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Facilitating Spatial Task Learning in Interactive Multimedia Environments While Accounting for Individual Differences and Task Difficulty

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Abstract

Two experiments examined the effects of interactive tutorial features (compared to “passive” features) on learning spatial tasks, an area seldom explored in interactivity research. Experiment 1 results indicated that for simple spatial tasks, interactive tutorials hindered learning for participants of higher spatial ability but improved learning for lower-ability participants. This interaction can be explained by “compensation,” the notion that people of higher ability can compensate for poor external support (passive tutorials) while people of lower ability need the better support. It is likely that the increased cognitive load of interactivity (Kalyuga, 2007) hindered high-spatial participants on a relatively easy task. In Experiment 2, task difficulty was increased, and the results revealed that the interactive tutorial produced better learning than the passive tutorial, regardless of spatial abilities. With the relatively difficult task, the benefits of interactivity became clearer because most people actually needed the interactive features despite the associated cognitive load.

Keywords: user interactivity; learning technology; spatial learning; multimedia; individual differences

Background

Education has changed markedly since “paper and pencil” was the dominant form of learning. An internet connection is now the only requirement for learners to reach previously-inaccessible worlds of information. Therefore, not surprisingly, technology-driven learning is on the rise. For example, a survey by the Sloan Consortium showed that almost three-quarters of universities report increasing demand for online courses (Parry, 2010).

Improving the quality of technology-driven learning is in the interest of educators and the public at large. One of the more intriguing features of educational technology is multimedia and any discussion about improving educational technology would be incomplete without studying how features of multimedia (materials that incorporate elements such as text, images, animation, video, interactivity, etc.) can be harnessed for positive learning outcomes.

One of the current discussions in technology-driven learning concerns the impact of user interactivity on learning outcomes. Interactivity can be defined as “reciprocal activity between a learner and a multimedia learning system, in which the [re]action of the learner is dependent upon the [re]-action of the system and vice versa” (Domagk, Schwartz, & Plass, 2010, p. 1025). Three aspects

of interactivity proposed by Moreno and Mayer (2007) are: pacing (controlling speed of information presentation), manipulating (controlling aspects of information presentation), and navigating (selecting information sources); these aspects were investigated in this study.

Some research suggests that students learn best when material is interactive; that is, when the user has a relatively high degree of control over the material and the actions of the user and material are closely related to the actions of the other. For example, Schwan and Riempp (2004) found that people using interactive learning tools could accurately complete knot-tying tasks with half of the practice time as those using non-interactive tools; they posited that interactivity allowed participants to tailor their information gathering by helping them more easily distribute study time to difficult tasks. A study by Khalifa and Lam (2002) showed that the understanding exhibited by users in “interactive conditions” was indicative of knowledge about how concepts link together; the users in “passive conditions” understood the material at merely a “list-like” level. In research about learner control, students have been found to better optimize their experiences and generalize findings when in control (Gureckis & Markant, 2012).

In some ways, interactive materials could confer educational benefits similar to those of “minimal guidance” interventions, which generally hypothesize that people learn more effectively when required to discover information on their own, as opposed to being directly instructed. Interactive interventions and minimal-guidance interventions allow learners to take control of the learning process, leading them to assess their knowledge gaps and methods to overcome them, both of which are productive activities (Chi, 2000). For example, with some interactive materials, a learner might have to choose a method of gathering information that will yield the information he or she needs; when directly instructed, learners tend not to have to assess their own learning as much.

However, not all research demonstrates consistent benefits for usage of interactive materials. Sometimes, interactivity becomes a mental burden on learners by introducing “non-essential extraneous processing load” (Kalyuga, 2007). For example, Moreno and Mayer (2005) found that interactivity helps people achieve “meaningful learning” only when sufficient guidance exists within the

interface. Therefore, interactivity seems not to be an inherently positive feature in learning materials; instead, the amount and aspects of interactivity are important keys in creating useful multimedia instruction.

The present study provides a nudge in clarifying some aspects of multimedia interactivity with respect to their impact on learning of spatial tasks. The chosen task for this study was partially solving Rubik's Cube, a spatial task that requires pattern recognition and inference-making. This task is of interest because it is unlike tasks that are driven by declarative knowledge; much of the existing interactive learning research already focuses on declarative knowledge. One of the goals in this study was to determine whether some aspects of multimedia interactivity could be used to foster understanding of tasks that are driven by spatial pattern recognition and inference-making, as opposed to primarily declarative knowledge (e.g. memorizing the capitals of all fifty states) or procedures (e.g. operating a vacuum cleaner). Another goal of this study is to more realistically represent passive conditions by allowing users the option of exercising basic control over videos as they would have in most online learning interfaces. Many studies in the past have created passive conditions in which users did not have the option of controlling any aspect of videos, situations that do not often arise with the modern internet.

Experiment 1

Participants used either an interactive or a "passive" video-based tutorial to learn how to create "the cross" on Rubik's Cube. Creating the cross involves two types of pieces: center pieces (in the middle of each cube face) and edge pieces (pieces with colors on two sides, as opposed to corner pieces that have colors on three sides). Participants were to A) place edge pieces around the yellow center such that a yellow "plus sign" was formed, and B) align the secondary (non-yellow) colors of those edge pieces with the colors of the adjacent centers. Figure 1 visually explains the cross.

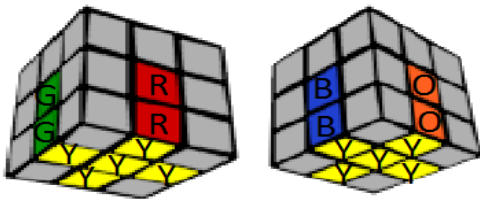


Figure 1: "The cross," shown from two angles (Y = yellow, G = green, R = red, B = blue, O = orange)

Method

Participants Participants were 31 college students (18-22 years in age; 15 interactive, 16 passive) who had no self-reported prior experience in systematically learning the Rubik's Cube (e.g. looking up instructions online, learning from a friend). The students received course credit for their participation and were randomly assigned to conditions.

Materials Two types of tutorials (shown in Figure 2):

- The interactive tutorial presented a series of Java applets featuring an on-screen cube whose faces would turn depending on user input. Each major step (and the moves within each step) were presented in succession. Learners could manipulate the learning pace through the use of the "step-by-step" buttons, navigate cleanly between move sequence animations through the use of the indexed steps, and manually rotate the virtual cube.
- The "passive" tutorial included a series of videos that are comparable in user control to videos commonly found on websites. That is, the videos are played straight through by default unless rewind, fast-forwarded, or paused. All information available in the interactive tutorial was available through the videos, although the videos afforded less control in its presentation of information.

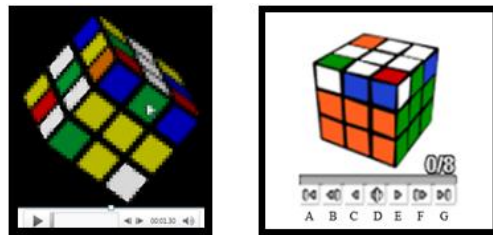


Figure 2: Passive tutorial (L) and interactive tutorial (R)

Design and Procedure The effects of tutorial type on participants' learning were examined with a between-subject design. Before starting the tutorial, each participant completed a demographics form and a spatial ability test (on-screen paper is folded, has a hole punched through it, and participants must predict what the paper looks like when unfolded again; Ekstrom et al., 1976).

The study started with participants being allotted eight minutes to read a Rubik's Cube introduction while having a cube available to use. After the reading period, participants were given 20 minutes to access their assigned tutorial.

After the tutorial phase, participants moved onto the assessment, in which they were given scrambled cubes (i.e., none of the edge pieces were already placed into the cross) and instructed to construct the cross within a four-minute period (cubes were physical, not virtual); inference-making was tested as the scrambled cube configuration differed from the cubes originally given to participants. Participants' times were recorded if they were able to create the cross.

Assessment Scoring Scheme Performances on the assessment were scored using a two-tiered scheme. This scheme was developed by one of the researchers and reviewed for face and external validity by 2007 Florida Open Rubik's Cube champion Andrew Chow (A. Chow, personal communication, November 27, 2012). Participants could score a maximum of six points in Tier 1. It encompasses the first step of creating the cross without regard for matching center colors. Points are awarded for each individual yellow edge piece placed around the yellow

center; the third and fourth edge pieces are weighted more heavily because placing those sometimes involves moving other edge pieces out of place, thus requiring more awareness. Tier 2 has a maximum of four points, and it involves matching the secondary colors of the edge pieces to the colors of their adjacent centers. The possible scores for a cube in Experiment 1 are shown in Table 1.

Table 1: Scoring possibilities for Experiment 1 (Tier 1 points must be complete before Tier 2 points can be earned).

Tier	Cross pieces in place	Number of matching centers	Score
Tier 1	1	0	1
	2	0	2
	3	0	4
	4	0	6
Tier 2	4	1	6
	4	2	8
	4	4	10

Results and Discussion

Main Effect of Tutorial Interactivity No significant differences in performance were found between the interactive condition participants ($M = 8.33$, $SD = 2.29$) and passive condition participants ($M = 8.81$, $SD = 2.23$), $F(1, 29) = 0.349$, $MSE = 5.10$, $p > 0.05$, $d = 0.21$ (non-parametric Mann-Whitney U test similarly non-significant, $p = 0.572$). The difference in solve time between those in the interactive condition ($M = 93.29s$, $SD = 55.71$) and those in the passive ($M = 84.5s$, $SD = 41.04$) was also found to be non-significant, $F(1, 11) = 0.157$, $MSE = 2,458.08$, $p > 0.05$.

A few explanations are possible for the relative similarity in performances between the two conditions. One revolves around a limitation of the study: The given assessment task might have been completed too easily by the participants, leading to ceiling effects in the achievement scores – more than two-thirds of the participants (21 out of 31) achieved a perfect score. With a majority of scores bunched at the high end of the scale, leaving little room for performance differences to be expressed in the data, any actual effects of the tutorial types would have been difficult to find. Experiment 2 addressed this issue by requiring participants to complete a more difficult cube-related task within the same time constraints.

In terms of the study manipulation, the possibility exists that for this relatively easy task, the differences between the tutorials were not large enough to elicit significantly different user actions (future studies should implement manipulation checks regarding how learners actually used the respective tutorials); that is, the way the participants used the interactive tutorial might not have been significantly different from how participants used the passive tutorial. For example, interactive participants had

the option of allowing whole sequences of moves to play consecutively without stopping, using the interactive applets almost like videos. For a relatively easy task, such an approach might have been sufficient.

However, even if participants did use the interactive tutorial differently from the passive one, those differences might not have revealed themselves in the scores. For example, one of the main distinguishing features of the interactive tutorial was the presence of “step-by-step buttons” that allowed participants to scroll through individual moves with self-selected pacing and relative ease. However, as access to internet videos becomes increasingly commonplace, especially among college students, perhaps the passive condition’s tasks of rewinding or fast-forwarding to search through a video is no longer much of a mental burden relative to searching through the use of the buttons. In fact, the interactive condition could even have introduced its own larger mental burdens with the emphasis it placed on user control of the tutorial (Kalyuga, 2007), negating any potential benefits of the interactivity.

Individual Differences in Spatial Ability As might be expected, a participant’s spatial ability had a significant positive correlation with his or her achievement score ($r = 0.415$, $p = 0.05$); spatial ability also had a significant negative correlation with solve time ($r = -0.495$, $p = 0.016$). In short, these results indicate that participants of high spatial ability generally performed better on the assessment task and finished the task more quickly than those of low spatial ability. In this study, “high-spatial” participants were those with spatial abilities above the median and “low-spatial” participants were those lower than the median. Furthermore, using a linear regression, spatial ability was found to uniquely account for a significant amount of achievement score variance that condition could not account for itself ($r\text{-change} = 0.154$, $p = 0.033$). To explain findings such as this one, Mayer and Sims (1994) posit that people with high spatial ability are able to achieve – while using fewer cognitive resources – the same understanding of the multimedia instructions as people with low spatial ability; therefore, they can transfer more of their resources to the actual task at hand (the cube, in this case).

Interaction Between Condition and Spatial Ability. As stated previously, the difference in mean achievement scores between the two tutorial types was not statistically significant. However, an ANOVA did demonstrate a significant interaction between tutorial type and spatial ability, $F(1, 26) = 4.27$, $MSE = 4.12$, $p = 0.049$. More specifically, the interaction suggested that low-spatial participants benefited more from interactivity than high-spatial participants did; that is, high-spatial participants scored about 46% higher than low-spatial participants when using the passive tutorial, while the differences between the participants were negligible when they used the interactive tutorial (larger sample sizes are needed for post-hoc tests to be conducted, however). Figure 3 illustrates this finding.

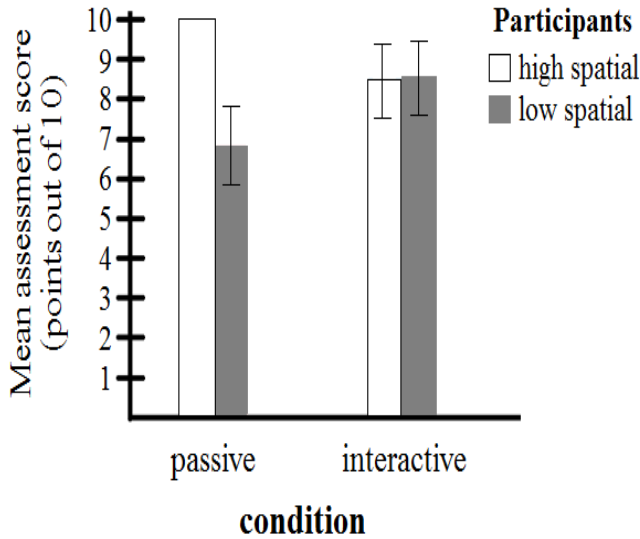


Figure 3: Interaction between condition and spatial ability

An explanation for this result is “compensation,” the notion that people of high spatial ability can compensate for ostensibly weaker external support (as experienced in the passive condition) while people of low spatial ability benefit from stronger external support (interactive condition). In this particular study, high-spatial participants were likely able to better mentally visualize and compensate for the information that the passive condition did not present as well, while low-spatial participants were significantly aided by interactivity because they had lower capacities to compensate and fill the information gaps themselves. In other words, interactivity was unnecessary for high-spatial participants, but made a positive difference for those on the lower end of the spectrum. This conclusion aligns with a finding from Hoffler and Leutner (2010) that high-spatial people generally learned well from either multiphase diagrams (low support) or animations (high support), whereas low-spatial people needed the animations to perform relatively better than they did with the diagrams.

Experiment 2 examined whether the effects of interactivity and spatial ability would change on a more difficult task (which also served to counter aforementioned ceiling effects). It was hypothesized that, in a task that could not be easily completed without good support, the benefits of interactivity would become more evident because the benefits would outweigh the associated cognitive load.

Experiment 2

Procedures for Experiment 2 were identical to those of Experiment 1 with the exception of the task assigned to the participants. The participants used either an interactive tutorial or a passive tutorial to learn how to create “the first layer,” which is one step further than the cross. Creating the first layer involves creating the cross and then placing the appropriate corner pieces around it such that the yellow side is complete and the colors of the corner pieces match the adjacent edge pieces. Figure 4 illustrates the first layer.



Figure 4: The “first layer” shown from three angles.

Method

Participants Participants were 47 college students (18-22 years in age; 23 interactive, 24 passive) who had no self-reported prior experience in systematically learning the Rubik’s Cube. The students received course credit for their participation and were randomly assigned to conditions.

Materials. All of the content related to the cross was identical to that of Experiment 1. The tutorials were extended to include the additional concepts that participants had to learn in order to create the first layer.

Design and Procedure. Participants experienced the same procedures as the participants in Experiment 1. That is, even though Experiment 2 required participants to learn more material, they were still allowed just 20 minutes during the tutorial phase and 4 minutes for the assessment. The time limit was held constant between experiments to increase the likelihood that the task for Experiment 2 was indeed more difficult than the task for Experiment 1.

Assessment Scoring Scheme. The 10-point scheme for the cross was kept in place, but 10 more points were added to account for the additional points possible for adding corner pieces; therefore, 20 points was the maximum possible score for creating the first layer. Table 2 outlines the 10 additional points for the corner pieces.

Table 2: Scoring possibilities for corner pieces in Experiment 2 (to be used if cross is completed).

Cross pieces in place	Number of matching centers	Corner pieces in place	Score
4	4	0	10
4	4	1	13
4	4	2	16
4	4	3	18
4	4	4	20

This scheme was reviewed by 2007 Florida Open Rubik’s Cube champion Andrew Chow (A. Chow, personal communication, May 11, 2015).

Results and Discussion

Main Effect of Tutorial Interactivity Participants using the interactive tutorial ($M = 11.04$, $SD = 6.06$) significantly

outperformed those using the passive tutorial ($M = 7.46$, $SD = 5.27$), $t(45) = 2.17$, $p = 0.04$, $d = 0.63$ (see Figure 5). Solve times were not compared due to the low number of participants who were able to actually complete the task.

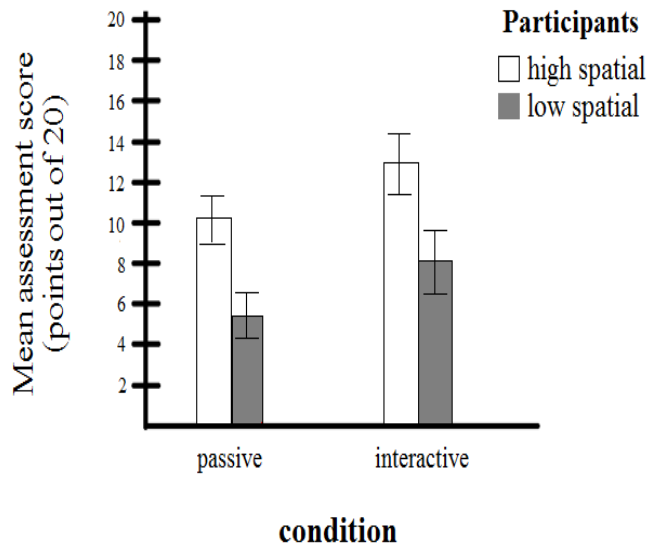


Figure 5: Assessment scores by condition and spatial ability

Participants using the interactive tutorial were originally hypothesized to score more highly on the assessment, and the results in Experiment 2 support that hypothesis. The interactive condition participants likely performed better because their tutorials encouraged user control of the learning process (Zhang et al., 2006). For example, as the interactive interface stopped after each individual move of a sequence, participants might have been relatively likely to self-question and reflect on their understanding of the move. If they did not understand, the “go back one move” button easily allowed participants to see the move again. The videos in the passive condition did not stop at the conclusion of individual moves unless the participant stopped it, and precise rewinding to view a move again was not as easy as in the interactive condition.

Another feature that encouraged reflection was the cube rotation mechanism, which allowed interactive condition participants to manually rotate the on-screen Rubik’s Cube at any time to view the positions of any pieces that were of interest. This feature helped participants to become more aware of their knowledge gaps because they had to deliberately find the information to fill those gaps when they were stuck. In the passive condition, the participants potentially received all of the same information because their on-screen cubes were rotated automatically, but the participants were perhaps less likely to know which knowledge gap was being filled by the presented information given their reduced control over the tutorial.

Both of these interactive features must be more deeply examined in the future for a better understanding of how learners used them for reflection. Of course, the interactive features existed in the interactive condition tutorials for

Experiment 1 as well, but they produced different performance effects because of the lower task difficulty in Experiment 1. Interactivity proved to be useful for both high- and low-spatial participants in Experiment 2 because the task was difficult enough to require external support; interactivity was not a superfluous feature for the high-spatial participants like in Experiment 1. Interactivity was not necessarily useful to high-spatial participants in Experiment 1 because the mental burdens of interactivity (Kalyuga, 2007) outweighed the benefits on a task they likely could have done well on without much support; low-spatial participants needed the support (compensation).

The reflection presumably encouraged in the interactive condition might have aided processes of metacognition. In the passive condition, participants might have known that a move was to be done, but be relatively unsure about the reasoning because they were less likely to be confronted with their gaps in knowledge at the right time. Participants in the interactive condition were more likely to learn *why* a move was done because the interface encouraged them to think about it through A) the step-by-step emphasis in the interface, and B) the user control of turning the cube for needed information. This deeper-level knowledge was likely the reason that interactive participants performed better on the assessment; the assessment required transfer and fundamental knowledge because participants were given a newly-scrambled cube for the assessment that differed in initial state from the one they used in the tutorial, diminishing the effectiveness of rote memorization.

Metacognitive processes demand mental resources, and sometimes can hinder performance (Kalyuga, 2007). However, the benefits of metacognition apparently outweighed the drawbacks in Experiment 2, corroborating the findings of other studies about the effectiveness of metacognition (e.g., van den Boom, Paas, van Merriënboer, & van Gog, 2004; Kramarski & Michalsky, 2010).

Individual Differences in Spatial Ability Spatial ability was correlated significantly with assessment score ($r = 0.45$, $p < 0.01$), in line with results from Experiment 1. However, unlike Experiment 1, no statistically-significant interaction was found between tutorial type and spatial ability, $F(1, 43) = 0.01$, $MSE = 28.00$, $p = 0.92$. Therefore, it can be concluded that the effects of tutorial type were relatively similar across participants of varying spatial abilities.

Video Games and Spatial Ability. A significant correlation was found between time spent playing video games and assessment score ($r = 0.44$, $p < 0.01$). The data from the present study do not indicate the nature of the causality, although the correlation between video game hours and spatial ability was also significant ($r = 0.37$, $p < 0.05$).

General Discussion

Perhaps the most intriguing finding from these two studies is the difference in data patterns between Experiment 1 and Experiment 2. With the relatively easy task in Experiment 1,

the results were consistent with the theory of compensation: high-spatial participants appeared to perform worse with the interactive features while low-spatial participants performed better with them (interaction effect), $F(1, 26) = 4.27$, $MSE = 4.12$, $p = 0.049$. When the task increased in difficulty for Experiment 2, the effectiveness of the interactive features was no longer dependent on a participant's spatial ability. Instead, there was a main effect of tutorial type, with both high-spatial participants and low-spatial participants receiving an equal boost from the interactive features.

Interactivity is a broad concept not limited to the aspects discussed here: pace, information manipulation, and navigation. Future studies implementing different aspects of interactivity could yield somewhat different results, and more granular data regarding tutorial usage (e.g., how aspects of interactivity affect user actions, cognitive load data) could help researchers identify and describe more exactly the low-level mechanisms driving the effects found here. Another concern is that Rubik's Cube is not necessarily representative of the many types of tasks, or even spatial tasks, that exist. Future research should identify the aspects in interactivity that improve learning, the people who benefit most from using those aspects of interactivity, and situations in which interactivity is most appropriate.

In 2011, almost one-third of US college students had taken at least one online course (Online Learning Consortium, 2012), and that percentage is growing. Countries like Great Britain (invested \$100 million in 2011 to boost online learning) and Australia (20% growth between 2007 and 2012) are also seeing online education as a not just a reasonable alternative to "traditional" schools, but a necessity in modern learning (International College of Economics and Finance, 2012). Learning technologies offer many conveniences over standard materials such as portability and information access. They also provide opportunities for user interaction that traditional textbooks cannot match. However, as demonstrated in this paper, interactivity is not "one size fits all." Accounting for individual differences and task-specific details can help educators harness the powers of interactivity to improve learning technologies and outcomes for all users.

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