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# Understanding Dynamic Systems with Direct-Manipulation Animation

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## Introduction

Understanding systems, especially dynamic and complex ones, is notoriously difficult for learners of all ages. Systems can be conveyed by text, static visuals, and animation. Research has demonstrated that text and text supplemented with visuals help people understand systems. In contrast, studies on the efficacy of animation in aiding learning have been inconclusive (Tversky et al., 2001). Recent studies from our lab (Chan & Black, 2006) showed that direct-manipulation animation helped learners comprehend and reason about dynamic systems, while system-controlled animation may have led to shallow cognitive processing. The present study extends these findings by examining the role of system complexity and presentation formats in supporting system understanding. We hypothesize that learners require different kinds of support or experiences to understand systems of varying degrees of complexity.

## Direct-manipulation animation (DMA)

Considering the cognitive load of thinking about dynamic systems and the transient nature of system-controlled animation, we implemented *direct-manipulation animation,* which allows learners to fully and directly interact with the content through hand controls. In DMA, learners can drag sliders to directly change the value of variables, then immediately see how this change influences other variables and/or the entire system (i.e., functional relations between system entities). We believe this tight coupling of direct manipulation of variables and immediate visualization of their impacts supports learners to perform crucial cognitive processes to understand and reason about systems.

## Method

Study participants were 183 sixth-graders in a New York City public school. Because energy is a major unit in the science standards, energy transfer was chosen as the study's topic. We randomly assigned students to learn about mechanical energy transfer to one of three scenarios: playground swing, roller coaster ride, and pole-vaulting. Students in each scenario were further assigned into one of three presentation-format groups: text-only, text-plus-visuals, and text-plus-direct-manipulation animation. A pretest was conducted and the dependent measures were: (1) verbal and visual recalls—summaries and drawings to illustrate energy transfer; (2) model-based reasoning tests—"What if?" and "What's wrong here?" scenarios; and (3) transfer tasks.

## Results

Three graduate students (double-blinded) rated the results independently; inter-rater reliability was .88. Using pretest score as a covariate, two-way ANCOVAs were carried out. Results showed a significant main effect of presentation format on all dependent measures: recall summary, $F(2, 173)=32.73$, $p=.000$; drawing, $F(2, 173)=40.30$, $p=.000$; "What if?" scenarios, $F(2, 173)=15.76$, $p=.000$; "What's wrong here?" scenario, $F(2, 173)=16.78$, $p=.000$; and transfer, $F(2, 173)=33.53$, $p=.000$. The effect sizes were .52, .56, .49, .40, and .53, respectively. The main effect for system complexity on drawing and transfer were significant, $F(2, 173) = 3.04$, $p=.050$, and $F(2, 173)=10.13$, $p=.000$, respectively. The effect sizes were .18 and .32, respectively. The interaction was not significant for all outcome measures.

## Discussion

Presentation formats matter for these sixth-grade students. Participants in the DMA group outperformed their counterparts on recall, model-based reasoning, and transfer. Since the interaction effect was not significant, the results did not corroborate our hypothesis. At this age (or grade), students seem to need the support of interactive animation, in addition to the usual text, to acquire a solid understanding of the systems, regardless of the degree of system complexity. Interestingly, in another study (Chan & Black, 2006) we conducted with seventh-graders in the same school, the interaction effect was significant, suggesting that for learners with greater mental memory capacity, the benefits of DMA for learning were more pronounced when the systems became increasingly complex. We do not know what accounts for the differential performance between these two populations. Possible explanations are working memory capacity and familiarity with the subject matter. More research is needed to explore these possibilities. This study makes two contributions to this field of research: (1) It demonstrates the potential benefits of incorporating the haptic channel in the learning process and extends Mayer's (2001) cognitive processing model of multimedia learning. (2) It shows that direct-manipulation animation may represent an example of how a passive medium (i.e., system-controlled animation) can be transformed into an active one. We argue that effective use of animation to promote learning lies not only in active engagement, but also in providing critical cognitive support that enables learners to perform the cognitive processes needed to comprehend systems and reason about their structural configuration and functional relations.

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