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Prior research has produced mixed results regarding the usefulness of interactivity in multimedia learning. In this study, participants learned to solve part of a Rubik's Cube using either a tutorial with interactive features or a passive (video-based) tutorial. Participants with low spatial ability benefited more from interactivity than those with high ability, though no performance main effects were found between the tutorials. Targeted use of interactivity could be effective in engaging students and helping them learn.

INTRODUCTION

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, as expected, 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 (the focus of this study). Any discussion about improving educational technology would be incomplete without studying how the powers of multimedia (materials that incorporate elements such as text, images, animation, video, interactivity, etc.) can be harnessed for positive learning outcomes.

Interactivity and Multimedia

One of the current discussions in technology-driven learning concerns the impact of user interactivity on learning outcomes from multimedia. Interactivity can be defined, among other ways, 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 chosen for investigation in this study. Some research suggests that students learn best when material is interactive (i.e. 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. A study by Mayer and Chandler (2001) concluded that learners performed better on transfer tests about lightning formation when they were allowed to control the pace of their learning. 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 addition, people not only learn better with interactive materials, they are also more engaged and motivated in the learning process when compared to those receiving non-interactive ("passive") instruction (Chapman, Selvarajah, & Webster, 1999).

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). Moreno and Mayer (2005) found that interactivity helps people achieve "meaningful learning" only when sufficient guidance exists within the interface. Another study showed that people who organized their materials learned less than those who received pre-organized materials (Moreno & Valdez, 2005). 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 attempted to clarify some aspects of multimedia interactivity with respect to their impact on learning of spatial tasks. Tasks based on spatial knowledge, often based on pattern recognition and inference-making, are of interest because they are unlike tasks that mostly use declarative knowledge (i.e. facts that can be learned and regurgitated); much of the existing interactive learning research already focuses on declarative knowledge. This sort of "non-declarative" knowledge is also more useful in the Information Age workplace in which anyone can use a search engine to find declarative facts online. In previous research, participants who "learned" declarative facts often did not necessarily understand them at a deep level; in other studies, they were often not asked to demonstrate deeper knowledge. Therefore, 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 pattern recognition and inference-making, not simple declarative knowledge (e.g. memorizing the capitals of all fifty states) or strict procedures (e.g. operating a vacuum cleaner). Furthermore, this study included passive conditions that allowed users the option of exercising control over videos as they would have in most online learning interfaces; many studies in the past have created passive conditions in which users do not have the option of controlling any aspect of videos, situations that are simply not realistic in today's internet age.

Participants in the present study learned how to perform a spatial task (solving a portion of a Rubik's Cube) in either a passive condition or an interactive condition. The passive condition provided information to the participants through the following mechanisms: an introduction to the Rubik's Cube via text and illustrations, and a series of video tutorials that are comparable in user control to videos commonly found on websites (videos are played straight through by default unless rewound, fast-forwarded, paused, or replayed).

In the interactive condition, participants had more control over these aspects: the learning pace through the use of the "step-by-step" buttons, the navigation between move sequence animations through the use of cleanly-organized steps, and the rotation of the virtual cube (which is necessary for the user to see the placements of tiles on sides that are hidden from view; in the passive condition, the cube is rotated periodically for the user). The information provided in each condition was the same; the only difference was the amount of interaction.

Hypotheses

It was predicted that participants in the interactive condition would perform better than their counterparts in the passive condition. This hypothesis was rooted in the assumption that the interactive condition would encourage participant control of the learning process, which would in turn create an awareness called metacognition, or "one's knowledge concerning one's own cognitive processes or anything related to them" (Flavell, 1976, p. 232). When participants reflected on their learning, they would be able to manipulate the materials to their personal needs and therefore learn in ways deeper than a passive condition would prompt – in the case of this study, a "deeper" understanding would be reflected in higher achievement during the testing period. One way in which participants were encouraged to self-reflect in the interactive condition is the natural "step-by-step" feel of the interface (i.e. the Rubik's Cube animations could be set to stop after each move, allowing participants to reflect on whether they understood the move – they could proceed if they understood or backtrack by exactly one move or more if they did not). The passive condition videos had pause capabilities, but the interface did not naturally stop at the conclusion of a move – the participant had to initiate a stop in the video if he or she did not understand the previous move. Therefore, participants in the interactive condition were afforded greater control over pace and navigation, both of which should contribute to deeper learning. Another possible feature that encouraged self-reflection was the cube rotation feature of the interactive condition – participants were able to manually rotate the on-screen Rubik's Cube at any time to view the positions of any tiles that were of interest. In the passive condition, participants were also privy to locations of all tiles, but the on-screen cube was rotated as part of the video and not by user control.

The interactive condition in the present study also facilitated two of the cognitive processes that Mayer (2005) deems essential for users in multimedia learning, selecting relevant images and organizing selected images. These processes were facilitated by the interactive condition because the control afforded to users allowed them to A) easily create their own pace and target information that they needed from the tutorial, B) produce actions more directly on the interfaces, which led to more personalized information gathering, and C) efficiently organize material in ways that addressed their needs through the use of the step-by-step buttons and manual cube rotation mechanism. Even those with spatial difficulties were predicted to have improved performance in the interactive condition because the control they had would offset some of their mental visualization challenges (Tabbers, Martens, & van Merrienboer, 2004). For example, in the interactive condition, a participant could easily play and rewind one particular step repeatedly until he or she understood it – such a procedure was more cumbersome in the passive condition.

A secondary hypothesis for this study concerned the spatial abilities of participants and their abilities to complete the spatial tasks presented to them. According to Mayer and Sims (1994), people with high spatial ability form enhanced visual mental models when using multimedia and, as a result, free up more cognitive resources for constructive activities. Therefore, it was hypothesized that "high spatial" participants would generally outperform the "low spatial" participants.

A related hypothesis involved enhancement, the notion that learners of higher ability are more likely to have the cognitive resources necessary to benefit from complex or interactive materials and information being represented in multiple ways. For example, Kline and Catrambone (2011) found that people of high spatial ability experienced enhanced learning when studying multiphase diagrams integrated with text – their low spatial counterparts were not able to glean this benefit. Mayer and Sims (1994) demonstrated that learners with high spatial ability were able to benefit from simultaneous presentations of narration and animation (as opposed to successive presentations) while learners with low spatial ability were not. These studies support the idea that high spatial people are able to use various and perhaps complex media to further their own learning, while people with low spatial ability are not as able to do so. Therefore, it was predicted that in the present study, high spatial participants would gain more in the interactive condition than their low spatial counterparts would – those with high spatial ability are better-equipped to take advantage of the opportunities to manipulate and represent information in various ways (they might also be better at finding superior information in the relatively freer interactive condition).

METHODS

Each session of this study lasted no longer than an hour. In that time, participants read an informed consent form, completed a demographics questionnaire, took a spatial ability test, were introduced to the cube, learned how to solve a portion of the cube through the use of multimedia, were assessed on their learning of the cube, and received a debriefing on the study.

Participants

Participants were 31 college students (18-22 years in age) who had no self-reported prior experience in systematically learning to solve a 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

Participants were given a demographics form to complete if they decided to participate in the study – it included questions about gender, age, major, grade-point average, standardized test scores, etc. All participants also took a computerized spatial ability test constructed by Ekstrom et al. (1976), which examined their abilities to foresee the shapes of sheets of paper after the paper had been folded in various ways.

The Rubik's Cube itself was introduced along with some text familiarizing participants with the mechanics and features of a Rubik's Cube. One of two multimedia tutorials was randomly assigned to each participant to help him or her learn how to solve "the cross" on the Rubik's Cube, the first step of solving the cube. Figure 1 displays the two different types of tutorial interfaces.

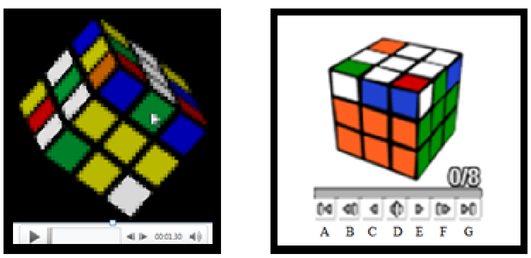

Figure 1. Passive tutorial (left) and interactive tutorial (right)

Solving the cross involves placing yellow "cross pieces" around the yellow center and matching the secondary colors (i.e. the other color aside from yellow) of those cross pieces to the colors of the centers of sides adjacent to the cross. Figure 2 visually explains the cross.

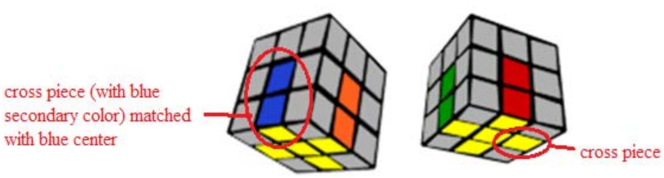

Figure 2. The cross (shown from two angles here) consists of the "plus sign" on the bottom of the cube and the cross pieces being matched with the centers of adjacent sides

Participants using the interactive interface had access to an online tutorial in which they could learn about solving the cross. The tutorial allowed users to scroll through moves one by one or in a connected manner (the moves could also be played forward and backward). Users were also able to rotate the virtual cube so they could see the positions of various tiles on all sides. The passive tutorial allowed access to videos containing the same information as the interactive interface. However, the videos resembled those commonly found online and had standard fast-forward, rewind, and pause capabilities. The cube on the screen could not be rotated by the user, but was rotated as part of the video so users could see all sides of the cube after each step.

Procedure

At the beginning of the study, participants were given a demographics form to complete and turn in to the researcher. After the initial paperwork, the study began with the computerized spatial ability test.

Learning about the Rubik's Cube started after the spatial ability test with the participants reading some introductory text to become familiar with the cube's functions and structures (a cube was provided to aid the participant with familiarization and could be used during the tutorial as well). The participants were given eight minutes to read this text and explore the cube. After the reading period, the participants were allowed access for a maximum of twenty minutes to either the passive tutorial or the interactive tutorial.

Participants moved onto the testing period after using the tutorials. The assessment test required participants to construct the cross within a four-minute time period. When the participants completed the task, their cubes were scored and their finish times were recorded. The experiment concluded with a short debriefing session.

Achievement Scoring Scheme

Performances on the test were scored using a two-tiered scheme which awards points for each cross piece that is placed correctly by the participant. This scoring scheme was developed by one of the investigators and reviewed for face and external validity by a subject matter expert (A. Chow, personal communication, November 27, 2012). Tier 1 involves forming the cross (i.e. yellow cross pieces placed around yellow center) without regard for matching cross pieces with centers of adjacent sides; no points can be earned in Tier 2 before Tier 1 is completed. Six of the 10 total points are awarded in Tier 1 because the tasks in Tier 1 are more fundamental than those in Tier 2. Tasks in Tier 2 involve matching cross pieces with centers (four points).

RESULTS AND DISCUSSION

Fundamentally, this study was designed to find differences between the mean achievement scores of participants in the interactive and passive conditions. However, no such differences were discovered between the interactive participants (M = 8.33, SD = 2.29) and passive participants (M = 8.81, SD = 2.23), F (1, 29) = 0.349, MSE = 5.096, $p > 0.05$; the difference in spatial abilities between the participants of the two conditions was not statistically significant (r = 0.309, $p > 0.05$). Interestingly, although the difference was not statistically significant, participants in the passive condition scored slightly higher than those in the interactive condition. The difference in finish time between those in the interactive condition (M = 93.29, SD = 55.71) and those in the passive condition (M = 84.5, SD = 41.04) was also found to be insignificant, 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 the fact that 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. Tasks in any future study like this one should have increased task difficulty (e.g. teaching participants to construct more than just the cross, decreasing time allotment); participants would then be able to distinguish themselves more clearly and easily.

Another possible explanation is that the differences between the tutorials were not large enough to elicit significantly different user actions or create significantly different information transmission – researchers in this area for future work should compare user actions between the conditions to find user action differences. 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 task of rewinding or fast-forwarding to search through a video is no longer much of a mental burden and therefore does not hinder learning. In fact, the interactive condition could have introduced its own larger mental burdens with the emphasis it placed on user control of the tutorial (Kalyuga, 2007).

Effect of Spatial Ability

As 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 produced a significant negative correlation with finish 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 ("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-$change$ = 0.154, p = 0.033). Because solving a Rubik's Cube is generally considered to be a spatially-oriented task, high spatial participants were predicted to perform better, and they did. 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 conditions (passive and interactive) was not statistically significant. However, the data did demonstrate a significant interaction between condition and spatial ability, F (1, 26) = 4.27, MSE = 4.12, p = 0.049). More specifically, the interaction reveals that low spatial participants benefited more from interactivity than high spatial participants did (i.e. high spatial participants scored much higher than low spatial participants when they used the passive tutorial, but the differences between the participants were negligible when they used the interactive tutorial). Figure 3 below illustrates this finding.

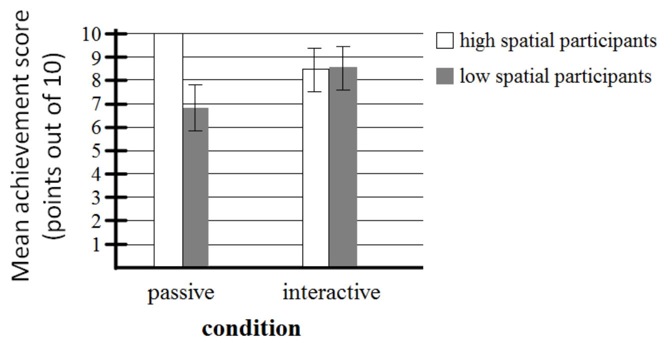

Figure 3. Interaction between condition and spatial ability.

An explanation for the above result is compensation, the notion that people of high spatial ability can compensate for poor external support (passive condition) while people of low spatial ability greatly benefit from good external support (interactive condition). In this particular study, high spatial participants were likely able to better mentally visualize 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 fill the information gaps by themselves. In other words, the type of tutorial used did not matter as much to those with higher spatial ability, but did make a 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 or animations, whereas low spatial people needed the animations to perform relatively better than they did with the diagrams. In fact, the high spatial participants in this study actually scored slightly lower when using the interactive tutorial, perhaps because the mental burdens of user control outweighed the relatively trivial benefits of interactivity.

CONCLUSIONS

As technology improves at ever increasing speeds and people of all ages gradually begin to embrace its presence, it is only natural that technology's role will increase in many pillar institutions – education is an example of one of these institutions. Learning technologies offer many conveniences over standard instructional materials in areas such as portability and information access. They also provide opportunities for user interaction with material, something that traditional textbooks cannot match. One of the main questions facing educators now is harnessing the powers of interactivity to improve learning technologies for all users.

The findings from this particular study indicate that for learning spatial tasks, the main effect of condition (interactive or passive tutorials) is insignificant, although interaction effects are present because people of low spatial ability do seem to respond to interactivity more positively than those of high spatial ability. However, along with the problems in the experiment noted previously (ceiling effects and small differences between the conditions), it should also be noted that interactivity is a broad concept not limited to the aspects of discussed here (pace, information manipulation, and multimedia navigation). Future research should strive to identify the aspects in interactivity that lead to better learning and the people who would benefit most from using multimedia with those aspects implemented.

Interactivity is apparently not a "one size fits all" mechanism, as this study and previously-mentioned studies demonstrate. The responsibility of researchers and educators is to create materials that are tailored, within reason, to the needs of various people. For example, people of high spatial ability (or high ability in general) might not need extremely interactive materials because they have the capacities to visualize information that is either not presented very well or otherwise difficult to find; forcing them to use interactive tutorials could hinder learning (or, at best, provide insignificant benefits) because of the resulting cognitive load that creates more trouble than it is worth. Of course, some particular aspects of interactivity could help some or all learners and finding those aspects should be one of the objectives for anyone developing learning technology. For people of low spatial ability, interactivity looks to be a factor in multimedia that generally increases learning achievement, and isolating the helpful aspects of interactivity is an exercise worth pursuing.

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