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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.

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

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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.

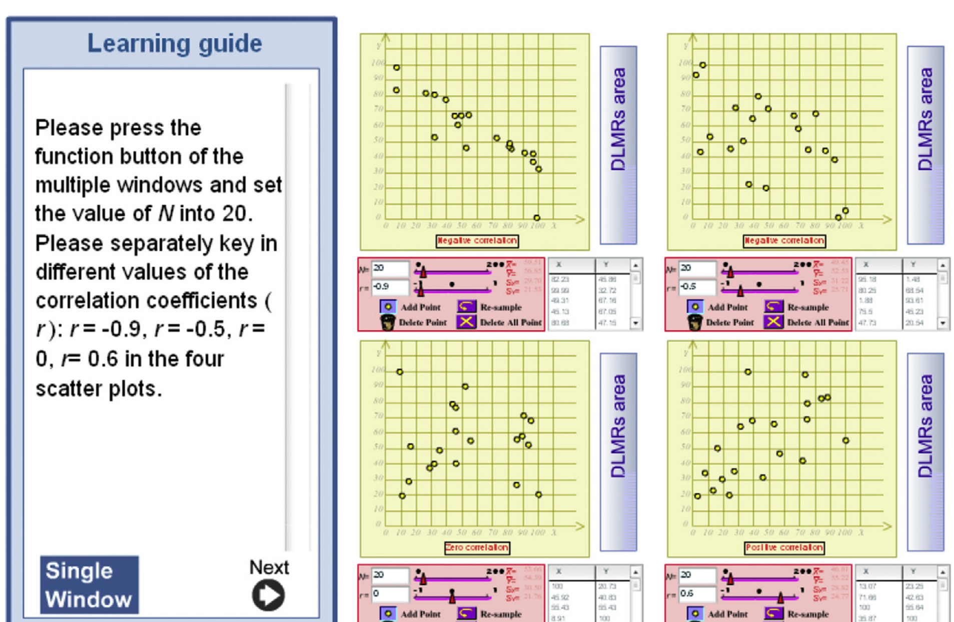

Fig. 1. A screenshot demonstrating a "multiple-frame" screen design (Liu et al., 2010).