Compositional design of animation improves relational processing of complex dynamics: evidence from an eye movement based relational index

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Abstract. Learners have difficulty in decomposing conventionally designed animations to obtain raw material suitable for building high quality mental models. A composition approach to designing animations based on the Animation Processing Model was developed as a principled alternative to prevailing approaches. It provides learners with pre-decomposed material that is structured and sequenced to facilitate the relation building required for effective mental model construction. Study of a compositional animation that presented material in a contiguous fashion resulted in higher quality mental models of a piano mechanism than non-contiguous or control (conventional) versions. Relation building required to link pre-decomposed material was investigated with eye movements data analysis: a relational index measure was devised and used to asses mental model construction. This relational index showed that the compositional animation led to superior mental models because it particularly fostered relational processing.

Keywords: Animation design; Animation Processing Model; Composition; Eye movements; Relational index.

Introduction

Researchers have investigated numerous interventions intended to increase animation's effectiveness as a tool for learning, from giving the learner control over the animation's display regime (Scheiter, 2014), to cueing the animation's high relevance information (De Koning, Tabbers, Rikers, & Paas, 2007) etc. However, achieving major improvements in the quality of the mental models that learners develop from animations has proven to be particularly elusive. To date, research on learning from animations has concentrated on interventions intended to improve the effectiveness of conventionally designed animated materials. In these animations, the subject matter is presented comprehensively – with the full complement of entities involved presented simultaneously and with all those entities faithfully portraying the changes that occur through time (Lowe & Boucheix, 2012). A risk of this ‚comprehensive' animation design is that learners become overwhelmed by the processing demands involved.

In order to investigate online cognitive processing, eye movements methods are now widely used in multimedia learning studies (van Gog & Scheiter, 2010). However, most often, one single measure is used, the total fixation duration in AOIs (Area Of Interest). More rarely, measures of transition saccades between AOIs complete fixation duration. Such measures did not provide useful details about relation building between the dynamic events during comprehension activities.

The present study examined the effect on learning of an alternative way of designing educational animations that we have termed a *Composition Approach*. This alternative gives primacy to how learners actually process these dynamic visualizations and compose information into high quality mental models. Instead of presenting the subject matter as it actually occurs through time (as is done in conventional ‚Comprehensive' animations), the composition approach uses a progressive, sequential staging of dynamic information to present complex, simultaneous and causally interconnected events in a more readily assimilable way (Lowe & Boucheix, 2012). This design is directly based on fundamental aspects of the Animation Processing Model (APM,Lowe & Boucheix 2008), specifically, *event unit analysis* of the dynamic subject matter and *relation sets* that are comprised of small groups of related *event units*. Although the sequencing of content presentation in this way is new to the field of animation design, there are precedents for sequencing complex tasks generally in order to make them more tractable for learners (for example, the Sequencing principle, van Merriënboer & Kester, 2014). However, the composition approach employed in the present experiment is fundamentally different from conventional temporal segmentation. Rather than simply chopping a pre-existing conventionally designed animation into pieces along its time course, it is concerned from the outset with helping learners to incrementally and hierarchically interconnect event units in order to build a mental model. Further, in order to follow online processing of the learners' composition activities, a new eye movement composite indicator, the relational index, was devised to "measure" relational processing depth during a fixed learning time. This relational index involved a ration between mean fixation duration and fixation counts.

Method

In order to test the composition approach, three differently-designed animations of an upright piano mechanism were compared. A control condition using a conventional comprehensive animation presentation was compared to two conditions that used incremental animation designs (Figure 1a,b,c). In the *contiguous* condition, a progressive sequential presentation of relation sets (pairs of event units) followed the forward causal chains of the system and was intended to foster the cumulative interconnection of event units. In the *non-contiguous* condition, the presentation of relation sets was in a quasi random sequence that did not follow the forward causal chain. We hypothesized that comprehension scores would be better in the contiguous condition (a compositional animation design) than in either the comprehensive or non-contiguous conditions. Regarding depth of processing, the contiguous condition was expected to result in fewer but longer eye fixations than the comprehensive and non-contiguous conditions (which should show more but shorter fixations). The ratio fixation number / fixation duration provided an efficient relational processing index.

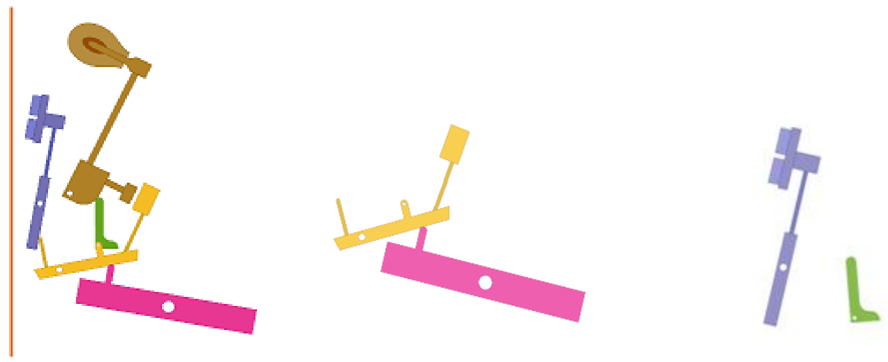

Figure 1. Snapshots from (a) comprehensive, (b) contiguous and (c) non-contiguous presentations

Participants were 60 undergraduate students randomly assigned to each of the three experimental conditions. Prior knowledge and spatial abilities (DAT) were controlled for each group.

The learning material consisted different animated versions of the same upright piano mechanism with components colored to help with identification. The same learning time of 4 minutes was used across all three conditions. Three post tests were designed to measure comprehension. Participants first performed a local dynamics task on a single static depiction of the complete piano mechanism (Boucheix, Lowe, Putri & Groff, 2013). Next, they generated an exhaustive written account of how all components of the piano mechanism work individually and together during its complete operational cycle (as an indicator of mental model quality). During each learning session, individual participants' eye movements were recorded. Areas of Interest (AOIs) were defined for the six major components of the original piano mechanism (Key, Whippen, Jack, Hammer sub-system, Damper sub-system, and String). A further Null AOI was established for all fixations that fell outside the six component AOIs.

Results

ANOVA performed on the overall comprehension performances (using means for local kinematics, mental model, and transfer scores) revealed a significant effect for animation design (F(2, 57) = 4.27, p = .019, ηp^2 = .13). Performance for the contiguous (compositional) condition was better than for the control (comprehensive) condition (F(1,57) = 4.13, p = .046) and the non-contiguous condition ($F(1,57) = 8.03$, $p = .006$). Control and non-contiguous conditions did not differ ($F < 1$). This effect was particularly marked for the mental model scores ($F(2,57) = 5.81$, $p = .005$, $\eta p^2 = .17$; contiguous/control, $F(1,57) = 6.61$, $p = .01$; contiguous/non-contiguous, $F(1,57) = 10.39$, $p = .002$).

Regarding eye movements, There was a negative correlation between mean fixation duration and count, $r = -.81$, $p < .001$. Participants in the contiguous condition had longer mean fixation durations than those in the control and non-contiguous conditions (respectively, $M = 0.48$s, 0.39s and 0.41s, $F(2,51) = 3.52$, $p = .037$, $\eta p^2 = .12$); However, fixation counts were higher in the control and the non-contiguous condition than in the contiguous condition (respectively, $M = 539$, 541, and 460, $F(2,51) = 3.82$, $p = .028$). Relational index data revealed that results for the contiguous, non-contiguous and control groups were significantly different, F (2, 51) = 5.41, p = 0.007, $\eta p^2 = .17$. This suggests a clear tendency for those in the contiguous condition to engage in more relational processing whereas the processing of those in the non-contiguous and control groups tended to be more exploratory.

Table 2. Mean scores (%) and mean fixation durations, counts and duration/count ratios in the seven AOIs (by condition)

Measures: Means (SD)	Condition		
	Contiguous	Non-contiguous	Control
Mental model score%	43.16 (11.15)	27.50 (18.22)	30.67 (15.88)
Overall Compreh. score %	49.43 (10.88)	38.97 (11.49)	41.93 (12.60)
Fixation duration (milliseconds)	475.62 (131)	396.61 (80.27)	406.01 (60.11)
Fixation count (n)	460.93 (105.8)	539. 42 (93.78)	540.89 (89.93)
Relational index (Duration/count)	1.12 (0.51)	0.77 (0.24)	0.79 (0.27)

Conclusion

Our motivation for devising a new approach to designing educational animations was to improve the fit between (i) how these visualizations present their information and (ii) the information processing characteristics of human learners. The composition approach resulted in learners constructing substantially superior mental models. We attribute this success to focusing animation design on facilitating the composition processes required for the learner to build a high quality *internal representation*. Eye movements relational indices for the three designs suggest that the compositional animation was indeed more likely to foster the hierarchical part-whole interlinking assumed to occur during mental model building. Qualitative data from the eye tracking videos were consistent with the interpretation that those viewing the compositional animation devoted more perceptual (and probably cognitive) resources to establishing the types of linkages posited to be formed in APM Phase 2 and 3 processing. Example of eye tracking videos will be presented at the conference.

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