

# Effects of Visuospatial Cues on Instructional Static and Dynamic Visualizations on Learner Mental Model Constructions

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## ABSTRACT

This empirical study investigated whether progressive visuospatial cues presented in a self-regulatory mode could help learners understand the operation of a mechanical system. The learners' prior knowledge and cueing condition were the independent variables in terms of investigating their effectiveness on retention and transfer test results. A total of 126 English as a foreign language (EFL) learners voluntarily participated in the study. First, their prior knowledge was evaluated. Then, they were assigned to one of the following experimental conditions—animation-only, entity-cued animation, and arrow-entity-cued animation. Immediately after the experimental treatment, retention and transfer tests as well as a cognitive load questionnaire were administered to assess the learners' test performance and cognitive load, respectively. The experimental results suggested that progressive snowballing cues were favorable in assisting learner retention and transfer test results.

## KEYWORDS

Animation, Cognitive Load Theory, Signaling Principle

## INTRODUCTION

When dynamic visualizations are displayed, several components move simultaneously and compete for learners' limited attention capacity. Overlapping actions of several components might cause confusion and prevent learners from discriminating between thematically-essential and thematically-nonessential components (e.g., Boucheix & Lowe, 2010; Boucheix et al., 2013; Hegarty et al., 2003; Kriz & Hegarty, 2007; Lowe & Boucheix, 2011, 2016). In terms of the structure of mechanical systems, some components are physically small in size and have slight moving amplitude, while other components are physically voluminous and have extensive moving amplitude which are more visually conspicuous. Large components with more extensive moving amplitude inherently attract more visual attention than smaller components with slight moving amplitude (Boucheix & Lowe, 2010; Lowe & Boucheix, 2011). Due to the incongruence between thematic relevance, moving amplitude, and component size of the components in a mechanical system during its operational procedure, learners might be attracted by visually-conspicuous but thematically-nonessential components but miss the visually-inconspicuous but thematically-essential components and undermine the quality of mental models (Boucheix & Lowe, 2010; Lowe & Boucheix, 2011). The presence of visuospatial cues is assumed to modify the inherent property of some components in a mechanical system (Boucheix &

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Lowe, 2010) by directing learners' attention to be equivalently distributed to each component rather than to the visually-conspicuous but thematically-nonessential components (Lowe & Boucheix, 2011) and thereby attain a comprehensive understanding of the operational procedure of a mechanical system.

## LITERATURE REVIEW

### Relevant Studies About Visuospatial Cues in Dynamic Visualizations

With respect to the functions of visuospatial cues, the cues can be categorized into external cues and internal cues. Visuospatial cues (e.g., arrow) that are separated from target components by indicating moving direction of components are termed external cues (Lowe & Boucheix, 2011). Visuospatial cues (e.g., shade or color) that are embedded within the boundary of components by showing visual contrast with remaining display to be perceptually conspicuous are termed internal cues (Lowe & Boucheix, 2011).

The presence of external arrow cues had been administered in previous studies by exploring learners' learning efficiency in learning the subject matter of the mechanical operation of a flushing cistern (Kriz & Hegarty, 2007; Hegarty et al., 2003), rock formation (Lin & Atkinson, 2011), fish's locomotion patterns (Imhof, Scheiter, Edelmann, & Gerjets, 2013), and mechanical operation of piano mechanisms (Boucheix & Lowe, 2010; Boucheix et al., 2013; Lowe & Boucheix, 2011) but failed to demonstrate the promising effects of arrow cues in learners' mental model construction. It was probably because the presence of arrow cues could not show a continuous passage to demonstrate the causal chains when components move consecutively in dynamic visualizations (Lowe & Boucheix, 2011). Besides, if the perceptual contrast of dynamic components was too extensive, arrow cues might be too weak to compete with the dynamics of animation for learners' attention and compromise its effectiveness (Boucheix & Lowe, 2010). Whether visuospatial cues could persistently capture learners' attention determine its effectiveness in supporting learners' construction of high quality mental models (Lowe & Boucheix, 2011).

To make up the weakness of external arrow cues, internal cues that overlaid within the boundary of components and proceeded synchronously along with proceeding dynamic visualizations by progressively associating components with close spatial-temporal relation together could persistently capture learners' attention and ameliorate the quality of mental models (Boucheix & Lowe, 2010; Boucheix et al., 2013; Lowe & Boucheix, 2011). The presence of progressive visuospatial cues that proceeded synchronously along with the time course of dynamic visualizations was aimed at assisting learners to understand consecutive and overlapping actions while a mechanical system was operating (e.g., Boucheix & Lowe, 2010; Yang, 2020, 2021).

Boucheix and Lowe (2010) and Boucheix et al. (2013) administered progressive visuospatial cues to piano mechanisms and observed promising effects of progressive visuospatial cues on learners' mental model construction. The presence of progressive visuospatial cues was better than conventional arrow cues in terms of capturing learners' attention towards visually-inconspicuous but thematically-essential components. Lowe and Boucheix (2016) and Lowe, Boucheix, and Menant (2018) presented learners with conventional animations, animations with contiguous components, and animations with non-contiguous components. They observed that the presence of contiguous components yielded better quality mental models than the conventional and non-contiguous animations. Segmenting animations by sequentially presenting components pair by pair helped mitigate misalignment between learners' internal information processing and the operation of conventional animations by helping learners deconstruct complex dynamic visualizations (Groff et al., 2014). Yang (2020, 2021) presented learners with non-cues, progressive entity cues, and progressive arrow-entity cues on animated piano mechanism and observed the potential benefits of arrow-entity cues on inducing deep cognitive processing as indicated by learners' retention and transfer test outcomes compared with entity-cued and non-cued animations. Progressive visuospatial cues presented synchronously along with proceeding dynamic visualizations can prevent visuospatial cues from being outcompeted

by the dynamic components in terms of learners' limited attention capacity and thereby minimize the incongruence between visual conspicuity and instructional relevance in mechanical systems (Boucheix & Lowe, 2010; Boucheix et al., 2013).

### Statement of the Problem

In terms of the structure of mechanical systems, previous studies mostly presented complete structures but seldom deconstructed them into pieces and displayed them as individual components piece by piece (e.g., Boucheix & Lowe, 2010; Boucheix et al., 2013; Hegarty et al., 2003; Kriz & Hegarty, 2007; Lowe & Boucheix, 2011). Presenting discrete components of a mechanical system one by one might help learners understand the causal chain and prompt them to mentally animate the events between different stages of a mechanical system prior to presenting complete dynamic visualizations (Narayanan & Hegarty, 2000). Breaking down a structure by initially presenting segments before gradually extending towards the whole structure can help minimize learners' extraneous cognitive load (e.g., Boucheix et al., 2013), because there is less cognitive load when processing smaller segments compared to processing a complete structure (Mayer & Chandler, 2001; Van Merriënboer, Kirschner, & Kester, 2003). Besides, studies investigating snowball-like cues (e.g., A, A + B, A + B + C, etc.) presenting each component progressively and consecutively throughout the dynamic visualizations showing thematically-essential components and how they relate and interact as a whole are lacking (Lowe & Boucheix, 2016). To make up the gap, the research questions were as follows:

1. What is the effect of visuospatial cues on learners' retention and transfer test results?
2. What is the effect of visuospatial cues on learners' cognitive load and learning efficiency?

## METHODOLOGY

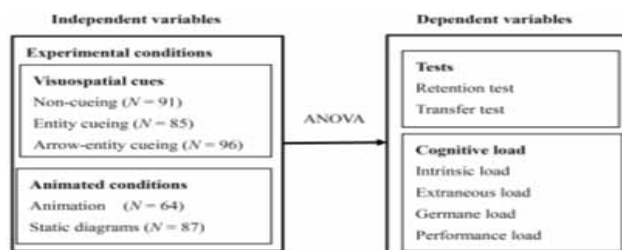
### Participants

A final total of 126 EFL learners (male = 87, female = 39) with an average age of 20 ( $M = 20.38$ ,  $SD = 0.828$ ) participated in the study. All of the students were recruited from the Chemical and Electricity Departments with limited prior knowledge of mechanical systems but rich experience in manipulating smartphones in daily life. A one-way ANOVA revealed no significant differences among the three conditions with respect to their background knowledge,  $F(2, 123) = 1.436$ ,  $p = 0.242$ .

### Research Design

This quasi-experimental study was to investigate whether progressive cues were more beneficial than the same visualizations without cues. A two-way ANOVA was used to compare the mean differences in the learners' test results and cognitive load ratings among the three experimental conditions. This study involved a 2 (high-prior knowledge vs. low-prior knowledge) x 3 (non-cued vs. entity-cued vs. arrow-entity cued) design (Fig. 1).

Figure 1. Experimental design



## Instructional Visualizations

In the present study, visuospatial cues in static illustrations and progressive cues in dynamic visualizations were presented. In terms of the static illustrations, the individual components in both the hammer and damper subsystems were highlighted in conspicuous colors as internal cues and presented one by one in the static illustrations. In terms of the dynamic visualizations, progressive cues were presented to demonstrate the sequence and directional movement of each component while a mechanical system was operating. Each cued component was progressively presented in a snowballing manner to help the learners obtain local comprehension, followed by regional comprehension, and eventually global processing. The kinematic operation of the piano used in the present study was divided into two stages: striking and rebound. The striking stage was initiated with the pressing of the key and ended with the striking of the string, whereas the rebound stage was initiated with the release of the key and ended with the release of the hammer. The progressive entity cues were represented by color bands indicating how the force proceeded step by step throughout the time course of the animation, with the red band demonstrating the moving procedure of each component in the hammer subsystem and the blue band demonstrating the movement process of each component in the damper subsystem. The progressive arrow cues were also marked blue and red where the red arrows appeared step by step prior to the appearance of the color-cued components in the hammer subsystem and the blue arrows appeared sequentially before the appearance of the color-cued components in the damper subsystem. The arrows indicated the moving direction of each component in the kinematic operation of the piano mechanism. The progressive arrow-entity cues depicted the status of the actions and components to accentuate the causal relationships between each component and the operational process.

The pictorial illustrations and dynamic visualizations were adapted from the *Christopher Piano Co. Ltd.* (<http://www.piano.christophersmit.com>). The dynamic visualizations in self-regulatory mode allowed the learners to play, pause, go forward and backward, and zoom in or out as necessary.

The participants in the non-cued group (NCG) were presented with the dynamic visualizations with a verbal explanation. The animations were situated in the top frame while the verbal explanation was displayed in the bottom frame. The kinematic operation of the piano mechanism was divided into fourteen steps explained by fourteen sentences (a total of 277 words). Based on the Flesch reading ease formula (Flesch, 1948), the readability score of the text was 74.5, and the difficulty level of the text was at grade seven. The entire animations were sixty-five seconds in length (Fig. 2a).

With respect to the entity-cued group (ECG), both static and dynamic entity cues were administered for the mechanical system. In terms of the static entity cues, twelve static illustrations depicting individual components in both the hammer and damper subsystems were displayed above the dynamic visualizations. Each cued component (e.g., hammer, whippen, repetition lever, jack, let-off button, damper head, wire, damper assembly, damper lever, and keyboard, etc.) in each illustration was highlighted in red with the remaining components in an anti-cueing pattern, visually suppressing the remaining display except for the cued component (Lowe et al., 2018). The learners could manually swipe each static picture leftwards or rightwards. In terms of the dynamic entity cues, the dynamic visualization in the ECG was the same as the one in the NCG but with additional color cues for each component. Each component was overlaid with salient color within the boundary and presented synchronously as the animation progressed to demonstrate the moving sequence. In the hammer subsystem, each component was progressively overlaid with red as the dynamic visualization progressed. In the damper subsystem, each component was progressively overlaid with blue in synchrony as the dynamic visualization progressed. Each red-blue entity-cued set lasted for five seconds, after which the following entity-cued set appeared, continuing successively to associate relevant components together in like manner until the end (Fig. 2b).

With respect to the learners in the arrow-entity cued group (AECG), both the static and dynamic visualizations in the AECG were the same as those in the ECG but with additional arrow cues in the animations to demonstrate the directional movement of each component during the kinematic

operation. In the hammer subsystem, each component was sequentially signaled with red arrows alongside the cued component during the time course of the animation. In the damper subsystem, each component was sequentially signaled with blue arrows alongside the cued component as the animation progressed. Each set of red-blue arrow cues appeared in the animated segment for five seconds and did not vanish until the next set of red-blue arrow cues appeared. Although the arrow cues were transitory, the entity cues were present in each component throughout the animation. The incremental and successive manner in which the entity cues were presented resembled snowballing cueing (e.g., A, A + B, A + B + C, etc.) by incrementally connecting each component one by one until eventually associating all of the components in a complete set. The arrow cues appeared successively but vanished after five seconds. The entity cues appeared incrementally but did not vanish until the end of each phase (Fig. 2c).

Figure 2. Sample screenshots of the experimental conditions



## Measures and Instruments

The 53 items on the retention test (Cronbach's  $\alpha=0.874$ ), 72 items on the transfer test (Cronbach's  $\alpha=0.814$ ) and the combined 125 items comprising both the retention and transfer tests (Cronbach's  $\alpha=0.894$ ) showed good internal consistency and high reliability (Wu & Tu, 2006).

## RETENTION TEST

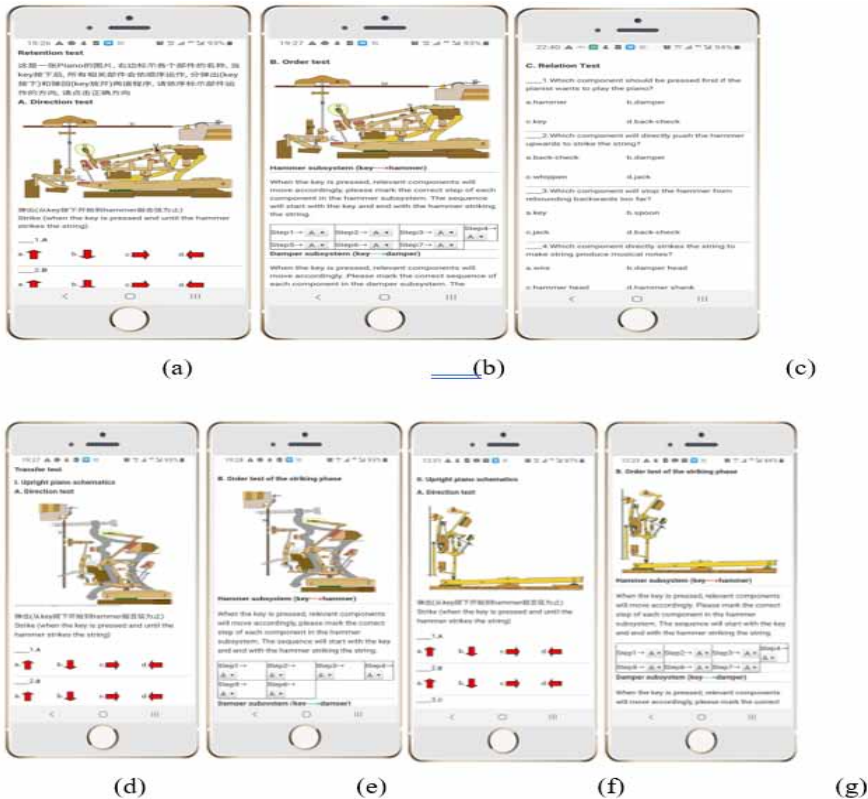
### Direction Test

25 items (Cronbach's  $\alpha=0.872$ ) were used to evaluate the learners' comprehension of the directional movements of each component in both the hammer and damper subsystems of a grand piano. The picture was adapted from Wikimedia (<https://commons.wikimedia.org>) with thirteen steps in the striking stage and twelve steps in the rebound stage. The picture was labeled with English alphabets for the learners to tap on the arrow (e.g., left, right, upwards, downwards). Each correct answer gained one point (Fig. 3a).

## Order Test

A total of thirteen items were in the order test (Cronbach's  $\alpha=0.816$ ). The illustration adapted from Wikimedia (<https://commons.wikimedia.org>) was labeled with English alphabets for the learners to tap on (e.g., step 1, step 2, step 3, and step 4) to identify the chronological sequence of each component (Fig. 3b). Each correct answer was worth one point.

Figure 3. Sample screenshots of the tests



## Relation Test

Fifteen items were in the relation test (Cronbach's  $\alpha=0.755$ ) to assess whether the learners could recognize the cause-effect relationship between components (Fig. 3c). Each correct answer was worth one point.

## Transfer Test

### Direction Test for The Upright Piano Without A Sticker

There were twenty-five items in the direction test (Cronbach's  $\alpha=0.786$ ). The illustration, labeled with English alphabets for the learners to tap on, was adapted from the Internet (<http://mirjamrodriguesdemiranda.nl>). There were thirteen steps in the striking stage and twelve steps in the rebound stage (Fig. 3d).

### Order Test for The Upright Piano Without A Sticker

A total of eleven items comprised order tests (Cronbach’s alpha=0.814). The illustration was labelled with English alphabets for the learners to tap the moving sequence of each component. Each correct answer merited one point (Fig. 3e).

### Direction Test for The Upright Piano With A Sticker

Twenty-three items were in the direction test (Cronbach’s alpha=0.889). The illustration was adapted from *International Piano Supply, Inc.* There were twelve steps in the striking stage and eleven steps in the rebound stage. The illustration was labeled with English alphabets for the learners to tap on to indicate the correct directional movement of each component (Fig. 3f). Each correct answer gained one point.

### Order Test for The Upright Piano With A Sticker

Thirteen items were in order tests (Cronbach’s alpha=0.899). The illustration was adapted from *International Piano Supply, Inc* (<http://www.pianosupply.com>). The illustration was labeled with English alphabets for the learners to tap on the ones that corresponded with the moving sequence of each component (Fig. 3g). Each correct answer earned one point.

### Prior Knowledge Test

A prior knowledge test (Cronbach’s alpha=0.850) was administered to determine the learners’ background knowledge concerning the piano mechanism. Twenty-two multiple-choice items were in the direction test and nine items were in the order test (Fig. 4).

Figure 4. Sample screenshots of the prior knowledge tests



## Cognitive Load Measurement

A cognitive load questionnaire (Kalyuga et al., 1999; Paas, 1992) using a 9-point Likert scale was administered to assess the learners' cognitive load. Items 1 through 5, respectively, represented intrinsic load, extraneous load, germane load, perceived difficulties in answering the retention test, and perceived difficulties in answering the transfer tests. Cronbach's alpha was 0.839. Bartlett's tests of sphericity were all significant. The Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) was 0.778. One component was extracted. The eigenvalue exceeded 1. The total explained variance of the measurement was 61.59%.

## Experimental Procedures

In the formal study, the learners first took the prior knowledge test to determine their background knowledge. Next, they could spend as much time as necessary to memorize the terminology concerning the grand piano. Afterwards, they accessed the learning area to learn the operation of the piano mechanism. Then they answered three cognitive load questions concerning the difficulty of the instructional material. After that, they answered the retention test and one related cognitive load question. Then they took the transfer test and answered one related cognitive load question. After the learners submitted their answers to the system, they logged out. The overall experimental procedure took approximately ninety minutes. The data from the experimental and control conditions were collected during separate class periods.

## RESULTS

### Research Question One: What is the Effect of Visuospatial Cues on Learners' Retention and Transfer Test Results?

A two-way ANOVA was conducted with prior knowledge and cueing conditions as the independent variables and the retention and transfer test results as the dependent variables. Tukey was used as a post hoc test. The means and standard deviations for the retention and transfer tests are summarized in Table 1. The ANOVA source for the direction subtest of the retention test indicated no interaction between cueing and prior knowledge,  $F(2, 120) = 0.800, p = 0.452$ , partial  $\eta^2 = 0.013$ . However, the main effect of prior knowledge was significant,  $F(1, 120) = 23.712, p < 0.001$ , partial  $\eta^2 = 0.165$ . The high-prior knowledge learners ( $M = 19.34, SD = 4.434$ ) significantly outperformed the low-prior knowledge learners ( $M = 16.13, SD = 5.707$ ). The main effect of cueing was also statistically significant,  $F(2, 120) = 18.464, p < 0.001$ , partial  $\eta^2 = 0.235$ . The ECG ( $M = 18.55, SD = 4.637$ ) significantly outperformed the NCG ( $M = 14.55, SD = 5.505$ ),  $p < 0.001$ . The AECG ( $M = 19.81, SD = 4.461$ ) also significantly outperformed the NCG ( $M = 14.55, SD = 5.505$ ),  $p < 0.001$ .

In regard to the hammer subsystem order test of the retention test, there was no interaction between prior knowledge and cued condition,  $F(2, 120) = 1.321, p = 0.271$ , partial  $\eta^2 = 0.002$ . However, the main effect of prior knowledge was significant,  $F(1, 120) = 10.789, p < 0.001$ , partial  $\eta^2 = 0.082$ . The high-level learners ( $M = 3.50, SD = 2.008$ ) significantly outperformed the low-level learners ( $M = 2.35, SD = 2.065$ ). The main effect of cueing was statistically insignificant,  $F(2, 120) = 1.685, p = 0.190$ , partial  $\eta^2 = 0.027$ .

As for the damper subsystem order test of the retention test, there was no interaction between prior knowledge and cued condition,  $F(2, 120) = 2.012, p = 0.138$ , partial  $\eta^2 = 0.032$ . The main effect of prior knowledge was statistically insignificant,  $F(1, 120) = 0.248, p = 0.619$ , partial  $\eta^2 = 0.002$ . The main effect of cueing was also statistically insignificant,  $F(2, 120) = 2.708, p = 0.071$ , partial  $\eta^2 = 0.043$ .

In regard to the relation subtest of the retention test, the ANOVA results failed to indicate an interaction between prior knowledge and the cued condition,  $F(2, 120) = 1.594, p = 0.207$ , partial  $\eta^2 = 0.026$ . However, the main effect of prior knowledge was statistically significant,  $F(1, 120) =$



13.12,  $p < 0.001$ , partial  $\eta^2 = 0.099$ . The high-level learners ( $M = 8.75$ ,  $SD = 3.599$ ) significantly outperformed the low-level learners ( $M = 6.98$ ,  $SD = 3.076$ ). The main effect of cueing was statistically significant,  $F(2, 120) = 11.573$ ,  $p < 0.001$ , partial  $\eta^2 = 0.162$ . The ECG ( $M = 9.71$ ,  $SD = 3.777$ ) significantly outperformed both the NCG ( $M = 6.50$ ,  $SD = 3.146$ ),  $p < 0.001$  and the AECG ( $M = 7.58$ ,  $SD = 2.805$ ),  $p = 0.005$ .

In regard to the overall retention test scores, there was no interaction between prior knowledge and the cued condition,  $F(2, 120) = 1.870$ ,  $p = 0.159$ , partial  $\eta^2 = 0.030$ . The main effect of prior knowledge was significant,  $F(1, 120) = 31.428$ ,  $p < 0.001$ , partial  $\eta^2 = 0.208$ . The high-level learners ( $M = 31.87$ ,  $SD = 7.311$ ) significantly outperformed the low-level learners ( $M = 25.77$ ,  $SD = 8.407$ ). The main effect of cueing was also statistically significant,  $F(2, 120) = 15.174$ ,  $p < 0.001$ , partial  $\eta^2 = 0.202$ . The ECG ( $M = 31.92$ ,  $SD = 8.534$ ) significantly outperformed the NCG ( $M = 24.35$ ,  $SD = 8.74$ ),  $p < 0.001$ . The AECG ( $M = 30.23$ ,  $SD = 6.386$ ) significantly outperformed the NCG ( $M = 24.35$ ,  $SD = 8.74$ ),  $p < 0.001$ .

As for the direction subtest of the upright piano without sticker in the transfer test, the ANOVA results failed to indicate an interaction between prior knowledge and the cued condition,  $F(2, 120) = 1.802$ ,  $p = 0.169$ , partial  $\eta^2 = 0.029$ . However, the main effect of prior knowledge was significant,  $F(1, 120) = 5.437$ ,  $p = 0.021$ , partial  $\eta^2 = 0.043$ . The high-level learners ( $M = 9.87$ ,  $SD = 2.93$ ) significantly outperformed the low-level learners ( $M = 8.92$ ,  $SD = 2.404$ ). The main effect of cueing was statistically significant,  $F(2, 120) = 12.03$ ,  $p < 0.001$ , partial  $\eta^2 = 0.167$ . The ECG ( $M = 11.05$ ,  $SD = 3.32$ ) significantly outperformed both the NCG ( $M = 8.55$ ,  $SD = 1.88$ ),  $p < 0.001$  and the AECG ( $M = 8.81$ ,  $SD = 2.199$ ),  $p < 0.001$ .

As for the hammer subsystem order test of the upright piano without sticker in the transfer test, there was no interaction between prior knowledge and the cued condition,  $F(2, 120) = 0.023$ ,  $p = 0.977$ , partial  $\eta^2 = 0.000$ . The main effect of prior knowledge was statistically significant,  $F(1, 120) = 6.694$ ,  $p = 0.011$ , partial  $\eta^2 = 0.053$ . The high-level learners ( $M = 2.92$ ,  $SD = 1.954$ ) significantly outperformed the low-level learners ( $M = 2.06$ ,  $SD = 1.80$ ). The main effect of cueing was not statistically significant,  $F(2, 120) = 2.879$ ,  $p = 0.06$ , partial  $\eta^2 = 0.046$ .

Regarding the damper subsystem order test of the upright piano without sticker in the transfer test, the ANOVA results failed to indicate an interaction between interactivity and the cued condition,  $F(2, 120) = 2.279$ ,  $p = 0.107$ , partial  $\eta^2 = 0.037$ . The main effect of prior knowledge was not statistically significant,  $F(1, 120) = 0.570$ ,  $p = 0.452$ , partial  $\eta^2 = 0.005$ . The main effect of cueing was also statistically insignificant,  $F(2, 120) = 1.491$ ,  $p = 0.229$ , partial  $\eta^2 = 0.024$ .

Concerning the total score of the upright piano without sticker in the transfer test, there was no interaction between prior knowledge and the cued condition,  $F(2, 120) = 0.887$ ,  $p = 0.415$ , partial  $\eta^2 = 0.015$ . However, the main effect of prior knowledge was statistically significant,  $F(1, 120) = 8.476$ ,  $p = 0.004$ , partial  $\eta^2 = 0.066$ . The high-level learners ( $M = 12.88$ ,  $SD = 4.112$ ) significantly outperformed the low-level learners ( $M = 11.11$ ,  $SD = 3.455$ ). The main effect of cueing was also statistically significant,  $F(2, 120) = 10.188$ ,  $p < 0.001$ , partial  $\eta^2 = 0.145$ . The ECG ( $M = 14.18$ ,  $SD = 4.361$ ) significantly outperformed the NCG ( $M = 10.95$ ,  $SD = 3.012$ ),  $p < 0.001$  as well as the AECG ( $M = 11.17$ ,  $SD = 3.497$ ),  $p < 0.001$ .

As for the direction subtest of the upright piano with sticker in the transfer test, the ANOVA results failed to indicate an interaction between prior knowledge and the cued condition,  $F(2, 120) = 0.261$ ,  $p = 0.771$ , partial  $\eta^2 = 0.004$ . However, the main effect of prior knowledge was statistically significant,  $F(1, 120) = 6.602$ ,  $p = 0.011$ , partial  $\eta^2 = 0.052$ . The high-level learners ( $M = 9.13$ ,  $SD = 2.104$ ) significantly outperformed the low-level learners ( $M = 8.11$ ,  $SD = 2.529$ ). The main effect of cueing was also statistically significant,  $F(2, 120) = 5.214$ ,  $p = 0.007$ , partial  $\eta^2 = 0.080$ . The ECG ( $M = 9.21$ ,  $SD = 2.697$ ) significantly outperformed both the NCG ( $M = 8.30$ ,  $SD = 2.163$ ),  $p = 0.032$  and the AECG ( $M = 8.13$ ,  $SD = 2.049$ ),  $p = 0.009$ .

As for the hammer subsystem order test of the upright piano with sticker in the transfer test, there was no interaction between prior knowledge and the cued condition,  $F(2, 120) = 0.956$ ,  $p = 0.387$ ,

partial  $\eta^2 = 0.016$ . The main effect of prior knowledge was statistically insignificant,  $F(1, 120) = 3.39, p = 0.068$ , partial  $\eta^2 = 0.027$ . However, the main effect of cueing was statistically significant,  $F(2, 120) = 2.861, p = 0.041$ , partial  $\eta^2 = 0.046$ . The ECG ( $M = 4.32, SD = 2.722$ ) significantly outperformed the AECG ( $M = 2.85, SD = 2.775$ ),  $p = 0.045$ .

Concerning the damper subsystem order test of the upright piano with sticker in the transfer test, the ANOVA results failed to indicate an interaction between prior knowledge and the cued condition,  $F(2, 120) = 2.151, p = 0.121$ , partial  $\eta^2 = 0.035$ . The main effect of prior knowledge was statistically significant,  $F(1, 120) = 5.79, p = 0.018$ , partial  $\eta^2 = 0.046$ . The high-level learners ( $M = 2.75, SD = 2.268$ ) significantly outperformed the low-level learners ( $M = 1.79, SD = 2.189$ ). The main effect of cueing was statistically insignificant,  $F(2, 120) = 2.369, p = 0.098$ , partial  $\eta^2 = 0.038$ .

In regard to the total overall scores of the upright piano with sticker in the transfer test, there was no interaction between prior knowledge and the cued condition,  $F(2, 120) = 1.045, p = 0.355$ , partial  $\eta^2 = 0.017$ . However, the main effect of prior knowledge was statistically significant,  $F(1, 120) = 8.353, p = 0.005$ , partial  $\eta^2 = 0.065$ . The high-level learners ( $M = 15.84, SD = 5.766$ ) significantly outperformed the low-level learners ( $M = 12.94, SD = 5.833$ ). Moreover, the main effect of cueing was statistically significant,  $F(2, 120) = 5.485, p = 0.005$ , partial  $\eta^2 = 0.084$ . The ECG ( $M = 16.79, SD = 6.09$ ) significantly outperformed the AECG ( $M = 12.81, SD = 5.123$ ),  $p = 0.004$ .

**Table 1. Means and standard deviation for the test results**

	NCG (N = 40)		ECG (N = 38)		AECG (N = 48)	
	M	SD	M	SD	M	SD
RTN-Drc <sup>1</sup>	14.55	5.505	18.55	4.637	19.81	4.461
RTN-Od-H <sup>2</sup>	2.88	2.278	3.39	2.112	2.62	1.931
RTN-Od-D <sup>3</sup>	0.43	0.594	0.26	0.503	0.21	0.410
RTN-Relation <sup>4</sup>	6.50	3.146	9.71	3.777	7.58	2.805
RTN-Total <sup>5</sup>	24.35	8.740	31.92	8.534	30.23	6.386
TRN-Up1-Drc <sup>6</sup>	8.55	1.880	11.05	3.320	8.81	2.199
TRN-Up1-Od-H <sup>7</sup>	2.28	2.100	3.11	1.798	2.21	1.786
TRN-Up1-Od-D <sup>8</sup>	0.13	0.335	0.03	0.162	0.15	0.357
TRN-Up1-Total <sup>9</sup>	10.95	3.012	14.18	4.361	11.17	3.497
TRN-Up2-Drc <sup>10</sup>	8.30	2.163	9.61	2.697	8.13	2.049
TRN-Up2-Od-H <sup>11</sup>	3.53	2.944	4.32	2.722	2.85	2.775
TRN-Up2-Od-D <sup>12</sup>	2.25	2.340	2.87	2.280	1.83	2.147
TRN-Up2-Total <sup>13</sup>	14.08	6.178	16.79	6.090	12.81	5.123
All Total	49.37	15.378	62.89	15.481	54.21	11.500

*Note.* <sup>1</sup>Direction subtest of the retention test; <sup>2</sup>hammer subsystem order test of the retention test; <sup>3</sup>damper subsystem order test of the retention test; <sup>4</sup>relation subtest of the retention test; <sup>5</sup>total score of the retention test; <sup>6</sup>direction subtest of the upright piano without sticker in transfer test; <sup>7</sup>hammer subsystem order test of the upright piano without sticker in transfer test; <sup>8</sup>damper subsystem order test of the upright piano without sticker in transfer test; <sup>9</sup>total score of the upright piano without sticker in transfer test; <sup>10</sup>direction subtest of the upright piano with sticker in transfer test; <sup>11</sup>hammer subsystem order test of the upright piano with sticker in transfer test; <sup>12</sup>damper subsystem order test of the upright piano with sticker in transfer test; <sup>13</sup>total score of the upright piano with sticker in transfer test.

As for the overall total scores, there was no interaction between prior knowledge and the cued condition,  $F(2, 120) = 0.856, p = 0.428$ , partial  $\eta^2 = 0.014$ . However, the main effect of prior knowledge was significant,  $F(1, 120) = 26.266, p < 0.001$ , partial  $\eta^2 = 0.180$ . The high-level learners ( $M = 60.59, SD = 13.422$ ) significantly outperformed the low-level learners ( $M = 49.82, SD = 14.574$ ). The main effect of cueing was also statistically significant,  $F(2, 120) = 12.582, p < 0.001$ , partial  $\eta^2 = 0.173$ . The ECG ( $M = 62.89, SD = 15.481$ ) significantly outperformed the NCG ( $M = 49.37, SD = 15.378$ ),  $p < 0.001$  as well as the AECG ( $M = 54.21, SD = 11.50$ ),  $p = 0.007$ .

**Research Question Two: What is the Effect of Visuospatial Cues on Learners’ Cognitive Load and Learning Efficiency?**

Learning efficiency was calculated by converting cognitive load and test results into Z-scores using the formula  $E = [Z_{score} - Z_{cognitive}] / \sqrt{2}$ . The AECG ( $E = 0.03$ ) and ECG ( $E = 0.145$ ) showed a relatively lower cognitive load and higher test scores, while the NCG ( $E = -0.176$ ) showed a relatively higher cognitive load and lower test score. A one-way ANOVA revealed statistical significance,  $F(2, 123) = 4.441, p = 0.014$ . The ECG displayed significantly better learning efficiency than the NCG,  $p = 0.01$ .

A two-way ANOVA was conducted by analyzing prior knowledge and cueing condition as the independent variables and cognitive load as the dependent variable. Tukey was used as a post hoc test. The ANOVA for the cognitive load ratings failed to indicate an interaction in regard to cognitive load,  $F(2, 120) = 0.257, p = 0.774$ , partial  $\eta^2 = 0.004$  (Table 2). The main effects of prior knowledge and cueing condition were not statistically significant.

**Table 2. Means and standard deviation for cognitive load**

	NCG (N = 40)		ECG (N = 38)		AECG (N = 48)	
	M	SD	M	SD	M	SD
Intrinsic load	6.18	2.086	6.68	2.015	5.85	1.750
Extraneous load	5.45	2.364	5.74	2.698	5.46	2.221
Germane load	6.88	2.040	7.08	1.776	6.40	1.954
Retention load	7.45	1.501	7.32	1.509	6.94	1.906
Transfer load	7.50	1.664	7.11	1.624	7.46	1.701
Total load	33.45	7.733	33.92	8.283	32.10	6.817

**DISCUSSION**

The presence of entity-cues accentuated the cause and effect relationships between adjacent components by associating components with close spatial-temporal relations together, which induced the learners to notice the causal relationships between components and eventually understand the operational procedure of the complex animation (Lowe et al., 2018).

**The Progressive Visuospatial Cues Yielded Better Quality Mental Models**

Breaking down a complete structure into individual segments and presenting each component successively helped the learners construct a coherent and hierarchical structure (Lowe & Boucheix, 2016). Both static and dynamic entity cues were presented to the AECG and ECG. The cues in each component in the static pictures enabled the learners to deconstruct the whole mechanical system into individual segments. Besides, the learners could reconstruct the structure into a complete set while

learning the dynamic visualizations where the individual components were integrated and interacted with each other to form a complete operational procedure.

The sequential presence of arrow and entity cues consistently captured the learners' attention to each component rather than just to the visually-conspicuous but thematically-nonessential components (e.g., Boucheix et al., 2013; Low & Boucheix, 2011; Yang, 2020, 2021). The visuospatial cues presented synchronously along with the time course of dynamic visualizations minimized the possibility that the dynamics of the components would outcompete the visuospatial cues (e.g., Boucheix et al., 2013; Low & Boucheix, 2011; Yang, 2020, 2021). Administering entity cues within the component by making them perceptually conspicuous to contrast them from the other components enhanced learning effectiveness (Boucheix & Lowe, 2010; Low & Boucheix, 2011). Continuous attention-capturing visuospatial cues prompted the learners to notice the relationships between adjacent components, cluster individual components into small sets, and eventually organize all relevant components in a causal chain comprising a coherent structure (Boucheix & Lowe, 2010; Boucheix et al., 2013; Renkl, & Scheiter, 2017). While the learners in the non-cued conditions had no visual cues to guide their attention, they could have been distracted by overlapping actions which made it challenging for them to determine the chronological order of the movements of the individual components (e.g., Yang, 2020, 2021). In that case, they would be more likely to pay more attention to the visually-conspicuous but thematically-nonessential components and less attention to the visually-inconspicuous but thematically-essential components, thus undermine the quality of their mental models.

Timely appearance of entity cues on the component when each time the component was activated would timely capture the learners' attention to notice the initiation and moving direction of each component. However, the effect of arrow cues was less significant than the entity cues in helping the learners to infer the directional movement of the components. The findings were inconsistent with the results of some previous studies (e.g., Yang, 2020, 2021) which indicated the arrow-entity cues prompted the learners to have better direction test results than the entity-cues alone. This was probably due to the transitory nature of the arrow cues which could not persistently capture learners' attention and compromise its effectiveness (e.g., Boucheix & Lowe, 2010; Lowe & Boucheix, 2011). That is, the arrows were likely not displayed long enough to persistently attract the learners' attention and therefore prevented them from correctly identifying the directional movement of the components.

The entity cues, presented in a successive and incremental manner, highlighted the moving sequence of each component in chronological order which gave the learners better understanding of the causal relationships between the components. Progressively presenting visuospatial cues in a snowballing pattern assisted the learners to identify the chronological order of components while the mechanical system was operating (e.g., Boucheix & Lowe, 2010). The configuration and orientation of the upright piano in the transfer test was different from the one used in the instructional material, which likely made it more cognitively demanding for the learners to infer the chronological order of each component in an unfamiliar mechanical system. Besides, the AECG was less facilitative than the ECG in helping the learners infer the moving sequence of the components in the mechanical system. These results somewhat were inconsistent with some previous studies (e.g., Yang, 2020, 2021), but corresponded with those in previous studies (e.g., Boucheix & Lowe, 2010; Boucheix et al., 2013; Hegarty et al., 2003; Hegarty, Canham, & Fabrikant, 2010; Kriz & Hegarty, 2007; Lowe & Boucheix, 2011) in which successive arrow cues were unfavorable at helping learners identify the moving sequences of components when the mechanical system was operating.

Persistent and continuous attention towards the components helped the learners understand how components interacted with each other. This eventually promoted deep cognitive processing which helped the learners better infer the operational procedure of an unfamiliar mechanical system, as indicated from the transfer test results. These findings are consistent with those found in some previous studies (e.g., Boucheix & Lowe, 2010; Boucheix et al., 2013; Jamet et al., 2008; Jamet, 2014; Lowe & Boucheix, 2011; Ozcelik et al., 2009, 2010), which indicated the progressive cues can help

learners develop high-quality mental models. However, the AECG was less desirable than the ECG in terms of the learners' transfer test results. Progressive entity cues presented in a snowballing manner were more effective than progressive arrow cues in demonstrating the causal chain comprising the animations (e.g., Boucheix & Lowe, 2010).

High-prior knowledge learners generally outperformed the low-prior knowledge learners on both the retention and transfer tests. There was no interaction between prior knowledge level and experimental conditions, which suggested that everyone gained equal benefit from the progressive visuospatial cues presented in a snowballing manner regardless of prior knowledge extent. The results were inconsistent with previous studies (e.g., Arslan-Ari, 2018; Boucheix & Guinard, 2005; Richter et al., 2016).

### **The Progressive Visuospatial Cues Induced Better Learning Efficiency**

The presence of progressive visuospatial cues and static visuospatial cues alleviated the predicament the learners encountered while trying to process complex dynamic visualizations. These results are consistent with those in some previous studies (Kalyuga et al., 1999; Lin & Atkinson, 2011; Yang, 2020, 2021). The sequential presence of visuospatial cues in static illustrations and progressive cues in dynamic visualizations enhanced learning efficiency by minimizing the learners' cognitive load and optimizing test outcomes.

## **CONCLUSION**

Entity cues presented synchronously and incrementally along with the animation process demonstrated continuous flow and assisted the learners in understanding consecutive actions by associating all thematically-essential components together (Boucheix & Lowe, 2010). Progressive snowballing cues solved the misalignment between visual-conspicuity and thematic-relevance in terms of the mechanical structure and ameliorated the quality of mental models. Making animations interactive (Imhof, et al., 2011; Lowe & Boucheix, 2016; Tversky et al., 2002; Yang, 2021) and presenting progressive visuospatial cues (Boucheix & Lowe, 2010; Boucheix et al., 2013; Yang, 2020, 2021) alleviated the difficulties that the learners encountered when mentally animating a complex mechanical system.

### **Limitations of the Study**

The present study could not use eye-tracking technique to investigate the learners' visual navigation to explore how the learners process visual and verbal information. The future researchers could utilize eye-tracking facilities to continue the research (e.g., Boucheix & Lowe, 2010; Lowe & Boucheix, 2011).

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