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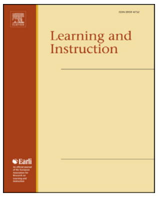

# Principled animation design improves comprehension of complex dynamics

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ABSTRACT

Learners can 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. Outcomes from studying novel and conventional animation designs (independent variable) were compared with respect to mental model quality, knowledge of local kinematics, and capacity to transfer (dependent variables). 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 but no significant differences regarding local kinematics or transfer. Eye fixation data indicated that the compositional animation led to superior mental models because it particularly fostered relational processing. Implications for future research and the design of educational animations are discussed.

## 1. Introduction

Animations have become a ubiquitous feature of technology-based learning materials (Höffler & Leutner, 2007). However it has also become clear that animation can be a two-edged educational sword (Lowe, 2014) - the undoubted benefits of animations must be weighed against the processing costs they may impose on learners (Lowe & Schnotz, 2008). The research reported here investigated a novel design approach for reducing such processing costs in order to better capitalize on animation's benefits.

Conventionally-designed animations that present complex subject matter to learners who are novices with respect to the depicted domain have proven to be particularly problematic. The difficulties learners experience with such depictions have been attributed to the very particular way in which they present their subject matter and the psychological consequences of those presentational characteristics. Prime amongst these characteristics is the dynamic nature of animations. While animations undoubtedly have a major advantage over static graphics in their direct, explicit presentation of spatiotemporal information, their dynamics can also have negative effects on learners' extraction of crucial task-relevant information (Lowe, 2003). This is because when learners are faced with animations that portray complex, unfamiliar dynamic subject matter, many and varied simultaneously presented aspects of the animation compete for the learner's limited attentional resources (Lowe, 1999; Schnotz & Lowe, 2008). Unfortunately, the information learners extract tends to be what is perceptually salient rather than what is task relevant. Further, the information presented in an animation is intrinsically transitory so the time available for the learner to process it is very limited. This situation can be exacerbated when animations present rapidly changing subject matter at a realistic speed. In the next section, we summarize ways in which researchers have attempted to ameliorate these processing challenges.

### 1.1. Efforts to improve educational effectiveness

Researchers have investigated numerous interventions intended to increase animation's effectiveness as a tool for learning (Ploetzner & Lowe, 2012). They include giving the learner control over the animation's display regime (Boucheix, 2008; Lowe, 2004, 2008; Scheiter, 2014), modifying the animation's presentation speed (Boucheix, Lowe, & Bugaiska, 2015; Fischer, Lowe, & Schwan, 2008; Meyer, Rasch, & Schnotz, 2009), subdividing the animation's

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time course into smaller segments (Spanjers, Wouters, Van Gog, & Van Merriënboer, 2011; Wong, Leahy, Marcus, & Sweller, 2012), cueing the animation's high relevance information (De Koning, Tabbers, Rikers, & Paas, 2007; Lowe & Boucheix, 2011; Boucheix, Lowe, Putri, & Groff, 2013), providing strategy training to learners regarding more effective animation processing (Kombartzky, Ploetzner, Schlag, & Metz, 2010; Ploetzner & Schlag, 2013), accompanying the animation with ancillary learning activities (De Koning, Tabbers, Rikers, & Paas, 2010; Mason, Lowe, & Tornatora, 2013) and displaying multiple animation segments simultaneously (Ploetzner & Lowe, 2014; Rebetez & Bétrancourt, 2009). However, achieving major improvements in the quality of the mental models that learners develop from animations has proven to be particularly elusive (Boucheix & Lowe, 2010).

Although many innovative interventions have been pursued by researchers thus far, there is one key aspect that has not yet been addressed: the fundamental design assumptions upon which the animations are based in the first place. We suggest that some major problems learners currently have in processing animations could be reduced by a fundamental re-thinking of animation design. The research reported here investigated the potential of an alternative approach to designing educational animations. Rather than being primarily concerned with animations as *external* representations of the target subject matter (as is the case with conventionally designed animations), the main focus of this alternative is on helping learners to compose better *internal* representations (i.e., mental models) (Lowe, in press). Because of its concern with the psychological processes involved in composing these mental models, we have termed this design alternative the *composition approach*. In the study reported here, conventional and novel types of animation design (independent variable) were compared with respect to their outcomes for mental model quality, knowledge of local kinematics, and capacity to transfer (dependent variables).

### 1.2. Theoretical foundations for compositional animation design

The origins of the composition approach lie in the Animation Processing Model (APM) (Lowe & Boucheix, 2008). This theoretical framework describes the perceptual and cognitive processes that are thought to occur when an individual is engaged in learning from *conventionally* designed complex explanatory animations. We characterize these conventional animations as *comprehensive* representations because they portray the targeted aspects of their subject matter in a relatively comprehensive and faithful manner, thus following a "physical fidelity principle" which is known to impair learning especially for domain novices (Van Merriënboer & Kester, 2014). They include all the referent system's relevant entities and depict their dynamics in a behaviorally realistic manner (Lowe & Boucheix, 2012). The APM can be used to identify potential sources of learner difficulty in processing complex comprehensive animations and to suggest ways of ameliorating such difficulties.

As summarized in Fig. 1, the Animation Processing Model has five main phases. Overall, this learner processing can be divided into two broad types of activity: *decomposition* (APM Phase 1) and *composition* (APM Phases 2–5). A distinction is thus made between (i) analytic processing in which the learner must initially decompose the animation's continuous flux of information into the discrete event units (entities plus their associated behaviors) that provide the raw material for mental model building, and (ii) synthetic processing in which this raw material is cumulatively and iteratively composed into the higher order knowledge structures that comprise a mental model of the target subject matter.

Previous research indicates that decomposition of a complex animation can be particularly problematic for learners who lack domain specific background knowledge (Lowe & Schnotz, 2014). Rather than decomposing the presented depiction appropriately into the thematically relevant event units required for building high quality mental models, learners tend to extract subsets of information on the basis of their perceptual salience (Schnotz & Lowe, 2008). The net result is that this unsuitable extracted raw material can severely compromise the quality of the mental models they are ultimately able to build from study of the animation.

The composition approach was devised with the intention of better matching the fundamental design of complex animations to the way learners process dynamic visualizations. It aims to remove a substantial barrier to acquisition of high quality mental models by relieving learners of the necessity to decompose comprehensive animations. Instead of having to carry out Phase 1 processing by themselves, learners are progressively 'fed' the total set of required information via a series of small, discrete portions that in one sense could be considered as a result of an 'ideal' decomposition. In terms of the APM, this essentially allows learners to by-pass error-prone Phase 1 processing activity and move straight to Phase 2 and subsequent processing involving the composition of dynamic microchunks into higher order structures. As explained later, practical implementation of the composition approach is particularly concerned with facilitating effective relational processing because of its importance to forming the hierarchically organized knowledge structures that are characteristic of high quality mental models.

Although the composition approach originated from the APM and is specific to learning from complex animation, it is consistent with a broader range of approaches that aim to facilitate complex learning and performance of complex tasks more generally (De Jong & Lazonder, 2014; Van Merriënboer & Kirschner, 2013). A key focus of research in this area is how instruction and tasks may best be sequenced (e.g., Van Merriënboer & Kester, 2014; Van Merriënboer, Kirschner, & Kester, 2003). Various alternatives are possible – for example, whole-part versus part-whole sequencing. Of particular relevance to the present investigation is the Sequencing Principle which indicates that "*… it is often better to sequence learning tasks or complex pieces of information from simple to complex than to present them in their full complexity at once*" (Van Merriënboer & Kester, 2014, p.116). It should be noted that in many cases, application of this principle implies that the material will need to be subdivided in some way in order that pieces are available to be sequenced.

A typical approach based on simple to complex sequencing is to break the material or performance into simple parts that are then trained separately and progressively combined into the whole (Van Merriënboer et al., 2003). Instructional sequencing has been used in a range of ways including with respect to information pretraining (Mayer & Pilegard, 2014; Mayer, Mathias, & Wetzell, 2002), element interactivity (Kester, Kirschner, & Van Merriënboer, 2004a, 2004b), and dynamic visualizations (Khacharem, Spanjers, Zoudji, Kalyuga, & Ripoll, 2012; Spanjers et al., 2011). Various studies have shown the positive effects of such sequencing techniques (e.g., Clarke, Ayres, & Sweller, 2005; Limniou & Whitehead, 2010; Mayer & Moreno, 2003; Mayer et al., 2002; Musallam, 2010; Pollock, Chandler, & Sweller, 2002).

However, the applicability of sequencing approaches can be highly specific. Sequencing may need to be implemented in very different ways depending on considerations such as the learning goal, the type of display, the subject matter involved and the learner's level of prior knowledge. For example, some types of sequencing appear not to be suitable for complex learning that requires coordination between parts, and the integration of knowledge, decisions and/or procedures (Naylor & Briggs, 1963; Van Merriënboer, 1997). In the case of complex comprehensive animations, it is clear that presentation of the subject matter as a whole can be very problematic for learners (Lowe & Boucheix,