Multimedia learning with computer games

TOBIAS, Sigmund, et al.
31  Multimedia Learning with Computer Games

Sigmund Tobias
State University of New York, Albany
J. D. Fletcher
Institute for Defense Analyses
Benoit Bediou
University of Geneva
Alexander P. Wind
State University of New York, Albany
Fei Chen
State University of New York, Albany

Abstract

In this chapter recent research focusing on the use of multimedia computer games for instruction is reviewed with an emphasis on the effects of games on improving cognitive processes. The research suggests that the greater the overlap in cognitive processes between games and external tasks, the more likely is transfer to non-game tasks. In addition, accumulating evidence suggests that playing fast-paced action games improves cognitive processes dealing with attention, task switching, and resistance to distractors, with some transfer to untrained domains. Studies with older adults suggest that intense computer game training may improve some cognitive processes. Results also indicate that although game playing reduces time spent on schoolwork, integrating games into the curriculum is likely to increase the probability of transfer from games to curricular goals. Finally, research identifying the cognitive processes engaged by multimedia presentations outside of games is recommended in order to clarify multimedia effects and facilitate studies of whether multimedia presentations are differentially beneficial for different groups.

Introduction

Computer games, sometimes called video games, are multimedia environments that respond rapidly to users' actions, present content as competition and/or challenges, include a story line with specific objectives to be attained, and are conducted with specific rules for participation. Most computer games use multimedia to display graphic images, along with some combination of text, sound effects, music, and oral communication.

This chapter reviews empirical research on the effectiveness of using multimedia computer games in instruction. We previously reviewed research on the instructional efficacy of games (Tobias & Fletcher, 2007, 2011a, 2012a; Tobias, Fletcher, Dai, & Wind, 2011; Tobias, Fletcher, & Wind, 2013). This chapter updates this work, concentrating on recently added studies, the multimedia features of games, and the effects of games on cognitive and neuro-physiological processes.

Some years earlier, Tobias (1982) pointed out that it is the cognitive processing engaged by any instrumental approach that determine learning and that some instructional methods induce deeper, more frequent cognitive processing than others, leading to more effective learning. Because multimedia games are highly motivating and played frequently by all age groups (Tobias & Fletcher, 2011b), they present opportunities for deep and frequent cognitive processing. This level of processing has been found to produce greater transfer and longer retention of learned material (e.g., Healy & Bourne, 2012; Kimball & Holyoak, 2000; Tobias, 1982; Wisser, Sabol, & Ellis, 1999). Another obvious and prominent feature of games is the strong motivation, if not compulsion, of users and, potentially, learners to play them. Even if research reveals that games are only as effective as other instructional methods, the motivation they engender and the time spent playing them can make games a cost-effective alternative for delivering instruction (Fletcher, 2011) or for supplementing other instructional methods.

Prior Research Reviews

The recommendations in this chapter for research on and design of multimedia games have evolved from our earlier reviews (listed in the introduction) of this research and that of others (Hay, 2005; Vogel et al., 2006; Young et al., 2012). These recommendations are briefly summarized here. The earlier reviews and references on which they are based should be consulted for more detailed descriptions and explanations.

The research indicates that if transfer from games to external tasks is desired, cognitive task analyses of both game and task are needed to determine the overlap in cognitive processes they both engage. The greater the overlap, the more likely it is that transfer will occur. Transfer cannot be assumed merely from superficial similarities between games and tasks, since such similarities do not necessarily indicate that task-relevant cognitive processes will be engaged by the games.
Especially intriguing are findings, discussed later, that fast-paced, action games, such as first-person shooter games, improve basic processes dealing with perception, attention, and cognition. Related findings suggest that, in general, cognitive load can be minimized through the use of multimedia. Instructional computer games use multimedia methods frequently and often intensely to present both verbal and spatial/pictorial information to the user. This practice is in accord with the multimedia principle, which stems from Mayer’s theory of perceptual/spatial and cognitive processing (Fletcher & Tobias, 2005; Mayer, 2005b).

Mayer’s theory and the multimedia principle view verbal and spatial/pictorial information as additive, independent cognitive activities that, because of their parallel operation, can reduce cognitive load in processing information. Given the ample empirical support for this point of view found in Mayer (2005a) and elsewhere, we might well expect games to increase the density of instructional information presented to the learner. Our review suggests that games do bring about learning, although not always in the way we expect. People learn from games. What they learn, however, is not always, or exactly what is intended or expected.

Current Research

Included in this review are studies that emerged after the publication of our prior reviews and studies of which we were then unaware. The quantity and quality of games research (Tobias et al., 2011) have increased in the past few years, and, despite efforts to the contrary, any published review is likely to be incomplete.

The studies we found fall into four categories: (1) value-added research, which assesses the effects on learning due to the absence or presence of a specific tactic or feature (e.g., spoken feedback, photographic representation) embodied in an instructional treatment; (2) instructional strategy research, which compares the impact of different instructional strategies on learning (e.g., lecture vs. game); (3) cognitive effects research, which assesses the effects of an instructional approach by itself (e.g., game vs. no instruction); and (4) correlational research, which quantifies the relationship between a personal characteristic (e.g., gender, frequency of computer game playing) and some competency of interest. The first three categories are close to, and adapted from, those suggested by Mayer (2011). The fourth category is analytical rather than experimental, but it is frequently used. It has made valuable contributions to our current understanding of learning from games and their multimedia attributes.

Among a growing number of exemplary research programs, we cite those of Mayer (2011) and Bavelier and associates (Anderson & Bavelier, 2011). Even though Mayer’s research was reviewed previously (Mayer, 2011), we will begin this section by briefly summarizing it because it may serve as a model for other games researchers.

Mayer’s Research Program

Mayer (2011) was particularly interested in value-added research, as already mentioned. However, he also included broader issues, such as comparisons of game-based learning with other instructional approaches and cognitive results from playing games. Mayer used five games especially developed for his research. For example, the Design-A-Plant game was succinctly described by Mayer:

You travel to another planet and you meet Herman-the-Bug who asks you to design a plant that will survive there. Herman-the-Bug describes the environmental conditions on the planet (such as low sunlight and little rainfall). You must choose the roots, the stem, and the leaves. Along the way, Herman-the-Bug offers feedback on your choices in which he provides short explanations of how plants grow. In all, you visit eight environments. (2011, pp. 284-285)

The media in Mayer’s games were not as elaborate as the advanced features of many commercially designed games or of some of the games used in studies reviewed in this chapter. Nevertheless, Mayer’s games, like most others, provide a multimedia environment with verbal information, a pedagogical agent, and a variety of graphics.

Table 31.1 summarizes the results of Mayer’s research program in three of the research areas listed earlier: value-added research (this is Mayer’s term); instructional strategy research; and cognitive effects research in which pre- and post-tests were administered to see what was learned by playing a single game. Mayer primarily used near transfer and effect size as measures. The What Works Clearinghouse (U.S. Department of Education, 2010) considers an effect size of less than 0.25 to be “not substantively important.” An effect size of greater than 0.80 is considered very large by Cohen (1988). The number of large and very large effect sizes reported by Mayer is impressive. They indicate the value of multimedia used in any instructional approach, including games.

The next sections consider the effects of computer game playing in five areas commonly found in games research: cognitive processes (especially visuospatial cognition, control of attention, task switching and multitasking); neurophysiological and neuropsychological processes; practical applications (research with seniors and patients); and school performance. (A table with brief descriptions of all the studies reviewed, their results, and strength of effect statistics is available at www.alexanderwind.com/rnn_learning_table.shtml.)
Table 31.1. Results of Mayer’s research program

<table>
<thead>
<tr>
<th>Game features that improve learning</th>
<th>$d$</th>
<th>Comparisons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spoken vs. printed words</td>
<td>1.41</td>
<td>9</td>
</tr>
<tr>
<td>Conversational, informal vs. formal speech</td>
<td>1.58</td>
<td>5</td>
</tr>
<tr>
<td>Explanatory feedback after every move vs. no feedback</td>
<td>0.68</td>
<td>1</td>
</tr>
<tr>
<td>Explanation of moves vs. no explanation</td>
<td>0.90</td>
<td>3</td>
</tr>
<tr>
<td>Reflection on underlying principles vs. no reflection</td>
<td>0.65</td>
<td>2</td>
</tr>
<tr>
<td>For women adding competition vs. no competition</td>
<td>0.24</td>
<td>1</td>
</tr>
<tr>
<td>For men adding competition vs. no competition</td>
<td>-0.54</td>
<td>1</td>
</tr>
<tr>
<td>Pre-training in key concepts vs. no pre-training</td>
<td>0.71</td>
<td>2</td>
</tr>
<tr>
<td>Use of polite vs. direct wording by instructional agent</td>
<td>0.93</td>
<td>1</td>
</tr>
<tr>
<td>Playing games vs. no games in after-school computer club: led to better understanding of math problems</td>
<td>0.87</td>
<td>1</td>
</tr>
<tr>
<td>Playing games vs. no games in after-school computer club: led to improved solving of math puzzles in new game</td>
<td>0.59</td>
<td>1</td>
</tr>
<tr>
<td>Playing games involving rotation of shapes (Tetris): improved mental rotation only of similar shapes</td>
<td>0.23</td>
<td>2</td>
</tr>
<tr>
<td>Playing games with vs. without strong narrative theme</td>
<td>0.16</td>
<td>1</td>
</tr>
<tr>
<td>Playing games vs. multimedia lesson with same graphics</td>
<td>1.00</td>
<td>2</td>
</tr>
<tr>
<td>Playing games vs. online lesson</td>
<td>0.97</td>
<td>3</td>
</tr>
<tr>
<td>Playing games vs. slideshow with same multimedia displays</td>
<td>-0.57</td>
<td>1</td>
</tr>
<tr>
<td>(Caige 17 game)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Playing games vs. slideshow with same multimedia displays</td>
<td>-0.31</td>
<td>1</td>
</tr>
</tbody>
</table>

* Cohen’s $d$. Where there were multiple comparisons, $d$ is the median effect size. These data are based on Mayer (2012).

Cognitive Processes

**Visuospatial cognition.** Studying the effects of game playing on players’ cognitive or perceptual processes (Anderson & Bavelier, 2011) is important for at least two reasons. First, since transfer from games to external tasks appears to be mediated by overlaps in processes engaged by both, improvements in cognitive and perceptual processes from game playing suggest that transfer to other tasks engaging these processes is possible. Second, playing fast-paced action games may enhance cognitive processing in some players, such as aging or perhaps even dyslexic individuals.

Gomer and Pagano (2012) found that spatial abilities contributed significantly to performance on a robotic task. An interaction between experience with games and time to complete research tasks indicated that participants who were high-frequency gamers, even those with low spatial abilities, completed the tasks rapidly. It has to be determined whether gaming improved the spatial abilities, as suggested by Bavelier summarized later, or improved their functioning in some other way.

Using several tasks, Sungur and Boduroglu (2012) found that frequent action computer/video game players (AVGPs) form more detailed representations of objects than non-computer/video game players (NVGPs), suggesting greater resolution among AVGPs in their visual representations of stationary and dynamic objects. Sanchez (2012) found that 25 minutes of training on an action game, compared with a puzzle game, improved not only visuospatial abilities, but also the use of these abilities in a post-test learning task of writing an essay on a visuospatial science topic.

De Lisi and Cammarano (1996) found that undergraduates who played a multimedia game requiring mental rotation of geometric figures for 1 week outperformed those who played Solitaire on a test of mental rotation. Men outperformed women on pre- and post-tests, and men who played the action games had higher scores than all other groups.

Similar results were obtained by Feng, Spence, and Pratt (2007), who showed that 10 hours of training on an action game improved both spatial attention and mental rotation, especially in women. Although men outperformed women before training, gender differences were reduced in the action group. Control subjects trained on a puzzle game did not improve.

Gallagher and Prestwich (in press) found that high-frequency gamers had higher scores than low-frequency gamers on cognitive tests of focused attention, spatial working memory capacity, spatial working memory manipulation, and executive planning. They also found that those playing a physics puzzle game were better at signal detection than others who played games like Solitaire.

“Brain training games,” discussed further later, have also become popular (Rabipour & Raz, 2012). Here the accumulated results (Nouchi et al., 2012; Owen et al., 2010) show mixed effects. Training effects that do appear are specific to the games used during training. Typically these games consist of a multitude of mini-games, each of them being relatively simple and tapping a specific cognitive function. Participants improve on the practiced mini-games, but there is little (if any) transfer to other tasks and functions, raising concerns as to their efficiency as training tools.

Jaeggi, Buschkuehl, Jonides, and Shah (2011, p. 10085) compared “computerized video game-like tasks,” such as those used in working memory research, with answering general knowledge and vocabulary questions. They found that elementary school students whose game training was above the median increased on untrained fluid intelligence tasks and that the increase remained after 3 months. Finally, they found that improvement on the game correlated with improvement on measures of fluid intelligence.

In summary, these studies found improvements in cognitive processes dealing with visuospatial cognition, working memory, and fluid intelligence, as a result of game playing.

**Control of attention.** One of the strongest effects of action computer game play is improved control of attention. Recent research in this field is reviewed in this section (for more details, see Green & Bavelier, 2012).
Clark, Fleck, and Mitroff (2011) studied the differences between frequent AVGs and NVGs by asking participants whether they noted changes in displays of images. They found that AVGs needed fewer trials to find changes than NVGs. Subsidiary analyses indicated that AVGs employed broader strategies in their searches, were more likely to search the entire display, and were less likely to perseverate on a part of the visual field.

Hubert-Wellander, Green, Sugarman, and Bavelier (2011) used a visual search task to see if the increased search abilities of AVGs were consistent with the idea that action computer games increase attentional skill. Their results are compatible with those of other studies in which AVGs not only demonstrated better spatial resolution of attention than NVGs (e.g., Bacles, Codina, Rabbat, & Paucau, 2010; Dye, Green, & Bavelier, 2009a; Feng et al., 2007; Green & Bavelier, 2003, 2006a; Spence, Yu, Feng, & Marshman, 2009), but could also process more information per unit of time (Dye & Bavelier, 2010; Green & Bavelier, 2003, 2006b; Li, Polat, Scalzo, & Bavelier, 2010). Further, AVGs were able to process two consecutive targets separated by very short delays (Dye & Bavelier, 2010; Green & Bavelier 2003). It is important to note that these benefits may extend beyond the visual domain. For example, Donohue, Woldorff, and Mitroff (2010) found that AVGs performed better than NVGs in tasks that required judging whether visual and auditory stimuli occurred simultaneously and determining their order of appearance.

In summary, these studies confirmed higher attentional control in AVGs, and some evidence of generalization to domains other than those used in training.

Task switching and multitasking. Cain, Landau, and Shimamura’s (2012) participants performed a directed discrimination task. They examined switch costs (differences in reaction time, RT, between ‘repeat’ trials with the same task rule and response as prior trials and ‘switch’ trials in which the task rule and/or response were switched). The results found lower switch costs in AVGs than in NVGs (see also Colzato, van Leeuwen, van den Wijngaard, & Houtz, 2010). In contrast, AVGs and NVGs did not differ in filtering out irrelevant information or in remembering details of aurally presented stories. Findings by Cain et al. suggest that the improved task-switching performance of AVGs was due to lower switch costs, not differences in other factors, such as motivation.

Green, Sugarman, Medford, Klobusicky, and Bavelier (2012) found that the switch cost advantage for AVGs over NVGs generalizes to (1) vocal responses in addition to traditional manual responses, (2) tasks that are cognitive (e.g., Is the number odd or even? Less than or greater than 57) rather than perceptual (e.g., Is the shape a square or a circle? Blue or red?), and (3) goal switches (switching task rules) as well as motor switches (switching stimulus–response mappings). Finally, a training study showed reduced switch costs in NVGs after 50 hours of training on an action game, whereas switch costs did not change for participants who received 50 hours of training on a social game. These results suggest a causal relationship between the reduction in switch cost and action game playing.

Stroebel, Frens, and Schubert (2012) found increased dual-tasking and task-switching abilities after 15 hours of computer game training on an action game compared to a puzzle game. Donohue, James, Eslick, and Mitroff (2012) had participants complete three visually demanding tasks (driving computer game, a multiple-object-tracking task, and a visual search), with and without a dual-task component (answering unrelated questions on a speakerphone). The performance of all participants on all three tasks deteriorated while they engaged in the additional dual task. There were no differences between AVGs and NVGs.

Karle, Watt, and Sheddin (2010) compared AVGs with NVGs in two experiments. In Experiment 1 they found that “with minimal trial–to-trial interference from overlapping task set rules, players demonstrated a task switching benefit compared to non-players” (p. 70). However, this benefit was reduced in Experiment 2 when substantial stimulus and response overlap in task set rules existed. The authors suggested that players’ task-switching advantage “may be limited to a relative benefit in the control and allocation of selective attention, and not in other cognitive control processes underlying task switching” (p. 70).

In summary, these studies demonstrate more effective task switching for AVGs. Observed improvements after action computer game training suggest that the relationship is causal.

Neurophysiological and Neuropsychological Correlates

Researchers have started to investigate the neurophysiological effects of computer games to gain a more comprehensive understanding of their effects. Such studies can be classified into three groups.

Studies in the first group measure activity during game playing (e.g., Mathiak et al., 2011; Mathiak & Weber, 2006; Sheikholeslam et al., 2007; Weber, Ritterfeld, & Mathiak, 2009) and tend to focus on affective responses. These studies showed that computer game playing activates brain regions sensitive to rewards (Koep, et al., 1998), confirming that computer games are highly rewarding and motivating. Studies in this category have also showed that playing violent games activates brain regions associated with aggression (Weber et al., 2006) and that repeated exposure to violent games could result in decreased physiological and neural responses to real-life violence (Carnegy, Anderson, & Bushman, 2007).

A second group of studies investigated short-term changes associated with game playing, generally following exposures of a few minutes to a computer game (e.g., Engellandt, Barthele, Kerr, & Bushman, 2011; Wang et al.,