Applied Cognitive Psychology, *Appl. Cognit. Psychol.* **25**: 166–173 (2011)
DOI: 10.1002/acp.1658

Video-Game Training and Naïve Reasoning About Object Motion

MICHAEL E. J. MASSON*, DANIEL N. BUB and CHRISTOPHER E. LALONDE

Department of Psychology, University of Victoria, Victoria, Canada

Summary: Naïve conceptions and associated misconceptions about object motion arise in part from limitations on perceptual experience. Certain commercial video games, such as Enigmo, provide interactive experience with realistic trajectories and practice at purposefully manipulating those trajectories. We tested the possibility that this experience could modify naïve intuitions about object motion, bringing them into closer alignment with Newtonian principles of mechanics. Fifty-one middle-school children were randomly assigned to play either Enigmo or a strategy game for six sessions. Only the Enigmo group improved their ability to generate realistic trajectories, but this improvement was limited to learning about the general parabolic shape of trajectories. After training, both groups received a 30-minute tutorial on Newtonian principles which generated a much larger improvement in producing realistic trajectories than did game play. This improvement was of similar magnitude in both training groups, indicating that gaming experience provided no advantage in deriving benefits from direct instruction. Copyright © 2010 John Wiley & Sons, Ltd.

> Playing in a persistent, society-based game like this is more valuable than reading Tolstoy in the original Russian.
>
> Bing Gordon, chief creative director and co-founder of Electronic Arts

Playing video games has become an increasingly significant part of the everyday occupation of youngsters and adults alike. Surveys indicate, for example that male teenagers spend an average of about an hour per day playing video games (Marshall, Gorely, & Biddle, 2006). Indeed, recent work reveals that parental concern about amount of time spent playing video games even takes precedence over concerns regarding the content of games (Kutner, Olson, Warner, & Hertzog, 2008). Against this alarm about the time devoted to video games is the observation that many games demand sophisticated cognitive processing. As illustrated by the epigraph above, some extravagant claims have been made about the virtues of playing cognitively demanding video games (e.g. de Aguilera & Méndiz, 2003; Johnson, 2005). These claims may be taken as justification for the extensive amount of time people spend on video gaming. Our goal here is to examine the scope of the benefits that may accrue from playing video games.

Previous research has shown positive effects of playing action video games on a range of tasks that assess visual attention and spatial processing (Feng, Spence, & Pratt, 2007; Green & Bavelier, 2003, 2006a,b; Greenfield, de Winstanley, Kilpatrick, & Kaye, 1994), spatial resolution of vision (Green & Bavelier, 2007) and visual acuity (Li, Polat, Makous, & Bavelier, 2009). Improvement in mental rotation and spatial visualization has also been demonstrated following experience with the Tetris video game, which involves speeded rotation and placement of different-shaped blocks, rather than simulated combat scenarios (Okagaki & Frensch, 1994). In addition, extended experience (over 20 hours) with a strategy video game that placed substantial demands on working memory led to significant improvement in executive function among older adults (Basak, Boot, Voss, & Kramer, 2008). Like this body of work, our interest lies in the kinds of learning that may occur when players engage interactively with a commercially available video game, rather than with games specifically designed to provide some type of educational experience or training. If some video games can incidentally entrain useful cognitive skills, then there might be some justification for the long hours that many people devote to playing them.

We examine the possibility that certain types of video games may provide the opportunity for players to enhance cognitive skills that are an inherent part of playing the game. Most previous demonstrations of the benefits of game playing have targeted visuo-spatial processing skills rather than conceptual abilities. In contrast, our concern lies with the potential of video game experience to refine or develop conceptually based knowledge. In particular, we ask whether people's reasoning about the trajectories of objects in motion may be enhanced by playing a video game that provides relevant experience with such trajectories. It is well established that typical untrained observers are subject to misconceptions about the principles that govern moving bodies (Caramazza, McCloskey, & Green, 1981; McCloskey, 1983; McCloskey, Caramazza, & Green, 1980; Shanon, 1976). These misconceptions suggest the erroneous understanding that force imparts to objects an impetus to move and that this impetus dissipates over time, possibly because of gravity. Consequently, attempts to depict trajectories may depart substantially from reality. For example, objects falling from a moving body such as an airplane are sometimes shown as dropping straight to earth or even falling slightly backward, instead of tracking a forward parabolic arc (McCloskey, 1983).

Naïve ideas about impetus appear to arise in part from limits on perceptual experience (Kaiser, Proffitt, & McCloskey, 1985b; McCloskey, Washburn, & Felch, 1983). An object dropped from a moving carrier is seen to fall against a background (the carrier) that itself is moving forward. Thus, relative to the carrier, the object moves straight down, or even

---

*Correspondence to: Michael E. J. Masson, Department of Psychology, University of Victoria, P.O. Box 3050, STN CSC, Victoria, BC, Canada V8W 3P5. E-mail: mmasson@uvic.ca

slightly backward if the influence of air resistance is present. If reasoning about object motion is driven by a naïve conceptual framework (McCloskey, 1983), interactive experience with valid trajectories might serve to modify this framework and correct some of the observer's misconceptions.

In contrast to the proposal that naïve observers rely on an intuitive theory of object motion, Proffitt and coworkers (Kaiser, Proffitt, Whelan, & Hecht, 1992; Proffitt & Gilden, 1989; Proffitt, Kaiser, & Whalen, 1990) argued that an important distinction must be drawn between two types of object motion scenarios: particle motion and extended body motion. Particle motion can be perfectly described by the motion of a point particle with its entire mass located at its centre of mass. For example, the path of an object in free fall involves simple particle motion. Extended body motion is much more complex and involves multiple dimensions that collectively determine an object's motion. An example of this type of motion problem is the instantaneous velocity of a wheel rolling down an incline, where the relevant dimensions are the vertical position of the wheel's centre of mass and how the wheel's mass is distributed (i.e. whether most of the wheel's matter is spread around the rim or bunched up near the centre of the wheel). This extended body motion problem becomes a simple particle motion problem if the wheel is in free fall, in which case the only relevant dimension is the vertical position of the wheel's centre of mass.

Proffitt and coworkers suggest that observers are able to use only one information dimension in a problem context when reasoning about an object's motion. Thus, errors are likely when motion is determined by more than one dimension or when observers misconstrue a one-dimension, particle motion context as an extended body context. Problems of the type used by McCloskey and coworkers are simple particle motion problems, but they are presented in static form and often in contexts that invite an extended body interpretation (e.g. show the path followed by a bob at the end of a pendulum if the string is cut just as the bob reaches the apex of its arc). When faced with problem contexts that incorrectly suggest an extended body problem, observers have difficulty determining the one truly relevant dimension that governs the object's motion. In these situations, answers may be based on an irrelevant dimension, which will lead to errors. Kaiser, Proffitt, and Anderson (1985a) showed that if problems of this type are instead presented in dynamic form and observers are asked to judge the naturalness of correct and incorrect variations on object motion in these contexts, then it is much easier for observers to determine the relevant dimension governing object motion and they are very likely to identify the correct trajectory.

On either the naïve-theory account or the extended-body account of the errors that arise when observers reason about object motion, experience with realistic, dynamic depictions of object trajectories may improve reasoning performance. From the naïve-theory perspective, the source of misconceived theories is perceptual experience with actual moving and falling objects (Kaiser et al., 1985b; McCloskey et al., 1983). Presumably, training that involves perceptual experience of correct trajectories, free of the naturally occurring illusions that can distort perceived trajectories, should go some distance towards improving the accuracy of naïve theories. Similarly, Kaiser et al. (1985a) have shown that dynamic displays of object motion permit subjects to more reliably parse the components of a problem so that the dimension governing an object's trajectory can more readily be identified. Extended experience with dynamic displays may entrain methods of parsing displays of object motion that will transfer to static depictions of similar problems, particularly if the display can be interactively controlled by the observer (Tversky, Morrison, & Betrancourt, 2002). Playing certain types of video games offers the opportunity to gain extensive experience not only viewing but also manipulating dynamic displays of object motion. Many contemporary video games involving object motion (e.g. baseball games) are constructed to depict realistic trajectories. Some games require interactive control of such trajectories so that players are not merely passive viewers, but must acquire knowledge to manipulate and alter movement patterns. It is crucial to bear in mind that our interest lies in investigating the potential of commercially available video games to modify naïve approaches to reasoning about object motion, not to evaluate the benefits of games specifically designed to provide instruction in this domain. The basic question we are addressing is whether successful video games, designed for entertainment rather than educational purposes, have an added intellectual benefit that potentially justifies the time spent playing such games.

We identified a commercially successful video game, *Enigmo*, that was ideal for our purposes. This game requires players to alter the trajectories of falling droplets so that they land in target receptacles. Neither the source of the droplets nor the receptacles can be moved. Players must use available tools to change the pathways followed by the falling droplets so that they land in the target receptacle (Figure 1). The depicted trajectories are realistic and follow basic principles of Newtonian mechanics (e.g. angle of reflection equals angle of incidence, pathways of unsupported, horizontally moving objects in a gravitational field follow parabolic arcs).

Such a game, which exposes players to repeated encounters with trajectories of falling and bouncing objects, provides abundant, direct perceptual experience that seems ideally suited to improving naïve reasoning about the dynamics of motion. Moreover, it is possible that this

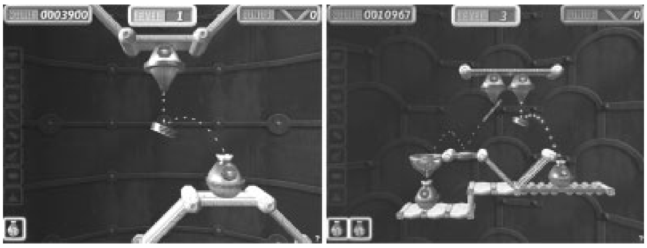

Figure 1. Sample displays from the *Enigmo* game (reprinted with permission). In each case, a stream of falling particles is redirected by placing an object to direct the stream towards the target receptacle near the bottom of the screen. Level 1 (left) displays a single stream, redirected by a drum. Level 3 (right) displays two independent streams, each redirected by a different type of object (a slide directs the particles in the left stream to a flexible part of the support structure, thence into the container; a drum directs the stream on the right into its container)

perceptual experience lays the groundwork for enhanced benefit from formal instruction in Newtonian principles of motion. If so, then players of a game like *Enigmo* should show better reasoning performance following direct instruction in the physics of motion than players of an unrelated video game. We report a study of adolescent school children who were given one of two types of video game experience: *Enigmo* or a strategy game not involving object motion. Before and after the game experience, subjects were given a test of reasoning about motion, creating a pretest/posttest comparison. The posttest was followed by a tutorial that explained the forces acting on moving objects, and a test based on that tutorial. The question of primary interest was whether game-based viewing and manipulation of realistic trajectories would improve naïve understanding of the motion of objects and whether this experience would provide an advantage in learning from formal instruction.

Although the success of Kaiser et al. (1985a) at enhancing reasoning by using dynamic displays encourages the possibility that playing a game like *Enigmo* will also lead to improved performance, this optimism is tempered by two challenges. First, in the Kaiser et al. study, subjects solved a set of problems twice, once using static displays and once using dynamic displays, with the order of display type counterbalanced across subjects. Performance in the static display condition was no better when that condition followed the dynamic display condition than when it was the first condition tested. Thus, subjects did not appear to learn a skill that could transfer from dynamic to static displays in the course of solving a few problems. Perhaps more extended experience with dynamic displays, on a scale comparable to that associated with video game playing, or experience that includes manipulation of dynamic displays might lead to more successful transfer of skill to static displays. Second, Goldstone and coworkers (Goldstone, Landy, & Son, 2008; Goldstone & Wilensky, 2008) have demonstrated the importance of perceptual grounding for transfer of conceptual skill, but they showed that such transfer depends on generating active, valid interpretations of the relevant perceptual situations and integrating these interpretations with the perceptual experience as it occurs. For example, students worked with a computer simulation designed to introduce the concept of simulated annealing (randomness applied then reduced to escape local minima). The first task involved balls dropping onto an uneven landscape with local minima. The task was to manipulate the strength of simulated ‘chance winds’ to cause balls to fall into the lowest region of the landscape (global minimum). Subjects were then transferred to a simulation in which the task was to find an optimal path through a series of obstacles. Here again, simulated annealing would help local minima to be avoided. Learning and transfer of the concept of simulated annealing across the two scenarios was successful only when the simulation was accompanied by a set of rules that allowed observers to actively interpret the influence of randomness on the system’s behaviour while manipulating the degree of randomness and observing its effects. It is an open question regarding the nature of the interpretations that video game players apply to dynamic perceptual events that unfold during a game. These two constraints on the transfer of experience with dynamic displays, then, create doubt about the potential effectiveness of video game playing as an adequate forum for developing transferable cognitive skill.

METHOD

Subjects

Fifty-one middle-school children (39 boys) were recruited. The children ranged in age from 11 to 15 years (median = 13). All subjects had some degree of previous video-game experience, although none had experience with either game used in the experiment. The most commonly reported type of game experience was with sport, adventure or combat games. Self-reports indicated that the subjects had extensive experience with as little as 5 or fewer games to as many as 30 games. Subjects were randomly assigned to one of two training conditions: *Enigmo* ($n = 25$) or strategy game ($n = 26$). The median number of extensively played video games for each resulting group was 9.0 and 9.5 for the *Enigmo* and strategy groups, respectively.

Materials

Two commercially successful video games were selected for use in the experiment. An arcade-style game, *Enigmo*, was selected because it provides experience with realistic trajectories of moving objects. The objective in this game is to redirect a stream of falling particles into a receptacle that is horizontally offset from the source of the particles, as shown in Figure 1. Redirection is achieved by placing various types of tools at the correct angle in the path of the particles. Particles bounce or roll off these tools and follow realistic, parabolic trajectories as they do so. The second game was a strategy game, *Railroad Tycoon 3*, which provides players with experience in building a simulated railway enterprise.

A test of knowledge about the motion of objects was constructed, using items from the literature on naïve physics (e.g. Kaiser et al., 1985a; McCloskey, 1983). Problems were presented on a laptop computer and subjects recorded their answers in a booklet. The problems required freehand drawing or multiple-choice selection of trajectories of statically depicted moving objects (see Figure 2). The test consisted of 15 items involving situations in which objects moved freely through space, bounced off rigid surfaces, or rolled along a smooth surface. We also created a self-paced tutorial, implemented as a series of PowerPoint slides, that explained the forces acting upon moving objects and objects at rest. A set of 13 test problems based on principles explained in the tutorial was also constructed. A subset of 10 of the problems on the physics test conceptually overlapped with a subset of 7 problems on the tutorial test (e.g. both tests included problems in which a falling object struck a stationary surface at a non-perpendicular angle).

Procedure

Subjects were tested in a quiet room in their school. In the first session, they were given the physics test and were

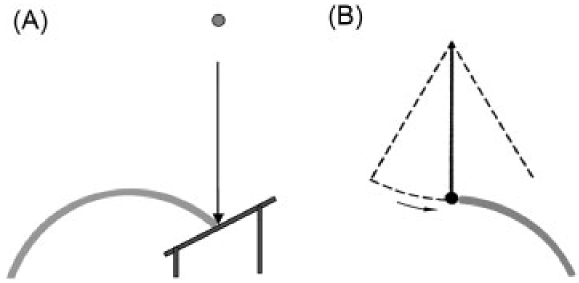

Figure 2. Sample problems from the physics test. (A) A ball is dropped onto a slanted surface. (B) A ball tied to a string is swinging like a pendulum and the string is cut when the ball reaches the midpoint of the swing. The correct trajectories (not shown in the actual problems displayed to subjects) are indicated by thick grey lines

randomly assigned to the *Enigmo* or strategy-game training group. Subjects returned on subsequent days for six training sessions of 1 hour each in which they played the assigned game. During training, subjects in the *Enigmo* group worked through as many levels of the game as they could (maximum possible = 50). They were provided with a solution to any advanced level that they reached but could not master within 15 min. The median game level completed by the subjects was 29. The reader is invited to examine Figure 3, which shows the starting and solution configurations for level 29, to gain an appreciation of the level of skill attained by subjects who succeeded at this level. Subjects in the strategy group played the *Railroad Tycoon 3* game and were given a different starting configuration and objective in each training session. The median number of days taken to complete the six training sessions was 28.0 and 25.5 for the *Enigmo* and strategy groups, respectively. After training, subjects were given the physics test for a second time. Subjects then worked for about 30 min to complete the self-paced tutorial presented on a laptop computer using PowerPoint. Finally, the tutorial test problems were administered using the same method as the physics test. The median delay between the final training session and the posttest session was 2 days for both groups.

RESULTS

Test responses were scored by two independent raters who were blind with respect to a subject's training condition. Responses requiring freehand drawing of trajectories were scored for the shape of the trajectory and, for eight of the problems on the physics test, for the angle of the trajectory as well (e.g. angle of reflection after a falling object strikes a sloped surface). Partial credit was given for a trajectory containing one or more straight segments rather than being entirely parabolic and for moderate deviations (no more than 5°) in the angle of the trajectory. The correlations between scores assigned by the two raters were 0.96 and 0.97 for pre- and posttest scores on the physics test, respectively, and 0.94 for the tutorial test. Discrepancies between the two raters were resolved by mutual agreement.

Mean proportion correct, aggregating across the shape and angle components of the responses, on the physics pre- and posttest for the two training groups is shown in the left panel of Figure 4. It is clear that the *Enigmo* group showed improvement after training, but the strategy group showed no change in mean performance. An analysis of variance (ANOVA) with training group and time of test as factors was computed, with type I error rate set at 0.05. This analysis revealed a significant main effect of time of test, $F(1, 49) = 9.57$, $MSE = 0.004$, and a significant interaction, $F(1, 49) = 6.16$, $MSE = 0.004$, verifying the impression that the *Enigmo* group showed improvement on the posttest, $F(1, 24) = 15.85$, $MSE = 0.004$, Cohen's $d = 0.61$, whereas the strategy group did not, $F < 1$.

Next, we examined separately the shape and angle components of drawn trajectories for subjects who were trained with the *Enigmo* game. All of the problems assessed trajectory shape and eight of them assessed angle of trajectory as well (e.g. cases where an object bounced off an angled surface; see Figure 2A). This analysis provided a more detailed view of the aspects of trajectories that subjects learned by playing the *Enigmo* game. For example, it could be that subjects learned only that objects moving through the air follow a curved or, more specifically, a parabolic trajectory. When asked to draw trajectories after *Enigmo* training, subjects may have favoured curved trajectories because of their superficial similarity to what had been seen in the *Enigmo* game. A more subtle aspect of object motion is the relation between the angles of incidence and reflection and the relation between those angles and the eventual shape of an object's parabolic trajectory. Notice that subjects actively manipulated the angle of incidence and thereby the angle of reflection to direct the droplets into the target containers.

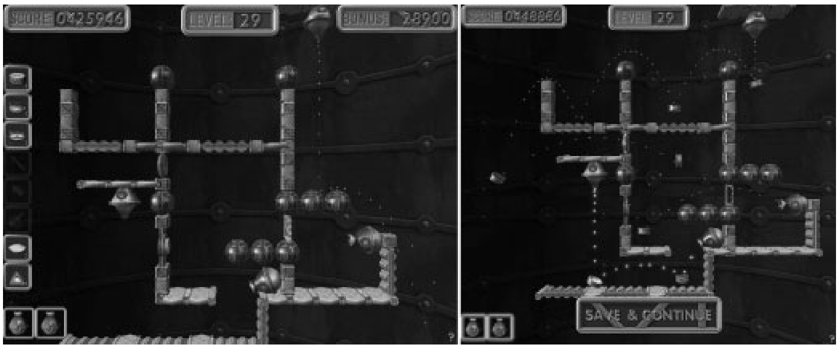

Figure 3. Starting (left) and solution (right) configurations for level 29 of the *Enigmo* game. This level consists of two streams each of which is directed into its assigned container. These streams are redirected using seven tools strategically placed to guide the streams into their target containers

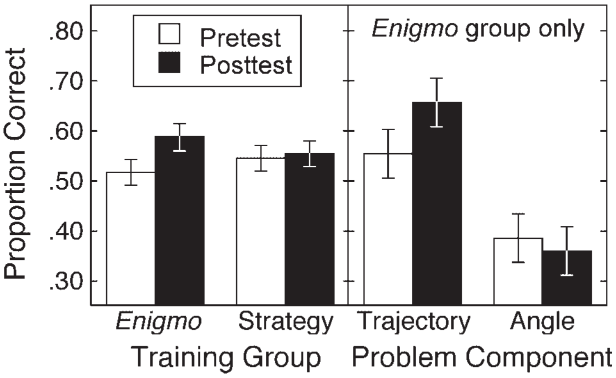

Figure 4. Mean proportion correct on the physics pre- and posttest as a function of training condition (left panel) and as a function of problem component for the *Enigmo*-training group (right panel). Error bars are 95% within-subjects confidence intervals (Loftus & Masson, 1994; Masson & Loftus, 2003) and are appropriate for assessing pretest–posttest differences

Thus, both the parabolic shape of the droplets' trajectories and the angles of incidence and reflection were consistently part of the visual experience available to subjects in the *Enigmo* group. We assessed sensitivity to the principle that the angle of incidence and the angle of reflection are equal by measuring the angle of trajectories produced by the subjects.

The mean proportion correct for the shape and angle components of drawn trajectories on the pre- and posttests is shown in the right panel of Figure 4. Scores for the shape component are based on all problems and scores for the angle component are based on only the eight problems that permitted clear assessment of the angle of the trajectory. An ANOVA with test (pretest vs. posttest) and response component (shape vs. angle) as factors indicated that scores were higher on the trajectory component than on the angle component, $F(1, 24) = 68.90$, $MSE = 0.019$, and that there was an interaction between component and pretest versus posttest, $F(1, 24) = 7.26$, $MSE = 0.014$. Pairwise comparisons revealed that there was a significant posttest improvement for the trajectory component, $F(1, 24) = 7.26$, $MSE = 0.014$, $d = 0.81$, but no improvement for the angle component, $F < 1$. These results indicate that the *Enigmo* subjects learned about the general parabolic shape of object trajectories, but failed to benefit from repeated, consistent exposure to correct examples of the relation between angle of incidence and angle of reflection.

An alternative way in which a change in reasoning about object motion might be generated is through enhanced learning from direct instruction. Performance on the test administered after subjects completed the tutorial on object motion, however, indicated that there was no significant difference between the two training groups. Mean proportion correct was 0.683 for the *Enigmo* group and 0.679 for the strategy group, $F < 1$. To verify that subjects indeed learned new information from the tutorial, we examined the 7 problems in the tutorial test that were analogous to 10 problems from the physics test (e.g. objects sliding or rolling off a flat or a slanted surface). Mean scores on these two sets of problems for each training group are shown in Figure 5. Here, the relevant items from the physics posttest can be treated as a pretest to assess knowledge prior to the tutorial, and the items given after the tutorial can be deemed a posttest. An ANOVA indicated that scores were reliably higher on the tutorial test than on the physics posttest, $F(1, 49) = 96.29$, $MSE = 0.009$, $d = 1.50$, but there was no significant interaction between test and training group, $F(1, 49) = 1.55$, $MSE = 0.009$. Thus, both groups benefited about equally from direct instruction – if anything, the strategy group showed slightly more improvement.

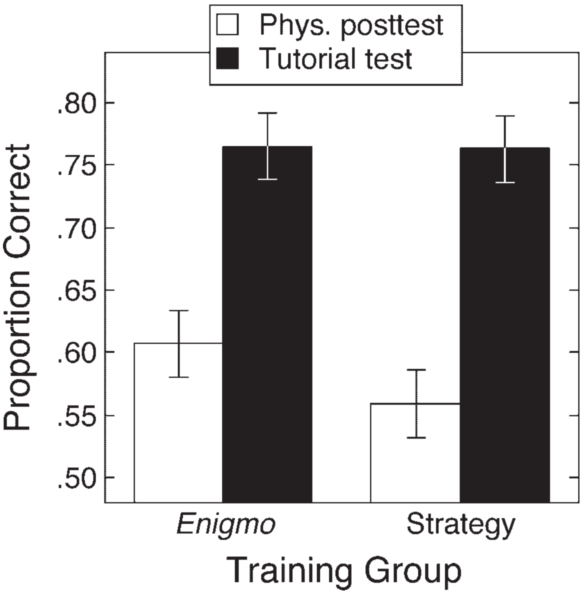

Figure 5. Mean proportion correct on comparable problems from the physics posttest and the tutorial test as a function of training condition. The physics posttest was given prior to the tutorial and the tutorial test was given afterward. Error bars are 95% within-subjects confidence intervals and are appropriate for assessing differences between the two tests

DISCUSSION

Our primary objective was to investigate the claim, made directly in the popular press (e.g. Johnson, 2005) and by highly successful commercial enterprises such as Nintendo's *Brain Training* game, that active engagement with video games can improve intellectual skills. The particular aspect of this question that we addressed was whether experience with a commercially successful video game requiring interactive manipulation of realistic trajectories would alter naïve reasoning about object motion. One basis for interest in this question is that, on some accounts, the source of naïve theories of motion lies in constraints on perceptual experience with moving bodies (e.g. McCloskey et al., 1983). A second and more general reason is that video games are potentially powerful means for training particular cognitive skills given the degree of engagement they invoke in players (Prensky, 2001). Indeed, demonstrations of improved visual attention and visual processing following experience with action-style video games (e.g. Green & Bavelier, 2003, 2007) are consistent with this possibility.

We found that extensive practice with *Enigmo*, a game that emphasizes observation and manipulation of realistic trajectories, moderately improved the ability to generate or make judgments about statically depicted paths of moving objects. Extensive practice on a strategy game yielded no such improvement. This finding is an encouraging one, in light of the result reported by Kaiser et al. (1985a), whereby solving dynamic versions of motion problems failed to improve subsequent performance on static versions of those problems. Our results showed that extensive, interactive experience with dynamic representations of physical motion did succeed in improving one component of reasoning about static displays of motion problems. The Kaiser et al. study involved less extensive exposure to dynamic displays and did not include any interactive component.

A critical question is whether the improvement among *Enigmo* players in using parabolic shapes to depict object trajectories reflects deep changes in the naïve theories or other cognitive processes that guide their reasoning about motion. Two kinds of evidence suggest that whatever was learned remained relatively superficial. First, although subjects improved their drawing of trajectory shape, better capturing the curved, parabolic path of objects with horizontal velocity, they showed no improvement in producing the correct angle of reflection, given a particular angle of incidence. Even though the point of the game was to modify such angles to redirect particles into target receptacles and after hundreds of episodes of interactively manipulating angles with feedback to guide responding, subjects appear to have noticed only the perceptually salient parabolic form of trajectories. They appear to have failed to perceive and understand the relationship between the angle of incidence and the angle of reflection and the resulting influence of this latter angle on the shape of the parabolic trajectory of the droplets. This lack of attention to the relationship between angles and trajectory shape may be due to the fact that the requirement of the *Enigmo* game is to direct the streams of droplets into target containers. Monitoring the shape of the trajectory of each stream is critical to success at this task, so it is quite possible, for example that as subjects used a trial and error approach to manipulate the angle of a drum onto which the droplet stream was falling, their visual attention was directed not at the drum itself, but at the stream of droplets as it approached the target container. The angle of the drum could be adjusted while watching the effect of that adjustment on the stream of droplets without any real need to visually monitor the drum's angle.

Subjects appear, then, to have learned how to manipulate the angle of incidence for a desired effect, but did not conceptualize the relationship between angle of incidence and angle of reflection. There is a broad literature on implicit learning indicating that subjects are capable of acquiring a skill or learning about relationships between stimulus events even though they may not have any awareness of that skill (Cohen & Squire, 1980; Musen, Shimamura, & Squire, 1990) or be able fully to articulate the principles governing those relationships (e.g. Lewicki, Hill, & Bizot, 1988; Sun, Slusarz, & Terry, 2005). Willingham, Salidis, and Gabrieli (2002) provided neuroimaging evidence indicating that procedural learning both with and without awareness relies on a common neural network, although substantial additional activation is associated with awareness during learning. Given their advancement through the various stages of the game, it is likely that subjects in the *Enigmo* training condition acquired a form of procedural skill that could be revealed in a task other than working with static depictions of trajectories. For example, if given the task of adjusting the angle of a surface onto which an object is about to fall so that the object bounces in a manner that allows it to intersect with a target point, then these subjects could well show improved efficiency following *Enigmo* experience.

We further propose that subjects' inability to transfer procedural learning of this kind to the posttest is due to the absence of an adequate interpretation of their perception of trajectory angles. As demonstrated by Goldstone et al. (2008; Goldstone & Wilensky, 2008), perceptual experience in the absence of adequate interpretation of the perceptual events jeopardizes the transfer of that experience to new situations. That is, the lack of a conceptual framework or schema that can be used to interpret perceptual events as they occur can place sharp limits on the transfer of a perceptually supported skill. Why, then, might learning about the shape of the trajectory transfer as well as it did? Recent work on the acquisition of structured knowledge in the absence of instruction (or externally provided interpretation) suggests that meaning can emerge as a result of the requirement to complete instances of a structure and can lead to improved transfer to novel situations (Halford & Busby, 2007). We may interpret the instances in which subjects adjusted the shape of the trajectory of a stream of particles as cases of structure completion (the flow of particles eventually is directed into the target container). It seems reasonable to suppose that the most salient aspect of the stream of particles in the *Enigmo* game is the path that they trace, particularly the part of the path that is proximal to the receptacle into which the particles are to land (a region of the trajectory that highlights the parabolic form of a free falling particle with horizontal velocity; see Figure 1).

The second indication that subjects' learning from the *Enigmo* game did not elicit substantial conceptual change derives from the effects of the physics tutorial. A 30-minute tutorial explaining basic principles of Newtonian mechanics led to nearly twice the benefit provided by 6 hours of interactive video game playing ($d = 1.50$ vs. 0.81). Furthermore, subjects in the strategy group showed as much benefit from the tutorial as the *Enigmo* group, implying that perceptual experience provided by the video game environment generated no advantage in subsequent acquisition of knowledge from formal instruction. Notice that the tutorial provided a form of interpretation for the perceptual events that the *Enigmo* group experienced during their game play (such as parabolic trajectories). The tutorial's information, however, was not synchronous with the game activity. That prior game experience failed to elicit enhanced benefit from the tutorial suggests that providing an interpretive context for perceptual experience after the fact is not effective. Rather, it may be crucial for interpretive information to occur together with perceptual events if conceptual change capable of supporting generalization is to be produced (see Goldstone et al., 2008; Goldstone & Wilensky, 2008).

It is possible that had we provided subjects with even more *Enigmo* training, they might have eventually shown evidence of a more substantial change in their understanding of object motion (e.g. sensitivity to trajectory angle or enhanced learning from direct instruction). We doubt this would happen, however, because the nature of game play and available elements used to influence the flow of droplets are much the same across the levels of difficulty built into the game. That is, subjects would be exposed to more of the same kind of experience had they extended their game play. By comparison, information provided in a structured tutorial exposed subjects to an analytic framework that was designed to reveal directly the relationships between factors that affect object motion. In the absence of such an analytic/interpretive approach, video game environments of the kind we have examined appear to offer little hope for significant conceptual advancement.

We acknowledge that the experiment we report examined only one instance of a commercially successful video game that provides experience with realistic trajectories. But the *Enigmo* game is especially well suited to provide players with perceptual experience relevant to the static problem displays with which they were later tested. Not only do players perceive a wide range of realistic trajectories in this game, but they are required to manipulate the trajectories within the constraints of the laws of physics. In this sense, *Enigmo* is an ideal commercial style game for our purposes. The critical element missing from this game, as with many commercially successful games, is the availability of instructional or interpretive information that might contribute to a player's conceptual understanding of perceived events and to subsequent transfer of that understanding to novel situations. We argue that this observation points to a more general principle that very likely applies to a wide range of successful video games. Namely, perceptual grounding of conceptual knowledge, even when presented in a dynamic, interactive environment, is unlikely to induce lasting conceptual change in the absence of a concomitant interpretive framework. Presumably, a more ideal form of *Enigmo* could be developed that would provide interpretive information to players in such a way as to draw attention to crucial aspects of a perceptual situation and to foster a generalized interpretation of them. For instance, at certain points in the game, such as when a stream of droplets strikes a slanted surface and forms a particular angle of incidence and reflection, the action could freeze and the game could introduce a puzzle for bonus points. This puzzle could begin by highlighting the relationship between the angle of incidence and reflection and asking the player to then apply the principle to a new problem in a novel context (e.g. reflecting sunlight from a mirror so that the reflected ray strikes a distant target point). In this way, relevant aspects of the experience of moving bodies can be validly parsed and interpreted (Goldstone et al., 2008; Goldstone & Wilensky, 2008), and the knowledge gained is more likely to be abstracted and generalized.

ACKNOWLEDGEMENTS

This research was funded through the Canadian Language and Literacy Research Network and by discovery grants from the Natural Sciences and Engineering Research Council of Canada to Michael Masson and Daniel Bub. We are grateful to Marnie Jedynak, Olav Krigolson, Hannah Sanford and Lisa Worth for their assistance in conducting the experiment.

REFERENCES

Basak, C., Boot, W. R., Voss, M. W., & Kramer, A. F. (2008). Can training in a real-time strategy video game attenuate cognitive decline in older adults? *Psychology and Aging*, *23*, 765–777.

Caramazza, A., McCloskey, M., & Green, B. (1981). Naïve beliefs in "sophisticated" subjects: Misconceptions about trajectories of objects. *Cognition*, *9*, 117–123.

Cohen, N. J., & Squire, L. R. (1980). Preserved learning and retention of pattern-analyzing skill in amnesia: Dissociation of knowing how and knowing that. *Science*, *210*, 207–210.

de Aguilera, M., & Méndiz, A. (2003, October). Video games and education: (Education in the face of a "parallel school"). *ACM Computers and Entertainment* [On-line serial], Article No. 10.

Feng, J., Spence, I., & Pratt, J. (2007). Playing an action video game reduces gender differences in spatial cognition. *Psychological Science*, *18*, 850–855.

Goldstone, R. L., Landy, D., & Son, J. Y. (2008). A well grounded education: The role of perception in science and mathematics. In M. de Vega, A. Glenberg, & A. Graesser (Eds.), *Symbols, embodiment, and meaning* (pp. 327–355). Oxford, England: Oxford University Press.

Goldstone, R. L., & Wilensky, U. (2008). Promoting transfer by grounding complex systems principles. *Journal of the Learning Sciences*, *17*, 465–516.

Green, C. S., & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature*, *423*, 534–537.

Green, C. S., & Bavelier, D. (2006a). Effect of action video games on the spatial distribution of visuospatial attention. *Journal of Experimental Psychology: Human Perception and Performance*, *32*, 1465–1478.

Green, C. S., & Bavelier, D. (2006b). Enumeration versus multiple object tracking: The case of action video game players. *Cognition*, *101*, 217–245.

Green, C. S., & Bavelier, D. (2007). Action-video-game experience alters the spatial resolution of vision. *Psychological Science*, *18*, 88–94.

Greenfield, P. M., deWinstanley, P., Kilpatrick, H., & Kaye, D. (1994). Action video games and informal education: Effects on strategies for dividing visual attention. *Journal of Applied Developmental Psychology*, *15*, 105–123.

Halford, G. S., & Busby, J. (2007). Acquisition of structured knowledge without instruction: The relational schema induction paradigm. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *33*, 586–603.

Johnson, S. (2005). *Everything bad is good for you: How today's popular culture is actually making us smarter.* New York: Penguin Group.

Kaiser, M. K., Proffitt, D. R., & Anderson, K. (1985a). Judgments of natural and anomalous trajectories in the presence and absence of motion. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *11*, 795–803.

Kaiser, M. K., Proffitt, D. R., & McCloskey, M. (1985b). The development of beliefs about falling objects. *Perception & Psychophysics*, *38*, 533–539.

Kaiser, M. K., Proffitt, D. R., Whelan, S. M., & Hecht, H. (1992). Influence of animation on dynamical judgments. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 669–690.

Kutner, L. A., Olson, C. K., Warner, D. E., & Hertzog, S. M. (2008). Parents' and sons' perspectives on video game play: A qualitative study. *Journal of Adolescent Research*, *23*, 76–96.

Lewicki, P., Hill, T., & Bizot, E. (1988). Acquisition of procedural knowledge about a pattern of stimuli that cannot be articulated. *Cognitive Psychology*, *20*, 24–37.

Li, R., Polat, U., Makous, W., & Bavelier, D. (2009). Enhancing the contrast sensitivity function through action video game training. *Nature Neuroscience*, *12*, 549–551.

Loftus, G. R., & Masson, M. E. J. (1994). *Psychonomic Bulletin & Review*, *1*, 476–490.

Marshall, S. J., Gorely, T., & Biddle, S. J. H. (2006). A descriptive epidemiology of screen-based media use in youth: A review and critique. *Journal of Adolescence*, *29*, 333–349.

Masson, M. E. J., & Loftus, G. R. (2003). Using confidence intervals for graphically based data interpretation. *Canadian Journal of Experimental Psychology*, *57*, 203–220.

McCloskey, M. (1983). Intuitive physics. *Scientific American*, *248*, 122–130.

McCloskey, M., Caramazza, A., & Green, B. (1980). Curvilinear motion in the absence of external forces: Naïve beliefs about the motion of objects. *Science*, *210*, 1139–1141.

McCloskey, M., Washburn, A., & Felch, L. (1983). Intuitive physics: The straight-down belief and its origin. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *9*, 636–649.

Musen, G., Shimamura, A. P., & Squire, L. R. (1990). Intact text-specific reading skill in amnesia. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *16*, 1068–1076.

Okagaki, L., & Frensch, P. A. (1994). Effects of video game playing on measures of spatial performance: Gender effects in late adolescence. *Journal of Applied Developmental Psychology*, *15*, 33–58.

Prensky, M. (2001). *Digital game-based learning*. New York: McGraw-Hill.

Proffitt, D. R., & Gilden, D. L. (1989). Understanding natural dynamics. *Journal of Experimental Psychology: Human Perception and Performance*, *15*, 384–393.

Proffitt, D. R., Kaiser, M. K., & Whelan, S. M. (1990). Understanding wheel dynamics. *Cognitive Psychology*, *22*, 342–373.

Shanon, B. (1976). Aristotelianism, Newtonianism and the physics of the layman. *Perception*, *5*, 241–243.

Sun, R., Slusarz, P., & Terry, C. (2005). The interaction of the explicit and the implicit in skill learning: A dual-process approach. *Psychological Review*, *112*, 159–192.

Tversky, B., Morrison, J. B., & Betrancourt, M. (2002). Animation: Can it facilitate? *International Journal of Human-Computer Studies*, *57*, 247–262.

Willingham, D. B., Salidis, J., & Gabrieli, J. D. E. (2002). Direct comparison of neural systems mediating conscious and unconscious skill learning. *Journal of Neurophysiology*, *88*, 1451–1460.