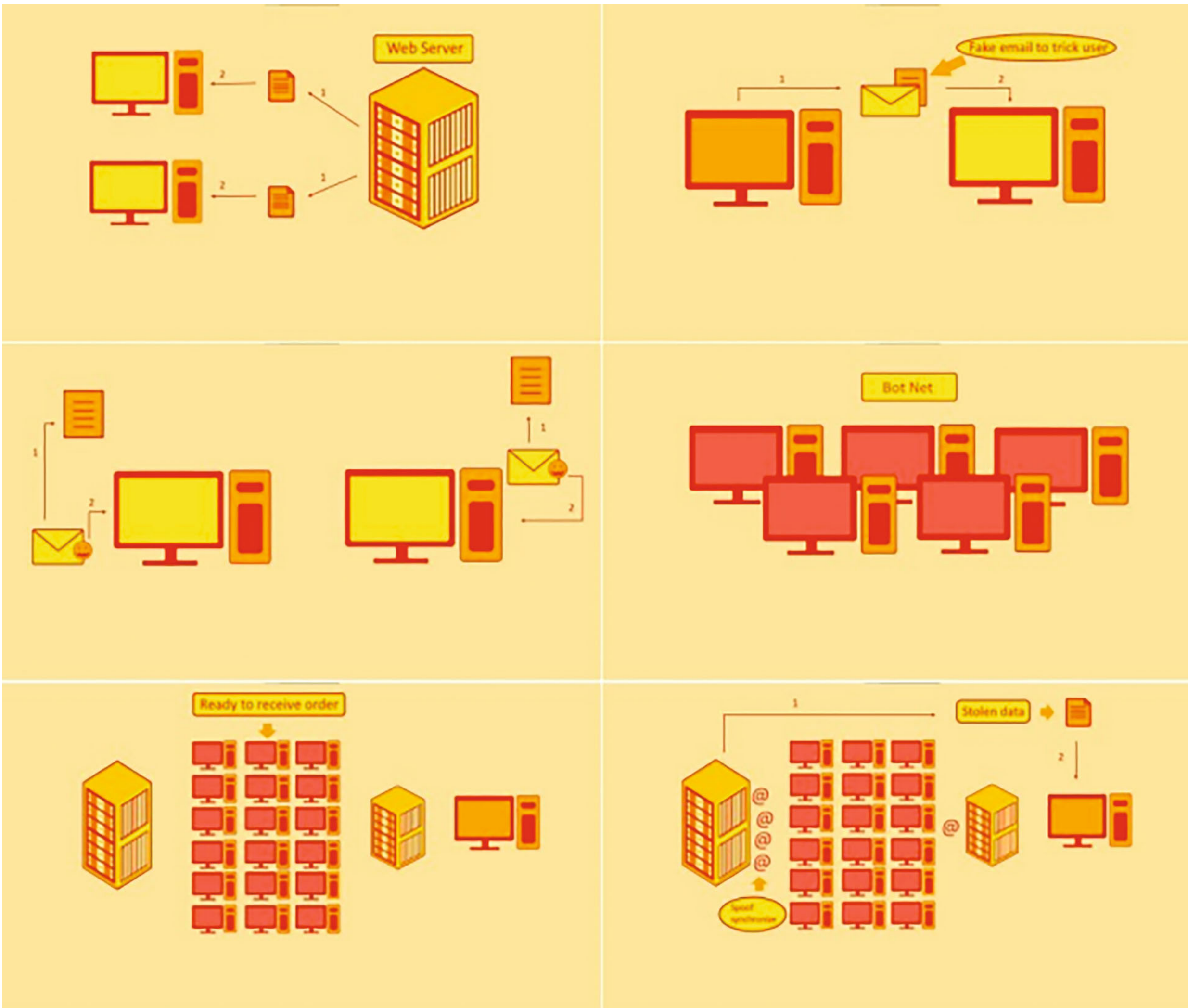

Figure 1: Sample multimedia learning visuals using warm color tone.

antivirus and firewall, or performing regular updates on antivirus

Two authors of this study referred to a prepared answer scheme guideline when scoring the posttest blind to the experimental conditions. The scores were highly consistent, with minimal disparities resolved through consensus between the scorers.

4.6. Participants and the Online Experiment. The emotional design effects can be modulated by learners' cultural traits, linguistic profile, prior subject knowledge, and educational background [4, 6, 7, 44, 45]. Thus, we set the sample participants as homogeneous as possible by involving only IT major first-year students in a large private Asian university with English as the instructional medium. More specifically, we targeted learners in their first trimester of the IT courses to obtain relatively novice learners, i.e., low prior knowledge of the instructional topic (as the learners have yet to be exposed to distributed denial-of-service attack topic within their courses). We conveyed an e-vite through emails, social media, and postings in course management systems to recruit participation in exchange for an e-voucher. The e-vite contained the link to access the online experiment platform (Alchemer) with introductory instructions for learners to

(1) use desktop or laptop rather than mobile devices

(2) use headphones, earphones, or high-quality speakers

(3) engage with the learning activity in a nondistractive environment

Over two weeks, IT majors ($n = 204$, males = 68%, females = 32%, all aged between 18 and 24) accessed the online experiment platform to engage with one of the three multimedia learning versions—warm, cold, or achromatic grayscale color and completed the surveys and posttest. Through the online experiment platform, we implemented measures for providing as much experimental control as possible within the chronological steps depicted as follows:

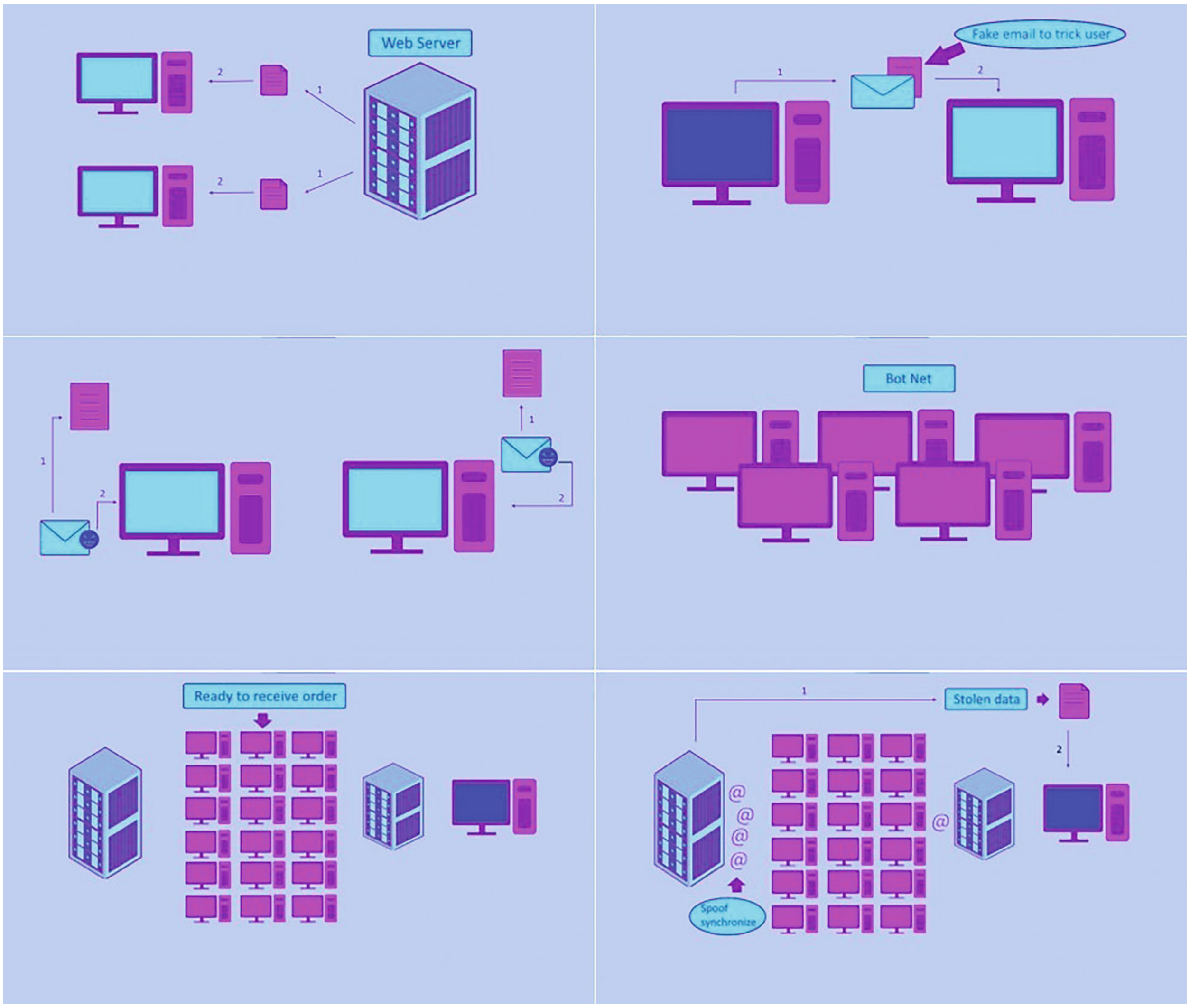

Figure 2: Sample multimedia learning visuals using cold color tone.

(1) The online experiment platform had a feature that permitted only learners to log on through desktops or laptops but prohibited logging on from mobile devices

(2) The online experiment platform allowed learners to log on to the experiment activity using their official university email address only once to forbid more than one attempt

(3) The online experiment platform asked learners to indicate informed consent through a checkbox

(4) The online experiment platform reminded learners to utilize earphones/headphones and delivered an audio test where learners had to type the correct spoken code before being granted access to the next page

(5) The online experiment platform administered surveys on demographics, distributed denial-of-service prior knowledge, and baseline positive emotions (Positive Affect Scale)

(6) The online experiment platform randomized the learners to engage with either one of the three multimedia learning—(1) warm, (2) cold, or (3) achromatic grayscale color versions. Learners were allowed to replay the respective multimedia learning material within ten minutes but could not access it after moving to the next phase

(7) The online experiment platform administered surveys on positive emotions after the multimedia learning (Positive Affect Scale), intrinsic motivation (Intrinsic Motivation Scale), and cognitive load ratings (Leppink's scale)

(8) The online experiment platform issued the retention and the transfer posttest with a system-facilitated timer: retention question 1 had three minutes each, whereas the remaining questions had eight minutes

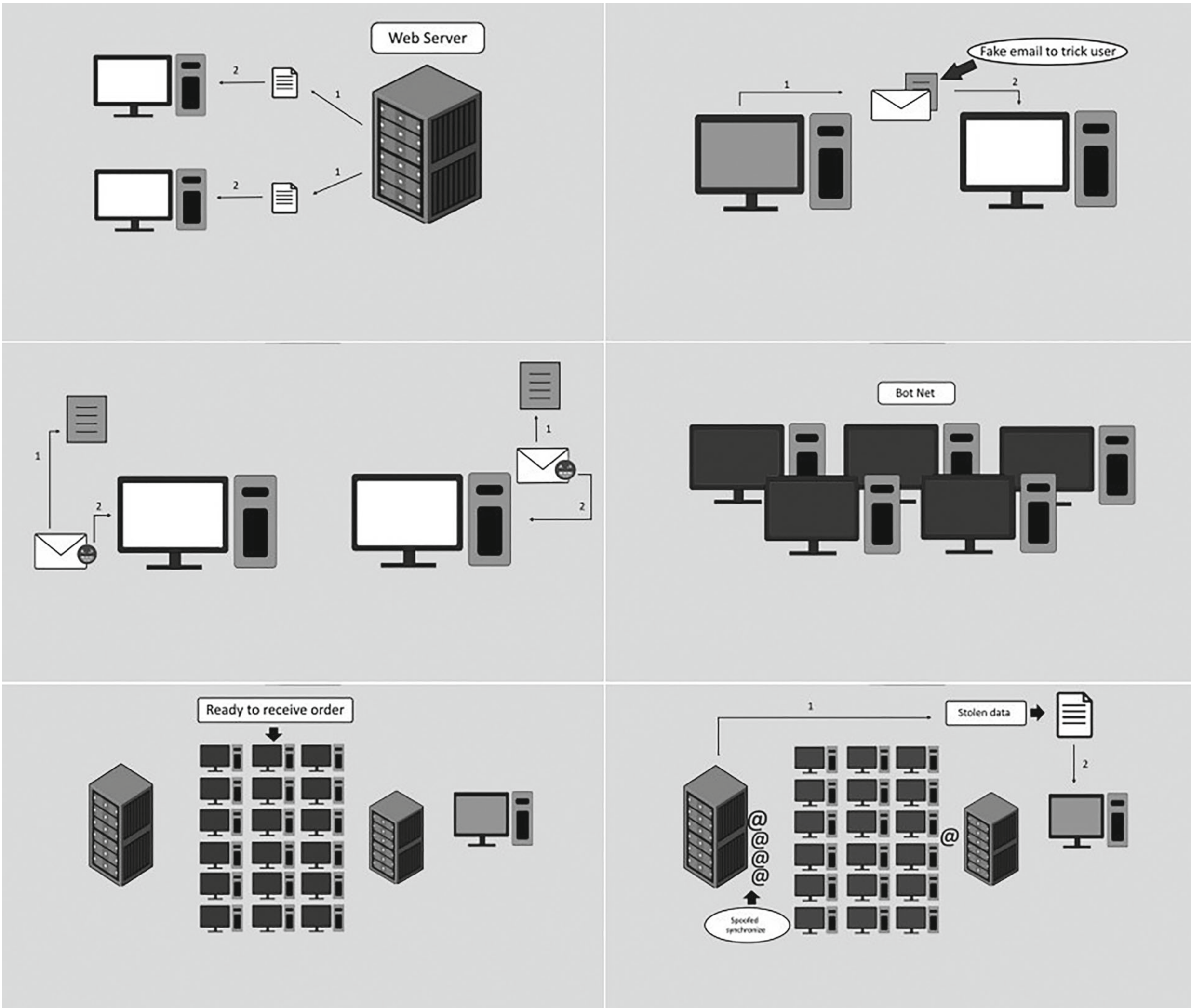

Figure 3: Sample multimedia learning visuals using achromatic grayscale color tone.

each. The webpage prompted learners not to obtain solutions externally and guaranteed that the posttest scores would not concern their course grades

(9) The online experiment platform thanked and debriefed the learners

5. Data Analyses and Results

5.1. Descriptive Data. Table 1 presents the means and standard deviations of the measures by multimedia learning color tones and learners' gender.

5.2. Does Learners' Prior Knowledge about the Instructional Topic Differ between the Multimedia Learning Color Tones and the Learners' Gender Conditions? A 2 (multimedia learning colors) $\times$ 2 (learners' gender) ANOVA with prior knowledge as the dependent variable found that the interaction effect and the main effects of the multimedia learning color tones and the learners' gender were nonsignificant, all p values > 0.05. Accordingly, the random assignment effectively created conditions equivalent in the learner's prior knowledge about the instructional topic.

5.3. Do Learners' Baseline Positive Emotions Differ between the Multimedia Learning Color Tones and the Learners' Gender Conditions? A 2 (multimedia learning colors) $\times$ 2 (learners' gender) ANOVA with PAS scores obtained before the learning engagement as the dependent variable found that the interaction effect and the main effects of the multimedia learning color tones and the learners' gender were nonsignificant, all p values > 0.05. Hence, the random assignment effectively created conditions equivalent in the learners' baseline positive emotions.

5.4. Do Multimedia Learning Color Tones and Learners' Gender Influence Positive Emotions? We conducted a 3 (multimedia learning color tones) $\times$ 2 (learner's gender) ANCOVA with Positive Affect Scale scores obtained before the learning engagement as a covariate and Positive Affect Scale scores reported after the learning engagement as the dependent variable. The results showed that the interaction

Table 1: Means and standard deviations of the measures for the e-learning color tones and learners' gender.

	Warm color tone			Cold color tone			Achromatic grayscale color tone		
	Male $n = 46$ M (SD)	Female $n = 20$ M (SD)	Total $n = 66$ M (SD)	Male $n = 43$ M (SD)	Female $n = 24$ M (SD)	Total $n = 67$ M (SD)	Male $n = 50$ M (SD)	Female $n = 21$ M (SD)	Total $n = 71$ M (SD)
Prior knowledge	3.47 (2.10)	3.62 (1.61)	3.52 (1.95)	3.09 (1.83)	3.76 (1.87)	3.33 (1.86)	3.85 (2.20)	3.85 (1.11)	3.85 (1.93)
Positive emotions before learning	31.93 (8.31)	30.50 (5.83)	31.50 (7.63)	29.81 (6.23)	31.21 (8.19)	30.31 (6.97)	29.02 (5.43)	33.05 (6.75)	30.21 (6.10)
Positive emotions after learning	34.61 (7.83)	32.15 (6.64)	33.86 (7.52)	30.81 (7.65)	33.00 (8.19)	31.60 (7.86)	31.92 (7.44)	34.81 (6.42)	32.77 (7.23)
Intrinsic motivation	38.80 (9.51)	38.05 (7.24)	38.58 (8.83)	34.88 (9.83)	40.17 (9.12)	36.78 (9.85)	35.90 (8.98)	40.34 (7.63)	37.21 (8.79)
Intrinsic load	4.39 (2.33)	4.32 (2.19)	4.37 (2.27)	4.56 (2.23)	5.14 (2.13)	4.77 (2.20)	4.19 (2.28)	4.19 (2.19)	4.19 (2.24)
Extraneous load	3.40 (2.05)	2.95 (1.71)	3.26 (1.96)	3.43 (2.22)	2.90 (2.13)	3.24 (2.18)	2.53 (1.94)	2.03 (1.73)	2.38 (1.89)
Germane load	6.57 (1.81)	6.29 (1.71)	6.48 (1.77)	5.66 (2.09)	6.35 (1.80)	5.91 (2.01)	6.24 (1.94)	6.27 (1.92)	6.25 (1.92)
Retention	2.07 (2.41)	0.85 (1.04)	1.70 (2.16)	1.42 (2.29)	1.21 (1.74)	1.34 (2.10)	2.16 (2.16)	0.95 (1.28)	1.80 (2.01)
Transfer	4.93 (3.47)	1.75 (1.62)	3.97 (3.36)	3.49 (3.45)	3.83 (3.92)	3.61 (3.60)	3.44 (2.69)	3.67 (2.50)	3.51 (2.62)

between the effects of multimedia learning color tones and learners' gender on positive emotions after the learning engagement was nonsignificant ($F(2,197) = 0.95$, $p = 0.39$, ${\eta_p}^2 = 0.01$). Moreover, the main effects of colors ($F(2,197) = 0.89$, $p = 0.41$, ${\eta_p}^2 = 0.01$) and gender ($F(1,197) = 0.21$, $p = 0.65$, ${\eta_p}^2 = 0.00$) on positive emotions after the learning engagement were nonsignificant. Hence, the multimedia learning color tones and learners' gender did not differently affect learners' positive emotions after the learning engagement.

We then computed paired samples t-tests to explore whether learners' positive emotions change upon engaging with the multimedia learning materials in the warm, cold, and achromatic grayscale color tones. The results showed that learners increased their total positive emotions after engaging with the multimedia learning presentations in the warm, cold, and achromatic grayscale color tones. However, when we analyzed each emotion type of the Positive Affect Scale separately, the data demonstrated that the multimedia learning color tones enhanced different positive emotion types, as shown in Table 2. The learners in the warm color tone condition had enhanced six positive affect types: interested, excited, enthusiasm, alert, inspired, and active. The learners in the neutral color tone condition experienced seven heightened positive affect types: interested, excited, strong, alert, inspired, attentive, and active. Contrariwise, only three elevated positive affect types were associated with the cold color tone: interested, proud, and alert.

5.5. Do Multimedia Learning Color Tones and Learners' Gender Influence Intrinsic Motivation? A 3 (multimedia learning color tones) × 2 (learner's gender) ANOVA with Intrinsic Motivation Scale scores as the dependent variable revealed that the interaction between the effects of multimedia learning color tones and learners' gender on intrinsic motivation was nonsignificant ($F(2,198) = 1.88$, $p = 0.16$, ${\eta_p}^2 = 0.02$). The main effect of multimedia learning color tones on intrinsic motivation was also nonsignificant ($F(2,198) = 0.15$, $p = 0.86$, ${\eta_p}^2 = 0.00$). However, the main effect of learners' gender on intrinsic motivation was statistically significant ($F(1,198) = 4.82$, $p = 0.03$, ${\eta_p}^2 = 0.02$). Across the multimedia learning color tones, the female learners ($M = 39.57$, SD = 8.04) collectively reported higher intrinsic motivation than the male learners ($M = 36.55$, SD = 9.50).

5.6. Do Multimedia Learning Color Tones and Learners' Gender Influence Cognitive Load? A 3 (multimedia learning color tones) × 2 (learner's gender) ANOVA with Leppink's Intrinsic Cognitive Load Scale scores as the dependent variable demonstrated that the interaction between the effects of multimedia learning color tones and learners' gender on intrinsic cognitive load ratings was nonsignificant ($F(2,198) = 0.38$, $p = 0.68$, ${\eta_p}^2 = 0.00$). Likewise, the results showed that the main effects of multimedia learning color tones ($F(2,198) = 1.40$, $p = 0.25$, ${\eta_p}^2 = 0.01$) and learners' gender ($F(1,198) = 0.25$, $p = 0.62$, ${\eta_p}^2 = 0.00$) on intrinsic cognitive load ratings were nonsignificant.

A 3 (multimedia learning color tones) × 2 (learner's gender) ANOVA with Leppink's Extraneous Cognitive Load Scale scores as the dependent variable indicated that the interaction between the effects of multimedia learning color tones and learners' gender on extraneous cognitive load ratings was nonsignificant ($F(2,198) = 0.00$, $p = 0.99$, ${\eta_p}^2 = 0.00$

Table 2: Paired samples t-test t-values and p values of each positive emotion type and total Positive Affect Scale scores for the e-learning color tones.

	Warm color tone	Cold color tone	Achromatic grayscale color tone
Interested	$t(65) = 3.91$, $p = 0.00^{**}$	$t(66) = 2.49$, $p = 0.02^{*}$	$t(70) = 3.49$, $p = 0.00^{**}$
Excited	$t(65) = 3.46$, $p = 0.00^{**}$	$t(66) = 1.49$, $p = 0.14$	$t(70) = 3.32$, $p = 0.00^{**}$
Strong	$t(65) = 1.14$, $p = 0.26$	$t(66) = 0.73$, $p = 0.47$	$t(70) = 2.79$, $p = 0.01^{*}$
Enthusiastic	$t(65) = 2.16$, $p = 0.04^{*}$	$t(66) = 1.83$, $p = 0.07$	$t(70) = 1.24$, $p = 0.22$
Proud	$t(65) = 1.43$, $p = 0.16$	$t(66) = 0.36$, $p = 0.72$	$t(70) = 1.09$, $p = 0.28$
Alert	$t(65) = 5.08$, $p = 0.00^{**}$	$t(66) = 2.63$, $p = 0.01^{*}$	$t(70) = 5.89$, $p = 0.00^{**}$
Inspired	$t(65) = 3.91$, $p = 0.01^{*}$	$t(66) = 3.16$, $p = 0.00^{**}$	$t(70) = 3.01$, $p = 0.00^{**}$
Determined	$t(65) = 0.81$, $p = 0.42$	$t(66) = 0.21$, $p = 0.84$	$t(70) = 1.74$, $p = 0.09$
Attentive	$t(65) = 1.29$, $p = 0.20$	$t(66) = 1.43$, $p = 0.16$	$t(70) = 3.29$, $p = 0.00^{**}$
Active	$t(65) = 2.20$, $p = 0.03^{*}$	$t(66) = 0.00$, $p = 1.00$	$t(70) = 2.30$, $p = 0.02^{*}$
Total PAS scores	$t(65) = 4.15$, $p = 0.00^{**}$	$t(66) = 2.48$, $p = 0.02^{*}$	$t(70) = 4.75$, $p = 0.00^{**}$

). The main effect of learners' gender on extraneous cognitive load ratings was nonsignificant ($F(1,198) = 2.63$, $p = 0.106$, $\eta_p^2 = 0.01$). On the other hand, the main effect of multimedia learning color tones on extraneous cognitive load ratings was significant ($F(2,198) = 3.87$, $p = 0.02$, $\eta_p^2 = 0.04$). Multiple comparisons through Tukey's HSD test revealed significant differences in extraneous cognitive load ratings between the warm color tone and the achromatic grayscale color tone ($p = 0.03$) and between the cold color tone and the achromatic grayscale color tone ($p = 0.03$). Specifically, the warm color tone ($M = 3.26$, SD = 1.96) and the cold color tone ($M = 3.24$, SD = 2.18) led to significantly higher extraneous cognitive load ratings than the achromatic grayscale color tone ($M = 2.38$, SD = 1.88).

A 3 (multimedia learning color tones) × 2 (learner's gender) ANOVA with Leppink's Germane Cognitive Load Scale scores as the dependent variable indicated that the interaction between the effects of the multimedia learning color tones and learners' gender on germane cognitive load ratings was nonsignificant ($F(2,198) = 1.09$, $p = 0.36$, $\eta_p^2 = 0.01$). The main effects of multimedia learning color tones ($F(2,198) = 0.73$, $p = 0.48$, $\eta_p^2 = 0.00$) and learners' gender ($F(1,198) = 0.28$, $p = 0.60$, $\eta_p^2 = 0.00$) on germane cognitive load ratings were also nonsignificant.

5.7. Do Multimedia Learning Color Tones and Learners' Gender Influence Learning Performance? A 3 (multimedia learning color tones) × 2 (learner's gender) ANOVA with retention posttest scores as the dependent variable found that the interaction between the effects of multimedia learning color tones and learners' gender on retention performance was nonsignificant ($F(2,198) = 1.19$, $p = 0.31$, $\eta_p^2 = 0.01$. The main effect of multimedia learning color tones on retention performance was also nonsignificant ($F(2,198) = 0.21$, $p = 0.81$, $\eta_p^2 = 0.00$). However, the main effect of learners' gender on retention performance was significant ($F(1,198) = 8.06$, $p = 0.01$, $\eta_p^2 = 0.04$). Regardless of the multimedia learning color tones, male learners ($M = 2.40$, SD = 2.43) collectively outperformed female learners ($M = 1.39$, SD = 1.61) on the retention posttest.

A 3 (multimedia learning color tones) × 2 (learner's gender) ANOVA with transfer posttest scores as the dependent variable determined that the interaction between the effects of multimedia learning color tones and learners' gender on transfer performance was significant ($F(2,198) = 5.93$, $p = 0.00$, $\eta_p^2 = 0.06$), thereby qualifying additional simple effect analyses. Analyzing the learners' gender separately, the one-way ANOVAs revealed significant differences in transfer posttest scores across the multimedia learning color tones among the male learners ($F(2,136) = 3.26$, $p = 0.04$, $\eta_p^2 = 0.05$) and female learners ($F(2, 62) = 3.29$, $p = 0.04$, $\eta_p^2 = 0.10$). Concerning the male learners, the assumption of homogeneity of variance was not violated per Levene's test for homogeneity of variances ($p > 0.05$); hence, Tukey's HSD post hoc tests were utilized. The results indicated that the male learners in the warm color tone condition ($M = 4.93$, SD = 3.46) performed marginally better on transfer posttest than the male learners in the cold color tone condition ($M = 3.49$, SD = 3.45) ($p = 0.08$) and the male learners in the achromatic grayscale color tone condition ($M = 3.44$, SD = 2.69) ($p = 0.06$). For the female learners, the assumption of homogeneity of variance was violated per Levene's test for homogeneity of variances ($p < 0.05$); thus, the Games-Howell post hoc tests were employed. The results showed that the female learners in the warm color tone condition ($M = 1.75$, SD = 1.62) performed marginally worse than the female learners in the cold color tone condition ($M = 3.83$, SD = 3.92) ($p = 0.06$) and significantly worse than the female learners in the achromatic grayscale color tone condition ($M = 3.67$, SD = 2.50) ($p = 0.02$). Examining the multimedia learning color tones individually, the one-way ANOVAs demonstrated a significant difference in transfer posttest scores between the male and the female learners in the warm color tone condition ($F(1, 64) = 15.37$, $p = 0.00$, $\eta_p^2 = 0.19$)—the male learners in the warm color tone condition ($M = 4.93$, SD = 3.46) had better transfer performance than the female learners in the warm color tone condition ($M = 1.75$, SD = 1.62).

The results above collectively demonstrate that the male learners performed better on retention posttest than the female learners, irrespective of the multimedia learning color tones. Noteworthy, the multimedia learning color tones differently influence the transfer performance of the male and female learners. Specifically, the warm color tone was associated with enhanced transfer performance among the male learners; in contrast, the warm color tone led to decreased transfer performance among the female learners.

5.8. Summary of Findings. Table 3 presents the summary of this study's findings.

6. Discussion

This study contributes novel findings and insights into the emotional design research. Both the male and female learners across the multimedia learning materials in the warm, cold, and achromatic grayscale color tones had increased overall positive emotions (sum of all the Positive Affect Scale's item scores) after the learning engagement compared to their baseline positive emotions. However, a closer inspection indicates that the warm and the cold color tones were associated with augmenting different positive emotion types (see Table 2). The learners who engaged with the multimedia learning material in the warm color tone experienced increased positive emotions for "interested," "excited," "enthusiasm," "alert," "inspired," and "active" compared to their baseline positive emotions. In contrast, the learners who engaged with the multimedia learning in the cold color tone experienced increased positive emotions for "interested," "proud," and "alert" compared to their baseline positive emotions. This observation supports the color literature [11] and emotional design research [6, 7] linking warm colors with enhanced arousal, attention, and stimulation. By the same token, the cold color tone intensified relatively less positive emotion types and notably did not heighten high-arousal affects like "excited," "enthusiasm," and "active" compared to the warm color tone, arguably because cold colors are associated with low-arousal emotions such as relaxation and calmness [11].

This study's data indicated that the warm color tone did not lead to more positive-activating emotions than the achromatic grayscale color tone—in fact, they elevated comparatively similar types of positive-activating affects (see Table 2). The female learners were more intrinsically motivated than the male learners irrespective of the different color tones applied in the multimedia learning presentations. This finding converges with and adds new insight into the recent discourse on the gender difference in motivational outcomes, as well as the inference that female than male learners tend to exhibit more situational interest, motivation, and positive perception toward multimedia learning activities [19, 61]. Apart from the learners' gender, the multimedia learning color tones did not differently impact intrinsic motivation. The preceding, taken in conjunction with the finding that the warm and the cold color tones were not superior to the achromatic grayscale color tone in increasing positive emotions, implies that chromatic colors alone without accompanying emotional design features such as anthropomorphism may be less robust in enhancing learners' affective-motivational states, echoing similar discoveries [4, 28, 38, 39].

Interestingly, learners ascribed significantly higher extraneous cognitive load ratings when interacting with the multimedia learning materials in the warm and the cold color tones than the multimedia learning presentation in the achromatic grayscale color tone. Given that Leppink et al.'s [60] extraneous cognitive load scale is indicative of learners' perception of difficulty stemming from instructional design flaws, thus, the warm and the cold color tones could have imposed distractions or challenges hampering fluent processing of the multimedia learning contents visually and cognitively. This result contravenes prototypical inference that positive emotional designs including chromatic colors tend to reduce learners' cognitive load or perceived difficulty compared to neutral emotional designs incorporating achromatic grayscale colors [4, 29, 34, 42, 62]—a premise that draws on the notion that pleasing aesthetics can prime learners to biasedly presume that the materials are easier to understand [6, 7].

On the other hand, this result is comparable with the nascent reports that chromatic colors could lead to greater perceived difficulty than achromatic colors [28, 39, 45]. Some plausible reasons underpinning this phenomenon have been cited: (1) the emotional design aesthetics compel learners to allocate cognitive resources for emotional regulation apart from attending to the learning contents [45], which coheres with the Emotions as Suppressor hypothesis [5, 32, 34], and (2) the incongruency between learners' neutral emotion before the learning engagement and positive emotional induction via chromatic colors in the multimedia learning material can stifle cognitive efficiency [28], per the mood-affect congruency hypothesis [63]. Within this study's context, the learners in the warm and the cold color tone conditions might have reported more extraneous load ratings because the applied colors were very vivid and highly saturated, which could have impeded efficient visual search and attention to the learning contents [64, 65]. Indeed, a few learners in this study have characterized the chromatic colors as "overly colorful," "too strong," and "too intense," forming negative feedback about the warm and the cold color tones. Specifically, an overly strong concentration of color saturation and intensity, irrespective of warm or cold color temperatures, could overwhelm people's visual senses and thus become distractors that challenge the visual search and cognitive processing of information [66]. Indeed, studies [65, 66] have observed that subdued or pale color tones, regardless of color temperatures, in a learning environment were favored more by learners, whereas vivid and highly saturated colors were acknowledged by learners as distractive, overstimulating, annoying, and inducing eye fatigue.

This study found that learners' gender distinctively influenced learning performance with the multimedia learning materials in different color tones. Male learners outperformed female learners on the retention test regardless of the color tones applied in the multimedia learning materials.

Table 3: Summary of findings for each measure.

	Findings
Positive emotions	The e-learning color tones and learners' gender did not affect learners' total positive emotions after the learning engagement. However, the cold color tone elevated lesser positive emotion types than the warm and the achromatic grayscale color tones.
Intrinsic motivation	The female learners reported higher intrinsic motivation than the male learners, irrespective of the e-learning color tones.
Intrinsic load	The e-learning color tones and learners' gender did not affect learners' intrinsic cognitive load ratings.
Extraneous load	The warm and the cold color tones led to higher extraneous cognitive load ratings than the achromatic grayscale color tone.
Germane load	The e-learning color tones and learners' gender did not affect learners' germane cognitive load ratings.
Retention	The male learners outperformed the female learners on the retention posttest, irrespective of the e-learning color tones.
Transfer	Compared to the cold and the achromatic grayscale color tones, the warm color tone enhanced the male learners' transfer posttest performance but decreased the female learners' transfer posttest performance.

This finding could be attributed to male than female learners generally possessing better spatial abilities for visualizing, managing, and relating graphical information during the multimedia learning process, which are even more crucial when the multimedia learning presentation utilizes static instead of animated visuals [18, 20, 21, 57, 58]. For transfer performance, however, the warm color tone led to contrasting effects between the male and the female learners. Compared to the cold and the achromatic grayscale color tones, the warm color tone enhanced the male learners' transfer performance but hampered the female learners' transfer performance. One perspective is that the male learners might have a more favorable perception toward the warm color tone than the female learners [24]; thus, the difference in the warm color inclination between the male and female learners could have facilitated or impeded deep processing of the multimedia learning materials [4]. From another viewpoint, this finding converges with the positive effects of warm colors on learning outcomes [4, 25, 39], although this study's male than the female learners might have higher spatial abilities and hence exhibited more cognitive resources or efficiency to benefit from the warm colors for a deeper learning process. Contrariwise, the female learners in this study might have lower spatial abilities and therefore were disadvantaged by static visual presentations compared to the males [18, 20]; thus, the cognitive deficiency could have framed the warm colors as visual and mental distractors that stifled deep learning among the female learners. Overall, this study offers new insights into the confluence of learners' gender and multimedia learning colors, as well as substantiating the notion that learners' gender modulates the affective-motivational, cognitive, and learning outcomes of colors [4, 22].

6.1. Implications for Theory and Practice. This study conforms with Plass and Kaplan [32]'s Integrated Cognitive Affective Model of Learning with Multimedia and Emotional Design thesis, demonstrating that aesthetics in multimedia learning materials can influence learners' affective-motivational, cognitive, and learning outcomes. An interesting detail related to the Cognitive Load Theory [2, 30] is that this study supports the Emotions as Suppressor hypothesis [5, 34] insofar as the vivid warm and cold color tones applied to the multimedia learning presentations could lead to higher extraneous load ratings. This coheres with the theorizing that aesthetics aimed at evoking positive emotions can have an opposing and undesirable effect on extraneous cognitive load when the emotional design attributes unwittingly impair or detract learners' attention and cognitive processing away from relevant information, i.e., the seductive detail effect [67], as well as potentially causing learners to allocate additional mental resources for emotional regulation. Last but not least, the gender effects found in this study relate to the individual differences principle of the Cognitive Theory of Multimedia Learning [2], which advocates accounting for diverse learners' attributes that can influence the effects of a multimedia learning design.

The findings of this study show that warm colors benefited male learners' while harming female learners' transfer performance. Thus, it is notable that color design in multimedia learning materials should not subscribe to the "one-size-fits-all" approach. Moreover, very vivid and highly saturated chromatic colors may impose a higher cognitive load as they can induce difficulty and eye fatigue during the visual search process as well as lead to mental distraction due to the overly concentrated colors being perceived as annoying and unpleasant. Hence, this study advocates applying chromatic color tones with subdued or pale intensity rather than strong, vivid colors [65]. In line with our data indicating that the warm and the cold color tones can evoke different types of emotions, we offer that instructional designers should decide on colors based on the types of learners' emotional states relevant to specific subjects [25, 26, 28] or learning tasks [51, 52]. In other words, a multimedia learning activity requiring more positive-activating emotions should be imbued with warm colors, whereas an e-learning activity benefiting from low-arousal feelings like calmness and relaxation can utilize cold colors.

6.2. Limitations and Future Outlook. Certain limitations exist in this study. Our learners engaged with the experimental activities online; thus, this study's findings possess higher ecological and external validity due to the more naturalistic and realistic settings. However, while our procedure involved steps in exerting controls within the online experiment, it might still lack the precise control measures of a laboratory experiment design, thereby influencing the results of this study. Given that the emotional design effects are shaped by learners' characteristics, including culture, prior knowledge, and educational background [4, 22, 26, 27, 44, 45], this study's findings may not be fully generalized beyond our learners' specific profiles. This study's relatively short multimedia learning presentation (165 seconds) could not discern between the novelty or habituation effects concerning the affective-motivational, cognitive, and learning effects of colors. Future works featuring laboratory experimental designs, diverse learners' characteristics and profiles, and longer multimedia learning presentations can address the limitations above.

We offer some recommendations for broadening the research field. This study utilized the Positive Affect Scale derived from the PANAS scale [59] to measure the positive emotions of learners, situated within the emotional design research's typical scope [4, 6, 7, 34]. Noteworthy, a small but increasing number of emotional design studies have incorporated negative emotions into the conceptualization and measurement, e.g., the Negative Affect Scale of the PANAS scale in exploring the effects of emotional design features, including colors [4, 25, 40, 68]. Extending the research domain to negative emotions can supply unique insights into how multimedia learning colors can influence affective-motivational, cognitive, and learning outcomes in light of empirical findings showcasing the interplay between colors, negative emotions, and learning outcomes [25, 68, 69]. Relatedly, Le et al. [29] observes that the PANAS scale measures limited emotion types while emphasizing high-activation emotional states, thereby excluding other potentially relevant emotions in emotional design research, such as low-activation affects like calm and relaxation. As cold colors have been theorized to elicit low-arousal emotions, e.g., "restful," "quiet," "calm," "fresh," "peaceful," and "relaxation," therefore utilizing other survey models can render a more accurate indication of learners' emotional states when exposed to different multimedia learning color tones. Finally, this research stream can be expanded by considering how diverse types of instructional topics [25] and learning activities [51, 52] can modulate the effects of warm, cold, and achromatic grayscale colors in multimedia learning environments.

Data Availability

Data is available on request.

Conflicts of Interest

The authors report no conflict of interest.

Authors' Contributions

SMT was the leader, and TWL was the main researcher of the research project associated with the grant mentioned in Acknowledgments. TWL and SMT contributed to the paper's research conceptualization, data analysis, and writing. CLG and WMP contributed to the research conceptualization, software development, and data collection.

Acknowledgments

We appreciate the assistance rendered by Shu Juan Lim and Siti Bahiah in developing the multimedia learning materials. Multimedia University Malaysia supported this research under the IRFUND grant with ID: MMUI/210127 awarded to TSM.

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