Systematic Design to Enhance Learning: Multimedia Resources in Online Learning

Misook Heo, Duquesne University, United States
Natalie Toomey, Duquesne University, United States

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Abstract
The study investigated whether spatial ability would be a predictor of learning outcome when using different types of multimedia resources. Specifically, this study hypothesized that individuals with lower spatial ability would experience greater learning benefits from dynamic resources (e.g., animation with narration) as opposed to non-dynamic learning resources (e.g., static visuals with narration), based on the ability-as-compensator hypothesis. The independent variables for the current, experimental study were type of multimedia resources and spatial ability. The dependent variables were learning outcomes in two, procedural knowledge learning tasks. A total of 246 participants were solicited on a voluntary basis from the undergraduate student population at a mid-size university in the Northeastern USA. All participants were directed to an online site offering a timed spatial ability test and two, time-limited learning tasks. Participants were randomly assigned to one of two multimedia resource groups (animation or static). The study found that spatial ability was an acceptable predictor of learning outcomes in both learning tasks. Contrary to the study hypothesis, however, individuals with higher spatial ability, not lower spatial ability, experienced greater learning benefits in the animation group. This finding would then correspond the ability-as-enhancer hypothesis, which suggests that higher spatial ability individuals have a greater cognitive capacity to deal with dynamic learning resources.

Keywords: Animation versus static visuals, spatial ability, learning outcomes, ability-as-compensator hypothesis, ability-as-enhancer hypothesis

Introduction

With current technological advancements, designing a variety of multimedia instructional resources such as animations and simulations has become increasingly feasible. Animations can solicit learner attention, clarify abstract concepts, and provide procedural information more efficiently (Berney & Bétrancourt, 2016). Considerable research has thus been devoted to the examination of animations and their influence on learning outcomes in recent years. While meta-analyses report greater learning gains with animated learning resources as opposed to static learning resources in general, discrepancies exist as to the effect size of learning outcomes with animations, specifically with procedural knowledge (Berney & Bétrancourt, 2016; Höffler & Leutner, 2011). Furthermore, the focus of many past studies has been on learning outcomes only, not particularly on the relationship between learner characteristics and learning outcomes.

Procedural information often requires learners to engage in the mental manipulation of visual objects. Spatial ability allows individuals to mentally manipulate objects effectively, which in turn enables better understanding of spatial relationships between objects (Lohman, 1996; Massa, Mayer, & Bohon, 2005). It is therefore a reasonable assumption that spatial ability plays an important role in the acquisition of procedural information offered by dynamic and static learning resources. This study thus examined the relationship between spatial ability and learning outcomes with static versus animated learning resources.

Literature Review

Spatial Ability and Visual Learning Resources

Spatial ability plays an important role in learning with multimedia resources (Höffler, 2010; Höffler & Leutner, 2011; Yilmaz, 2009). In fact, individuals with higher and lower spatial ability show differences in performance when learning with visual resources (Berney, Bétrancourt, Molinari, & Hoyek, 2015; Höffler, 2010). As individuals with lower spatial ability have more difficulty dealing with visual resources, efforts are often made to better aid their understanding. Such strategies include explicitly drawing attention to key components of images (Roach, Fraser, Kryklywy, Mitchell, & Wilson, 2019) or using different types of visual resources, such as dynamic images (Hegarty & Kriz, 2008). The latter strategy is based on the ability-as-compensator hypothesis (Mayer & Sims, 1994).

According to the current interpretation of the ability-as-compensator hypothesis, optimal instructional design (e.g., with dynamic images) can reduce the need for mental manipulation of visual resources by offering an explicit representation of relationships among components of the visual resource (Berney et al., 2015; Höffler, 2010; Höffler & Leutner, 2011). Dynamic learning resources can accordingly mitigate differences in learning outcomes between individuals with higher and lower spatial ability by aiding those with lower spatial ability to efficiently build accurate mental models (Hegarty & Kriz, 2008), thus enhancing learning outcomes (Höffler, 2010; Höffler & Leutner, 2011). Many research studies provide empirical evidence supporting learning differences based on spatial ability when dealing with images, as summarized in Höffler (2010), with an overall medium effect size.

An alternative view regarding spatial ability in dealing with visual resources is the ability-as-enhancer hypothesis. This hypothesis asserts that individuals with higher spatial ability possess greater cognitive capacity and thus are better able to deal with dynamic visuals containing additional procedural information (Mayer & Sims, 1994). Empirical support for the ability-as-enhance hypothesis, however, is less abundant, compared with the ability-as-compensator hypothesis (e.g., Mayer & Sims, 1994; Huk, 2006). Regardless of which perspective is adopted, it is clear that interactions between spatial ability and learning outcomes exist, particularly when processing learning resources containing dynamic visualizations.

Research Question and Hypothesis

The purpose of the study was to investigate whether spatial ability would be an adequate predictor of leaning outcomes and how learning outcomes would differ based on multimedia learning resource type. Referencing the ability-as-compensator hypothesis as the research framework, this study hypothesized that the predictive power of spatial ability on learning outcomes would be stronger when using static learning resources than when using animation, as animations would mitigate spatial ability differences by reducing the need for mental manipulation of visual objects.

Methodology

Variables

The independent variables for this experimental study were spatial ability and type of multimedia resources (two-levels: animation and static). The dependent variables were learning outcome as measured by the number of correct responses in two, procedural knowledge learning tasks.

Participants

A total of 245 participants were solicited on a voluntary basis from the undergraduate student population at a mid-size university in the Northeastern USA. The majority of the participants were female (N=193, 78.8%) and between the ages of 18 and 22 (N=236, 96.3%).

Instruments

This study used a spatial ability test and two learning tasks. The spatial ability test was to assess learner's ability to apprehend, encode, and manipulate spatial objects mentally (Lohman, 1988). A timed, paper-folding test from French, Ekstrom and Price (1963), which asks learners to imagine the folding and unfolding of pieces of paper, was adopted. Each of the learning tasks covered a unique, procedural knowledge topic, which could be encountered in an informal learning setting: 1) the functioning of a toilet cistern and 2) the functioning of a car brake system. The toilet cistern task was adapted from Höffler et al. (2017) with permission. The brake system task was created for the study, inspired by the work of Mayer, Mathias, and Wetzell (2002).

Each learning task contained three, time-limited multimedia resources presented as either static images or animations. The multimedia resources were designed and developed with consideration of multiple, multimedia related principles. For example, in an effort to balance visual and auditory working memory capacity, the multimedia resources included simultaneously narrated explanation, thus employing both the modality principle (Low & Sweller, 2014) and the temporal contiguity principle (Mayer & Fiorella, 2014). Following the pre-training principle (Mayer & Pilegard, 2014), participants were first offered pre-training resources (e.g., labeled images of a toilet cistern and a car brake system), with the goal of familiarizing learners with each task topic prior to engaging in the main tasks. These pre-training resources further adopted the spatial contiguity principle and the signaling principle in order to reduce extraneous cognitive load and manage essential processing (Mayer & Fiorella, 2014; Mayer & Pilegard, 2014). Finally, the main tasks were each divided into three segments, following along with the segmenting principle in an effort to manage essential cognitive processing (Mayer & Pilegard, 2014).

The multimedia resources in both learning tasks were each followed by questions related to the concepts covered. The learning questions adopted Bloom's taxonomy and included progressive levels of complexity through knowledge, comprehension, analysis, synthesis, evaluation, and transfer. Each learning task contained a total of ten questions.

Procedure

Participants were recruited via on-campus flyers containing the URL and a QR code for online participation. After responding to basic demographic questions, participants were randomly assigned to one of the two, multimedia resource groups (animation or static). Upon completion, participants were provided with a compensation code, which they could use to collect a twenty-dollar gift card.

Data Analysis

For the data analyses, simple linear regression for each learning task was conducted using the R statistical computing environment, version 3.5.3. Assumptions for regression analysis were examined, including independence, homoscedasticity, linearity, and normality. As participants were randomly assigned to groups, independence was assumed. Both visual inspection and non-constant variance score test (ncvTest) revealed no significant deviation from homoscedasticity. Linearity was found between the independent variables (spatial ability and multimedia resource type) and the dependent variables (task scores) following examination of correlations; there was a significant, moderate to strong positive correlation between spatial ability and learning outcomes in the toilet cistern learning task (r=0.504, N = 245, p = 0.000, one-tailed) and brake system learning task (r=0.465, N = 245, p = 0.000, one-tailed). This finding was similarly found for both the animation and static groups: toilet cistern learning task (r=0.595 and r=0.413, respectively) and brake system learning task (r=0.516 and r=0.420, respectively). While the data for spatial ability and the brake task score did not meet the assumption of normality, both these variables were fairly symmetric (skewness) and had light tails (kurtosis), showing values that fell within the acceptable range of |1.96|. Overall, it was thus judged that the assumptions to proceed with simple linear regression were met. Descriptive statistics are provided in Table 1.

Table 1: Descriptive statistics

		Mean	*SD*	Skew	Kurtosis
Total (N=245)	Spatial ability	9.38	4.01	-0.04	-0.86
	Learning outcome - toilet cistern	4.38	1.44	-0.25	-0.41
	Learning outcome - car brake system	5.51	1.79	-0.06	-0.79
Animation (N=121)	Spatial ability	9.31	4.03	-0.03	-0.93
	Learning outcome - toilet cistern	4.40	1.47	-0.21	-0.50
	Learning outcome - car brake system	5.47	1.71	-0.04	-0.61
Static (N=124)	Spatial ability	9.45	4.00	-0.05	-0.82
	Learning outcome - toilet cistern	4.36	1.41	-0.29	-0.38
	Learning outcome - car brake system	5.56	1.86	-0.08	-0.97

Findings

Regressions

The regression analyses, conducted to investigate the predictive power of spatial ability on learning outcomes, revealed a statistical significance for both learning tasks: the toilet cistern learning task (p=0.000, r^2=0.251) and the car brake system learning task (p=0.000, r^2=0.213) regardless of multimedia type. Additional regression analyses, which examined the static and animation groups separately, showed a very strong statistical significance in the animation group: the toilet cistern learning task (p=0.000, r^2=0.348) and the car brake system learning task (p=0.000, r^2=0.260). For the static group, although statistical significance was found, the total variance explained by the regression model was smaller: the toilet cistern learning task (p=0.000, r^2=0.164) and the car brake system learning task (p=0.000, r^2=0.169). Table 2 summarizes the results of the regressions analyses. As the animation group model explained a greater amount of variance than the static group model, the study hypothesis was rejected.

Table 2: Simple linear regression analyses of spatial ability and learning outcomes

	Intercept	*B (SE)*	*t*	*p*	CI Lower	CI Upper
All cases						
Toilet cistern	2.683	0.181 (0.020)	9.103	0.000	0.142	0.220
Car brake system	3.571	0.207 (0.025)	8.191	0.000	0.157	0.257
Animation						
Toilet cistern	2.389	0.216 (0.027)	8.067	0.000	0.163	0.269
Car brake system	3.433	0.219 (0.033)	6.571	0.000	0.153	0.285
Static						
Toilet cistern	2.977	0.146 (0.029)	5.009	0.000	0.088	0.204
Car brake system	3.711	0.196 (0.038)	5.108	0.000	0.120	0.271

Discussions

The findings of the current study provide empirical evidence that spatial ability is an adequate predictor of learning outcome regardless of whether animated or static learning resources are used. However, more variance was explained (i.e., greater differences in learning outcomes between individuals with higher and lower spatial ability) when animated learning resources were used, contradicting the ability-as-compensator hypothesis. If animated learning resources did reduce the need for mental manipulation of visual objects, the differences in scores between individuals with lower and higher spatial ability should have been smaller in this group.

Animated learning resources did not close the learning gap between individuals with lower and higher spatial ability, implying that a greater cognitive capacity was needed to deal with this type of learning resources. A potential reason for this unexpected finding could be that animated learning resources are transient, limiting the opportunity for re-inspection of visual information (Tversky & Morrison, 2002). While individuals with higher spatial ability may have greater working memory capacity to process transient visual information, individuals with lower spatial ability may require more time process the same information. Another potential reason could be that animated learning resources provide additional visual information not present in static learning resources such as the movements of the system (Tversky & Morrison, 2002). This added information again requires greater cognitive capacity to process. From these perspectives, namely that individuals need spatial ability to retain transient information and to process added visual information, the findings of the current study are better aligned with the ability-as-enhancer hypothesis (see Mayer & Sims, 1994), implying that spatial ability is more critical for learning from animated learning resources.

Conclusion

This study examined the potential of spatial ability as a predictor of leaning outcomes and how learning outcomes would differ based on multimedia learning resource type. The study contributes to the literature by providing empirical evidence of the ability-as-enhancer hypothesis, which thus far has had limited support (Höffler, Schmeck, & Opfermann, 2013; Huk, 2006; Nguyen, Nelson, & Wilson, 2012). It also adds to the limited examination of the influence of static versus animated learning resources on learning outcomes (Höffler et al., 2013). This study may further illuminate the relationship between individuals' choices in academic major and occupation, especially STEM fields where spatial ability demands are high (Blazhenkova & Kozhenikov, 2009). Finally, this study contributes to practice by suggesting the need for strategic design and implementation of multimedia learning resources to elicit better learning outcomes for diverse learners.

The readers, however, are cautioned given the following limitations: Learners' prior knowledge can play a role in processing new information. The study, however, did not ascertain learner's prior knowledge as a potentially confounding variable. Future study may benefit by controlling for participants' prior knowledge. Additionally, the study participants were recruited from one research site and were disproportionally female. It is recommended that future study employ a more diverse and purposeful sampling strategy. Overall, the field would benefit from additional studies examining the relationship between the spatial ability and different types of multimedia resources. Finally, it is worth noting that participants had to complete all learning tasks to be compensated. This participation setting might have implicitly emphasized a performance goal approach, rather than a mastery goal approach. Future researchers may consider the potential impact of different goal orientations when designing studies.

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Contact email: heom@duq.edu