Improving the frame design of computer simulations for learning: Determining the primacy of the isolated elements or the transient information effects

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ABSTRACT

Computer simulations were used to teach students basic concepts associated with correlation. Half of the students were presented information in a sequential series of single frames in which each frame replaced the preceding frame while the other half were presented the information in simultaneous multiple frames in which each frame was added to the previous frames without replacement. It was hypothesized that if the isolated elements effect occurs, the single-frame condition should be superior. Alternatively, if the transient information effect dominates, the multiple-frame condition should be superior. Results confirmed the superiority of the single-frame presentation. Eye-tracking indicated that participants who learned with single frames paid more attention to the important representations than participants who learned with multiple frames.

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1. Introduction

Computer simulation is an important learning tool that has been widely applied in many fields, such as physics (e.g., Blake & Scanlon, 2007; Chen, Hong, Sung, & Chang, 2011), statistics (e.g., Liu, 2010; Liu, Lin, & Kinshuk, 2010; Morris, 2001), and economics (Huk & Ludwigs, 2009). Although computer simulation is presented in a variety of ways for different learning purposes, simulations can be broadly defined as programs where the users manipulate different values of variables and then immediately obtain the results of the simulation under a preset formula (Rey, 2011). The process of manipulating and observing the results of different values of variables is intended to assist learners to understand concepts more easily.

While computer simulation may have the potential to benefit learning, frequently it is not easy for students to learn effectively (Plass, Homer, & Hayward, 2009; Rey, 2011). Cognitive load theory can be used to predict the difficulty and effectiveness of instructional procedures using our knowledge of human cognitive architecture (Sweller, 2011; Sweller, Ayres, & Kalyuga, 2011). There are three categories of cognitive load (Sweller, 2010). Intrinsic cognitive load is affected by the number of interacting learning elements in a subject domain and by the learners’ prior-knowledge. An interacting learning element is an element that cannot be learned meaningfully without considering other elements. For example, we cannot learn the meaning of a correlation coefficient without simultaneously considering the manner in which two sets of numbers co-vary. Extraneous cognitive load refers to the number of interacting elements that must be unnecessarily processed due to poor instructional design. Germane cognitive load refers to the working memory resources needed to deal with intrinsic cognitive load. Setting an appropriate level of intrinsic cognitive load and avoiding extraneous cognitive load are the main ways of controlling cognitive load to benefit learning (Kalyuga, 2009; Wouters, Paas, & van Merriënboer, 2008).

Based on cognitive load theory, many researchers proposed and examined the effects of various instructional designs for improving computer simulations (e.g., Huk & Ludwigs, 2009; Lee, Plass, & Homer, 2006; Rey, 2011). However, few studies focused on improving frame design during computer simulations. For example, a single-frame screen design in most computer simulations may cause students to suffer...
from the risk of cognitive overload because each manipulation result disappears when conducting the next manipulation. The students need to temporally keep different manipulation results in working memory to find the relations between frames because each manipulation is transient (Kalyuga, Plass, Homer, Milne, & Jordan, 2007). When using a computer simulation to assist in understanding “the strength of correlation” concept, students may set different correlation coefficient values successively and then compare and integrate the corresponding results. In order to carry out the integration and comparison, students learning using a single-frame design must keep the corresponding results of different correlation coefficient values in working memory because the results will disappear when they set another correlation coefficient value. Those processes require considerable cognitive resources.

Unlike “single-frame” screen designs, “multiple-frame” screens can show more than one frame at a time. Students can observe the results of more than one frame manipulation simultaneously. Fig. 1 provides a screenshot of a multiple-frame screen design. The single-frame design was identical except that there was only a single frame. Although the problems of the single-frame design and the potential solution of the use of multiple-frame design have been proposed by Liu (2010), those assumptions have not been tested. Therefore, the current study focused on improving frame design by manipulating the number of frames learners had to deal with simultaneously. Both dealing with a single frame at a time and dealing with multiple frames simultaneously can impose an excessive cognitive load but for different reasons. Those reasons are exemplified by two cognitive load effects: The isolated elements effect and the transient information effect.

The isolated elements effect occurs when the intrinsic cognitive load of a task is too high to allow the interacting elements to be processed in working memory (Ayres, 2006, 2012; Blayney, Kalyuga, & Sweller, 2010; Pollock, Chandler, & Sweller, 2002). Interacting elements associated with an intrinsic cognitive load are elements that cannot be learned and understood in isolation because they interact (Sweller, 2010). For example, when learning about correlation concepts, students will confront multiple representations including texts (i.e., learning guides), figures (i.e., scatter plots), tables (X, Y table) and different symbols (e.g., r, N). In order to fully understand the meaning of a correlation, students need to relate these various elements associated with the concept of a correlation. Because the meaning of a correlation cannot be properly understood without relating these elements to each other, element interactivity is high. There may be too many elements for working memory to simultaneously process.

While the intrinsic cognitive load of a task cannot be reduced because it is intrinsic to the task, it may be possible to change the task to a related one that has a lower intrinsic cognitive load. For example, if a task requires many interacting elements to be processed simultaneously, thus overwhelming working memory, it may be possible to present the elements in isolation rather than in interacting form. By presenting the elements in isolation, they can be learned but not fully understood because understanding requires learning the interactions between elements. Interactions can be learned subsequently by presenting the elements in interacting rather than isolated form. Blayney et al. (2010) and Pollock et al. (2002) found that presenting information in isolated elements form followed by integrated elements form was superior to presenting the same material twice in integrated form.

The transient information effect occurs when information is presented in a form that is transient in nature (Leahy & Sweller, 2011; Wong, Leahy, Marcus, & Sweller, 2012). Animations are usually transient in that earlier information disappears to be replaced by current information. One factor that reduces the effectiveness of animation is that animations are fleeting (Betrancourt, 2005; Tversky, Morrison, & Betrancourt, 2002). When information is transient or fleeting, if earlier information is required in order to understand and learn current information, a heavy working memory load is generated that is likely to interfere with the assimilation of information into long-term memory. Presenting information in smaller segments can reduce the cognitive load. As can be seen, the isolated elements and the transient information effects are related in that both effects rely on the presentation of high element interactivity information in smaller segments.

Fig. 1. A screenshot demonstrating a “multiple-frame” screen design (Liu et al., 2010).
The current experiments compared learners using simulations presented on a single-frame screen to learners presented the same simulations on a multiple-frame screen when studying correlation concepts with simulations. The use of multiple-frame screens may be beneficial because they eliminate transience and so may reduce the extraneous cognitive load associated with having to hold representations of different correlation coefficients in working memory. On a multiple-frame screen, instead of having to remember a previous screen in order to make comparisons, several screens are available simultaneously and can be compared, thus reducing transience. If reducing transience is important, multiple-frame screens should be superior to single-frame screens.

Nevertheless, each screen not only consists of interacting elements (graph, table, correlation coefficient) but is itself an element that needs to be related to other screens acting as elements. To fully understand the meaning of correlation, learners must understand the manner in which a screen changes when the correlation coefficient changes from, for instance, +0.5 to −0.2. If students compare screens, they are learning something that is important to understand the concept of correlation but there is a cost. Multiple-frame designs heavily increase the number of interacting elements due to intrinsic cognitive load that learners must process. Instead of just processing the information associated with a single screen, learners must compare and contrast the information of several screens. If all of those elements can be processed, the multiple-frame design may be superior to the single-frame design. If the many interacting elements cannot be processed, the single-frame design may act as the equivalent to an isolated elements presentation and by reducing intrinsic cognitive load, may be superior to the corresponding multiple-frame design.

In effect, we are testing whether it is more important for learners to just process the three representations of a correlation (correlation coefficient, graph and table of values) or whether it is more important to compare the changes in these three representations as the correlation values change. If it is more important to only process the three representations, then, due to the isolated elements effect, a single-frame representation should be superior because the transient representations reduces the ability of learners to make comparisons between frames and emphasizes comparisons between representations. If it is more important to compare the representations of different correlation values, then the reduction of transience associated with the multiple-frame presentation should result in that presentation being superior to a single-frame presentation.

Eye tracking may have the potential for investigating participants' cognitive processes by measuring their eye positions and eye movements. Van Gog and Scheiter (2010) argued that eye tracking has contributed to the study of multimedia learning by providing unique information about what representations are visually attended to, in what order, and for how long. In recent years, eye tracking data also has been adopted to explain cognitive load effects (e.g., Holsanova, Holmberg, & Holmqvist, 2009; Jamet, 2014; Liu, Fan, & Paas, 2014; Schmidt-Weigand, Kohnert, & Glowalla, 2010). Several indices have been used to study the distribution of attention, such as numbers of fixations on Areas of Interest, fixations on Areas of Interest as a percentage of the total number of fixations, fixation times on Areas of Interest, the fixation time on Areas of Interest as a percentage of total fixation time and the number of transitions between the Areas of Interest (e.g., Holsanova et al., 2009; Schmidt-Weigand et al., 2010). For example, Holsanova et al. (2009) studied how and why the split-attention effect occurred by comparing differences in eye movement behavior of participants who read the text and diagrams in split-attention and integrated formats. They found that participants who read the integrated formats had more transitions between the related segments of text and pictures (i.e., integrative saccades) than participants who read the split-attention formats. Schmidt-Weigand et al. (2010) studied the differences in learning performance and eye movement behavior of participants who learned using pictures accompanied by either written or spoken text. The results indicated that participants who learned with pictures accompanied by spoken text had a better learning performance and longer fixation times on the picture area than participants who learned with pictures accompanied by written text.

In summary, participants' distribution of attention to the representations of correlation when learning with simulations were collected to throw light on relations between the isolated elements and the transient information effects. If the isolated elements effect occurs, a single-frame design is predicted to allow learners to pay more attention to the important representations of correlation than the multiple-frame design because the single-frame design reduces the representations that need to be processed, reducing intrinsic cognitive load. Under these conditions, it is hypothesized that learners presented single frames should have a reduced learning time, better post-test performance, and a lower cognitive load than multiple-frame learners. If the transient information effect dominates, the results should be reversed because in a single-frame design, each representation disappears to be replaced by the next representation. Not having to hold previous representations in working memory under multiple-frame conditions should reduce extraneous cognitive load. Under these conditions, it is hypothesized that learners presented multiple frames should have a reduced learning time, better post-test performance, and a lower cognitive load than single frame learners.

2. Method

2.1. Participants and design

In order to avoid ceiling effects, a prior knowledge test was conducted to select the participants for this study. Thirty two undergraduate Taiwanese students (17 males, 15 females with an average age of 20.22) whose prior knowledge test scores were less than 6 points and who were willing to participate in the experiment were selected. All participants had learned the basic concepts of correlation in senior high school. They were recruited via the internet. The majors of the participants were diverse, including Liberal Arts, Engineering, Physics, and Management. All participants received a monetary reward of 250 TAIWANESE Dollars (approximately 8 US Dollars) for their participation. These students were randomly assigned to a single-frame or a multiple-frame group.

2.2. Equipment and materials

The computer simulation used in this study was extracted and revised from Simulation Assisted Learning Statistics (SALS: Liu, 2010; Liu et al., 2010) that is used for supporting students in learning ten important correlation concepts. The revised version used in this study, named SALS II, was written in the programming language, Ruby on Rails (http://rubyonrails.org/). SALS II emphasizes using a combination of learning guides and simulation manipulation to enhance students’ understanding of correlation concepts. When learning with SALS II,
students were guided to set different values of correlation coefficients and to observe the corresponding changes of the arrangement of sample points on a scatter plot and on a table of x, y values. A web keyboard designed for SALS II was used to avoid the participants having to lower their heads to input the r values using the keyboard and so interfere with the recording of eye movements (see Fig. 2). The participants were encouraged to understand the concepts of correlation by finding the relation between the r values, the arrangement of sample points on the scatter plot and on a table of x, y values.

There were three learning units used to teach three concepts of correlation respectively. The three concepts were the direction of correlation (Unit 1), the strength of correlation (Unit 2), and the discrimination of positive (or negative) correlation and perfect positive (or negative) correlation (Unit 3). The main idea taught in Unit 1 was “The positive sign and the negative sign of r indicates the direction of the correlation”. The main idea taught in Unit 2 was “The absolute value of r indicates the strength of the correlation”. The main idea taught in Unit 3 was “A positive correlation is one where as a value of x increases or decreases, the corresponding value of y probably increases or decreases. A perfect positive correlation means that as the value of x increases or decreases, the value of y will certainly increase or decrease.” Every unit was composed of four screens that required participants to set four different r values and observe the corresponding results in each r value.

Two versions of SALS II were designed to examine the effects of single and multiple-frames on learning with computer simulations. The contents of the two versions were the same apart from the number of frames appearing on each screen.

The single-frame displayed one simulation frame at a time. Participants who learned using a single-frame were asked to successively set different values of correlation coefficients into the same simulation frame four times (e.g., $r = 0$, $r = 0.3$, $r = 0.7$, $r = 1$). When participants set one correlation coefficient value and observed the corresponding results, they were asked to set the next value in the same frame. When setting the coefficient value for one frame, the results of the previous manipulation disappeared. After the participants completed the final setting of the coefficient value (i.e., $r = 1$), they were asked to compare the corresponding results of the four different correlation coefficients values that appeared at different times after they completed all settings. In order to find the features of the corresponding results of different correlation coefficient values, the participants were requested to observe the features of scatter plots and x-y value of $r = 1$ and recall the features of scatter plots and x-y value of $r = 0$, $0.3$ and $0.7$ that appeared previously. Fig. 3a includes four screenshots demonstrating the learning procedures of the single-frame version. (For purposes of depiction, this figure combined four screenshots but in the experiment, for the single-frame display, each learning procedure was demonstrated using only one screenshot at a time.)

In contrast, the other version of SALS II was multiple-frame screen design that displayed four simulation frames at once. Participants who learned with multiple-frames were asked to successively set four specific correlation coefficients values into the four frames on the screen (e.g., $r = 0$, $r = 0.3$, $r = 0.7$, $r = 1$). Each of these values of the correlation coefficient was incorporated into the four different frames simultaneously using the following sequence: upper left ($r = 0$), upper right ($r = 0.3$), lower left ($r = 0.7$), lower right ($r = 1$). When participants incorporated one of the correlation coefficient values (e.g., $r = 0$ into the upper left frame) and observed the corresponding results, they were asked to set the next correlation coefficient value into the next frame (e.g., $r = 0.3$ into the upper right frame). The corresponding results of the previous manipulation were retained in the previous frame during this time. After the participants completed the final setting of the coefficient value (i.e., $r = 1$), they were asked to compare the results of the four different correlation coefficients values in the four frames. In order to find the features of the corresponding results of different correlation coefficients values, the participants were requested to observe the features of scatter plots and x-y values of $r = 0$, $0.3$, $0.7$, and $1$ that appeared in the four frames respectively. Participants of the two groups were allowed to learn at their own pace and their learning processes and learning times were recorded by SALS II. Fig. 3b
Fig. 3. a. Screenshots demonstrating the learning procedures of the single-frame version. b. Screenshots demonstrating the learning procedures of the multiple-frame version.
includes four screenshots demonstrating the learning procedures of the multiple-frame version. As can be seen, each of the four screenshots includes four figures presented to learners simultaneously in the multiple-frame screen design. Each learning procedure was demonstrated using one screenshot incorporating four figures.

An EyeLink 1000/2k Eye Tracker with a 35 mm camera and 19" TFT-LCD monitor in the ratio of 5:4 (1280 × 1024 pixels) was used to collect real-time eye movement data. The distance between the participants and the screen was fixed at 70 cm. Participant’s eye movements were recorded from the right-eye only at a sampling rate of 250 Hz. Gaze Tracker 9.0 was used to record and analysis the eye movement data. A gaze point lasting for at least 100 ms was identified as a fixation.

2.3. Measures

A pre-test was composed of ten short answer questions used to investigate the students’ prior knowledge about concepts of correlation and also used to select the participants requiring instruction concerning correlation since only students requiring instruction were used in the experiment. An example item was “please draw a scatter plot which represents a negative correlation”. The internal consistency reliability coefficient (KR-20) for the pre-test was 0.75.

A post-test, composed of 10 multiple choice questions, was used in this experiment to examine how well students had learned to establish relations between the different representations of correlation. This test was used to examine participants’ performance in identifying the correct arrangements of sample points on a scatter plot and the arrangements of x and y values for a specific r value. In other words, students were tested on their ability to relate an r value, its scatter plot and its table of x and y values, all of which provide different representations of correlation. Fig. 4 is an example item of the post-test. The internal consistency reliability coefficient (KR-20) of the post-test was 0.87.

A cognitive load rating scale was used to measure the perceived amount of invested effort. The cognitive load rating scale was an adapted version of the scale developed by Paas and van Merriënboer (1994). The scale asked the participants at three time periods to rate the amount of effort they had to invest in learning with the learning material. The Likert type nine-point scale had the following verbal labels: “very very low,” “very low,” “low,” “high,” “very high,” “very very high” and “very very very high”. The highest score on the rating scale was 9 points and the lowest score was 1 point.

Instructional efficiency was used to investigate the relation between the post-test performance and cognitive load spent on learning. Instructional efficiency was calculated according to the formula proposed by Paas and van Merriënboer (1993; see also Van Gog & Paas, 2008). According to their computational approach, each of the participants’ cognitive load score and post-test score was standardized, which yielded z-scores for cognitive load (C) and performance (P). Then, an instructional efficiency score (E) was computed for each participant using the formula: \( E = \frac{P - C}{\sqrt{2}} \).

Regarding the analysis of eye movement, this study defined the learning guide and the three important representations of the correlation concept as the Areas of Interest (AOIs) in the analysis of the eye movement data. These three representations were the correlation coefficient (r), the table of x, y values, and the scatter plot. The number and duration (in seconds) of fixations were analyzed to compare eye movements while viewing AOIs. The percentages of the number and duration of fixations on AOIs compared to the total number and duration of fixations were used as an index to present the eye movement data. In addition, as attending to the relations between different representations is a key task for successful learning of the concept of correlation, the number of transitions between the three important representations in the same frame is also taken as an important index. The transitions between the three important representations means the transitions of the fixations between the correlation coefficient (r), the table of x, y values, and the scatter plot in one frame. Fig. 5 displays the transitions between the table of x, y values and the scatter plot in one frame. This is one example of the transitions between the three important representations. It should be noted that for the multiple-frame group, if the student’s fixations between correlation coefficient (r),
Fig. 5. Examples of transitions between different important representations of the two versions.
(a) The example of transitions between the same important representations across different frames

(b) The example of transitions between different important representations across different frames

Fig. 6. Examples of transitions between important representations across different frames.
the table of x, y values, and the scatter plot occurred in different frames, it was not counted as part of this index but was counted as a separate index for the multiple-frame group (Fig. 6).

2.4. Procedure

The experiment had five phases.

2.4.1. Pre-test

Participants were assessed with the pre-test before the intervention. Because a primary purpose of this phase was to confirm that the participants who participated in this study required instruction concerning correlation, all participants were encouraged to try their best to answer the questions in this phase without a time constraint. The results indicated that there was no significant difference between the single-frame group ($M = 2.44, S = 1.82$) and the multiple-frame group ($M = 2.56, S = 2.50$) in their prior knowledge scores before the intervention, $t(30) = 0.16, p > .05$, Cohen’s $d = 0.05$.

2.4.2. Calibration exercise

After the prior knowledge test, a calibration exercise was conducted prior to the formal experiment. A 9-point calibration and validation procedure was performed to make sure that participants’ eye condition was suitable for participation in the experiment. Details concerning the calibration and validation procedure may be found in the Eyelink User Manual (2009). The average time spent in the calibration process was about 10 min. Participants passing the calibration process went to the next phase.

2.4.3. Basic concept learning

This phase was conducted to assist the participants to manipulate the simulation smoothly in the intervention phase because most of the participants had forgotten the key terms associated with the concepts of correlation. In this phase, basic concepts of correlation (e.g., the key terms associated with the concepts of correlation) were taught by the experimenter. The time spent on this phase was 5 min. Every participant learned the same contents within the same time limit.

2.4.4. Intervention

The participants were randomly assigned to learn with the SALS II integrating single-frame or multiple-frame screen designs. The participants were asked to complete the learning task within 20 min and the cognitive load scale was applied while learning after each learning unit.

2.4.5. Post-test

Participants were asked to complete the post-test within 7 min.

Table 1

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Single-frame group</th>
<th>Multiple-frame group</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>$M$</td>
<td>$SD$</td>
</tr>
<tr>
<td>Learning time (min)</td>
<td>12.28</td>
<td>3.41</td>
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<tr>
<td>Cognitive load (1–9)</td>
<td>3.25</td>
<td>1.40</td>
</tr>
<tr>
<td>Post test (0–10)</td>
<td>8.94</td>
<td>0.77</td>
</tr>
<tr>
<td>Instructional efficiency</td>
<td>0.51</td>
<td>0.77</td>
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</table>


Table 2

<table>
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<th>Variable</th>
<th>Single-frame group</th>
<th>Multiple-frame group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total fixation numbers</td>
<td>$1971.88$</td>
<td>$1914.63$</td>
</tr>
<tr>
<td>Fixation numbers on learning guide</td>
<td>$603.44$ (31.57)</td>
<td>$503.75$ (34.36)</td>
</tr>
<tr>
<td>Fixation numbers on important representations</td>
<td>$146.94$ (22.88)</td>
<td>$171.71$ (6.14)</td>
</tr>
<tr>
<td>Fixation numbers on other areas</td>
<td>$614.29$ (17.63)</td>
<td>$595.54$ (20.83)</td>
</tr>
<tr>
<td>Fixation time on learning guide</td>
<td>$161.53$ (27.45)</td>
<td>$173.57$ (29.67)</td>
</tr>
<tr>
<td>Fixation time on important representations</td>
<td>$284.98$ (45.55)</td>
<td>$235.62$ (39.28)</td>
</tr>
<tr>
<td>Fixation time on other areas</td>
<td>$167.77$ (27.17)</td>
<td>$186.35$ (31.05)</td>
</tr>
<tr>
<td>The number of transitions between the three important representations</td>
<td>$103.06$ (48.89)</td>
<td>$50.75$ (31.39)</td>
</tr>
<tr>
<td>The number of transitions between the same important representations across different frames</td>
<td>$28.88$ (19.16)</td>
<td>$13.50$ (10.48)</td>
</tr>
</tbody>
</table>

The number of transitions between different important representations across different frames
3. Results

3.1. Learning time, cognitive load and post test performance

Table 1 presents the mean scores and standard deviations for each group for the learning time (in minutes), cognitive load, post-test performance, and instructional efficiency. A one-way Analysis of Covariance (ANCOVA) was conducted on the post-test scores after confirming the requirement of homogeneity of within-cell regressions, with pre-test scores as the covariates to detect any significant differences between the two groups. The results revealed a significant difference, $F(1, 29) = 5.41, MSE = 1.54, p < .05$, Cohen’s $d = 0.16$ indicating a superior performance by the single-frame group.

There was no significant difference between the two groups in learning time, $t(30) = 0.68, p > .05$, Cohen’s $d = 0.24$ but participants of the multiple-frame group perceiving higher cognitive load than the participants of the single-frame group, $t(30) = 2.03, p = .05$, Cohen’s $d = 0.72$. There was a significant difference between the two groups in instructional efficiency, $t(30) = 2.54, p < .05$, Cohen’s $d = 0.91$. The single-frame group was significantly more efficient than the multiple-frame group.

3.2. Results of eye movement analyses

Means and standard deviations of the eye movement data are presented in Table 2.

The analysis of the results indicated that there were no significant differences between the two groups in the number of fixations on the learning guides as a percentage of the total number of fixations, $t(30) = -1.19, p > .05$, Cohen’s $d = 0.42$. Regarding the fixation time on the learning guides, there were also no significant differences between the two groups in the fixation time on the learning guides as a percentage of the total fixation time, $t (30) = -0.91, p > .05$, Cohen’s $d = 0.23$. There was a significant difference between the two groups in the number of fixations on the three important representations as a percentage of the total number of fixations $t(30) = 3.17, p < .01$, Cohen’s $d = 1.12$. The participants of the single-frame group had a significantly higher percentage than the participants of the multiple-frame group. There also was a significant difference between the two groups in fixation time on the three important representations as a percentage of the total fixation time, $t (30) = 2.10, p < .05$, Cohen’s $d = 0.74$. The participants of the single-frame group had a significantly higher percentage than the participants of the multiple-frame group. In addition, there was a significant difference between the two groups in number of fixations on the other areas (i.e., the areas that were not defined as an AOI) as a percentage of the total number of fixations, $t(30) = -2.78, p < .01$, Cohen’s $d = 0.98$. The participants of the multiple-frame group had a significantly higher number of the other areas than the participants of the single-frame group. Lastly, there was a significant difference between the two groups in the number of transitions between the important representations in the same frame, $t(30) = 3.60, p < .01$, Cohen’s $d = 0.74$. The participants of the single-frame group had a significantly higher number of transitions between the important representations than the participants of the multiple-frame group.

With regard to the transitions between important representations across different frames for the multiple-frame group, the mean number of transitions between the same important representations across different frames was 28.88, which accounts for 31.33% of the sum of the number of transitions. The sum of the number of transitions is the number of transitions between the important representations in the same frame adding to the number of transitions between the same/different important representations across different frames. The mean number of transitions between different important representations across different frames was 13.50, which accounts for 14.71% of the sum of the number of transitions.

4. Discussion

In summary, the multiple-frame group perceived a significantly higher cognitive load than the single-frame group while learning. Participants of the single-frame group performed better in identifying the relations between the representations than the multiple-frame group. As a consequence of these results, learning was more efficient using the single-frame than the multiple-frame condition. We can conclude that learning the relations between the representations of correlation was important and that the single-frame group learned these relations better than the multiple-frame group. When using cognitive load theory (Sweller, 2010) to explain the results, two of the most important sources of intrinsic cognitive load associated with the instructional material are the interacting elements that constitute the various representations of a correlation and the interacting elements that need to be processed in order to compare and contrast one correlation with another. If the relations between representations have not been learned, it is probably fruitless attempting to learn how each representation changes with changes in a correlation, since the meaning of a representation is yet to be assimilated. Accordingly, directing working memory resources (germane cognitive load) to relations between different correlation coefficient values as occurred in the multiple-frame condition may be less effective than directing those resources to relations between representations.

Our results can be explained in terms of the isolated elements effect (Aires, 2006, 2012; Blayney et al., 2010; Pollock et al., 2002). It is important for students to learn the relations between various correlation coefficients and until they have done so, they have not fully assimilated the concept. Nevertheless, since learning how the representations of correlation relate should take precedence, it may be better to first learn the meaning of individual correlations before generalizing to other correlation coefficients. In other words, each correlation should initially be treated as an isolated element as occurred in the single-frame condition. By attempting to have learners assimilate both the relations between representations and the relations between different correlation coefficients simultaneously, the element interactivity due to intrinsic cognitive load may have been excessive resulting in the superiority of the single-frame condition. These findings could also echo the studies of Blayney et al. (2010) and Pollock et al. (2002), which indicated that information presented in isolated elements form followed by information presented in integrated elements form was better than the same material presented twice in integrated form.

The multiple-frame condition was intended to reduce the effects of transient information (Leath & Sweller, 2011; Wong et al., 2012). It may not have been superior to the single-frame condition in this experiment because the need to relate various correlation coefficients may have been premature. It may be possible that if testing more knowledgeable learners, the multiple-frame condition may be more effective.
This suggestion, based on the expertise reversal effect (Kalyuga, Ayres, Chandler, & Sweller, 2003), can be tested with further experimentation.

The analysis of the eye movement results provided information explaining the results. If learning to understand the relation between representations is important, then we might expect learners to devote a greater percentage of their gaze episodes and time to the important representations of correlation concepts. The single-frame group had a greater percentage of their gaze episodes and time devoted to the important representations than the multiple-frame group. On the other hand, the multiple-frame group had a greater percentage of their gaze episodes devoted to the areas other than AOs than the single-frame group. More importantly, we might expect the single-frame group to more frequently emphasize a comparison between the representations than the multiple-frame group by frequently switching their gaze from one representation to the other. A large effect was obtained on this comparison. The eye-tracking data allow us to conclude that the single-frame condition was superior to the multiple-frame condition because learners spent a greater percentage of their episodes and time attending to the important representations and, assuming that a switch in gaze reflects a comparison between representations, because the single-frame condition results in more comparisons between representations.

The findings of the transitions between the representations across different frames and the worse learning performance for the multiple-frame group support the suggestion that students need to learn the relations between representations of a correlation before they learn to compare different correlation values. It can also be predicted that when students in the multiple-frame group compare representations across different frames, their gaze episodes might be focused on areas other than AOs. This orientation of focus might be a reason why the multiple-frame group had a significantly higher number of fixations on areas other than AOs compared to the single-frame group.

With respect to applications, the major general conclusion of the current results is that we need to carefully limit the amount of information that we require learners to assimilate at a given time. The fact that learners need to be able to understand the relation between different correlation coefficients does not justify presenting the relevant information during the early stages of learning. In accord with the isolated elements effect, sometimes it may be better to shield learners from essential information until they are ready to assimilate it.

One way to improve the frame-design of computer simulations is to have a multiple-frame presentation follow a single-frame presentation. The initial single-frame stage would allow learners to focus on the relations between different representations. Once relations between representations have been learned, the subsequent multi-frame stage would allow learners to concentrate on comparisons between values. In related fashion, the use of more knowledgeable learners who already know the relations between representations should allow the use of multiple-frame presentations.

A limitation of this study is that cognitive load was measured by a single-item survey measure, which does not allow us to measure the different types of cognitive load that resulted from the frame design. The multiple-item measures of cognitive load developed by Leppink, Paas, Van der Vleuten, Van Gog, and Van Merriënboer (2014) should be used in future research.

In conclusion, the current study indicates that when teaching topics such as the meaning and use of statistical correlation, it may be better to present information as isolated elements before requiring learners to assimilate large amounts of integrated information. Learners need to learn the meaning of individual elements before learning how to integrate those elements. While it is important for learners to integrate individual elements of information, working memory load may prevent them from assimilating large amounts of integrated information simultaneously. Large amounts of integrated information should be presented only after individual elements of information have been acquired. The current experiment provided parallel evidence for these contents from test performance, subjective ratings of cognitive load, and eye-movement data.

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