# Connecting Learning Goals and Component Cognitive Skills in Digital Games

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**Abstract**

Growing bodies of research have investigated how digital games might be used as pedagogical tools and separately, how playing commercial games influences basic cognitive capacities or skills. The goal of the present research is to draw from these separate lines of research to ask how changes in basic cognitive capacities and formal learning gains may be related. The present study employed a game in which a ship moves through different environments using forces. The game teaches the basic relationships between objects and forces in Newton's Laws of Motion. Students played one of two versions of the game. The predictive version encouraged planning and reflection, by allowing students unlimited time to place forces along a path. In the real-time version, forces immediately affected the player when selected. The results suggest that learning was equivalent across the versions, but changes in attentional capacities may differentially contribute to learning between versions.

**Keywords:** Education; Psychology; Learning; Classroom studies; Experimental research with children; Digital games

## Introduction

Video games have been present in mainstream culture for decades, but have recently become a popular topic for research. One branch of research on video games in Cognitive and Social Psychology, has investigated the impact of recreational game play on basic cognition and behavior. A second branch of research has investigated the impact of games specifically designed to teach concepts within a discipline. Though these divisions do not cover all the relevant work, they do account for a majority of publications on videogames. In the present work, we investigate how games can train concepts and basic cognitive capacities. Beyond this, we begin to address the complex question of how cognitive skill training and discipline-specific learning may each contribute to learning gains on an assessment of students' basic understandings of Newton's Laws of Motion.

Much of the recent research on videogames in Cognitive Psychology has been connected to the somewhat surprising finding that some of commercial action video games may actually train basic cognitive capacities of players (e.g. Dye, Green, & Bavelier, 2009; Feng, Spence, & Pratt, 2007). One particularly interesting finding is that games may train networks that control three basic aspects of visual attention (Dye et al., 2009). There have been some concerns about the conclusions drawn in these studies (Boot, Blakely, & Simons, 2011). However, the possibility of a *positive* impact of games that may otherwise have negative social effects (e.g., Carnagey, Anderson, & Bushman, 2007) has been a compelling topic for research.

Other research on videogames for learning has focused on learning discipline specific content knowledge, skills, processes, attitudes, and engagement (e.g., NRC, 2010). This education-focused work spans several fields and is often referred to as research on "serious games" or "games for learning" although there are multiple other names as well. Again, this work has typically focused on how games produce learning gains in a particular discipline or skill.

The present project differs from most prior Cognitive Psychology and Education-focused work, but is designed to benefit from the approaches of both of those areas of research. The present work uses a conceptually-integrated game (Clark & Martinez-Garza, 2012) under development called EGAME in which the target concepts are integrated directly into gameplay mechanics, rather than being presented through separate activities. The basic prototype of the game involved in this study (see Figure 1) was designed to promote an accurate intuitive understanding of Newton's Laws. The game provides puzzle-like scenarios in which players use a limited palette of forces to move a ship to a target. Unlike in many popular games, movement in this game is controlled by combining unidirectional forces of varying magnitudes and durations. Furthermore, the game models realistic motion and is sensitive to the constraints of the environment (e.g., the presence or absence of friction).

Two versions of our game prototype were used in this study. The first, *predictive*, version of the game was designed to encourage planning and reflection. In this version, students dragged forces from a palette onto a level map. The students would then "run" the simulation to observe the results of their choices. This design minimized competition between cognitive resources necessary to select forces and the resources available to observe and evaluate the effects of choices. The *placement* play phase involved selecting locations for forces, looking at the palette, and dragging icons with the mouse. The *observation* play phase involved watching the ship respond to forces placed on the map (and optionally stopping the simulation).

The real-time control version of the game combined placement and observation. Students had unlimited time to look at a level and plan before selecting a force, but as each force icon was clicked, the ship moved accordingly. In this

version, students made force selections as the ship moved and had to time actions appropriately. Our expectation was that this design imposed greater cognitive demands on students. For example, the real-time game encouraged more strategies such as memorizing available forces and preparing actions before beginning a level. Moreover, the real-time version required continuous monitoring of the position of the ship and continuous shifting of attention between the force palette and the game map [see Droll & Hayhoe (2007) for how attention and working memory may be coordinated in related contexts]. Due to the presumably greater load imposed by the real-time game, we hypothesize **greater learning gains for the predictive game version than for the real-time game version (hypothesis 1)**.

Neither version of game was truly an "action game," like those that have been shown to train cognitive capacities in other studies, but our manipulation of game versions allowed us to isolate certain features of typical action games. More specifically, as in typical action games, the real-time game type encouraged monitoring multiple regions of the screen and timing actions with onscreen motion. Thus, the primary differences between the game types are in terms of how players must distribute attention and select relevant information. Therefore, in investigating differences in capacities that might be trained by the two game types, we focused on changes in scores on the attention network test (ANT) across players in each version of the game. Based on brain imaging and behavioral evidence, the ANT is reported to measure attentional capacities in terms of three distinct network components: (1) an executive component, related to inhibiting irrelevant information, (2) an orienting component, related to shifting the focus of attention to particular spatial locations, and (3) an alerting component, related to preparing to process upcoming information (see Dye et al., 2009 and Rueda et al., 2004). In research by Dye et al. (2009), the authors find that frequent action game players had larger scores on the executive and orienting components of the ANT and had faster baseline RTs with equivalent accuracy. Given these findings and the similarities between the real-time game and typical action games, we hypothesize that **changes in orienting and executive attention networks (and baseline RT) after gameplay will be larger for the real-time game group (hypothesis 2)**.

In addition to measuring changes in attention networks, we investigated the relationship between gains in basic cognitive capacities, gains on our formal assessment, and measures of motivation. At the most basic level, we predict that motivation will support learning and that **we will observe a positive correlation between motivation and physics learning gains for both game types (hypothesis 3)**. We also predict that **network scores on the ANT pre-test and will be more strongly positively correlated with learning gains on the physics test for the real-time game (hypothesis 4)**. This hypothesis is based on the premise that the real-time game imposes greater attentional demands and thus, students with a greater initial capacities might learn more more than others fort that game. Though we do not have a specific prediction for how *changes* in basic cognitive capacities will relate to *changes* in physics understanding across versions, we also predict that **changes in ANT network scores may have different relationships to learning gains across the two game versions (hypothesis 5).** Our final hypothesis, following Dye and colleagues (2009) is that **students that more frequently played action video games will have higher initial orienting and executive scores on the ANT (hypothesis 6)**.

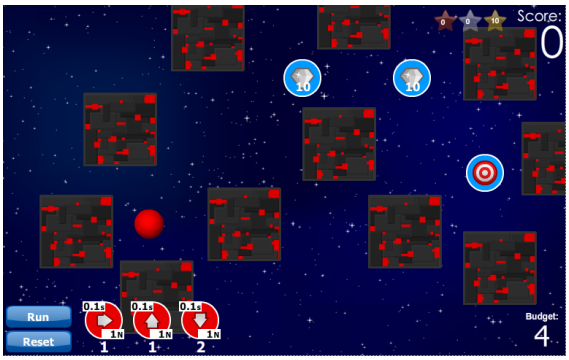

Figure 1: Screenshot of EGAME level.

## Method

### Subjects

143 middle school students (70 female and 73 male) in the Southeastern United states participated in this study. The school served a racially diverse, primarily middle-class population. Students participated together during their normal 8th grade science class for approximately 3 hours of game play and 1 hour of pre-post assessments spread across one week. The sample consisted of students from 6 classes under the same teacher. Data was only used from students who completed the assent form. All analyses only included students that completed the measures reflected in those analyses.

### Equipment

Students used MacBook Air computers to play the game. The game and cognitive tests were designed using Adobe Flash. The prototype versions of the game used in this study as well as current versions of the game can be viewed at www.surgeuniverse.com.

### Assessments and Questionnaires

**Physics Understanding** Students completed pre-and post-tests consisting of 12 questions based on the Force Concept Inventory (Hestenes et al., 1992). Questions covered the following basic concepts relevant to understanding Newton's Laws: vector combination and diagonal motion (vectors); the relationship between velocity, acceleration, and position (acceleration); the influence of friction on

motion (friction); the influence of mass on motion (mass); and the influence of gravity on motion (gravity).

**Attention Networks (ANT)** We administered an adapted child-friendly version of the ANT developed by Rueda et al. (2004). The ANT evaluates the efficiency of three distinct attentional networks (executive, orienting, and alerting). In the pre- and post-test, 144 critical trials were presented in a fixed random order. On each trial (after a 1500ms ITI), a fixation cross was presented (400 to 1600ms). Following this, one of four cue types was presented (150ms). Cues were gray circles occupying approximately the same area as the target (1.7˚). Cue conditions were: no cue, a central cue (at fixation), a double cue (at possible target locations), or a spatial cue (at the upcoming target location). After a 450ms delay, the target stimulus was presented either 1.9˚ above or below the prior fixation location. The target was a spherical furry character used in game tutorials. The target was presented alone (neutral trials) or flanked by distractors (2 to the left and 2 to the right). Students responded to what direction the target was facing. On incongruent trials, distractors faced the opposite direction of the target. On congruent trials, all characters faced the same direction. The critical stimuli were presented for up to 1500ms. Feedback was provided in the following forms at fixation: correct response: "+10 pts", incorrect response: "oops", and delayed response: "too slow".

**Mental Rotation** Students completed a mental rotation task adapted from Widenbauer & Jansen-Osmann (2008). The task required students to decide whether two images were identical or mirrored. Because numerous students misunderstood the instructions and for the sake of brevity, data from this task are not discussed further.

**Motivation and Engagement (QCM and GEQ)** The game engagement questionnaire (GEQ) is a measure developed by Brockmyer and colleagues (2009). The questionnaire yields a single composite score of engagement in terms of: presence, flow, absorption, and immersion. Each item had three choices: "no", "sort of", and "yes". We adapted this questionnaire to refer to our game. For more details on the GEQ, see Brockmyer et al. (2009).

The QCM is a measure of achievement motivation. The QCM differentiates the following factors: anxiety, challenge, interest, and probability of success. We used a modified version of the short form of the QCM (Freund et al., 2011). Specifically, we replaced "task" with "game" in all questions and removed one concerning item: "I am afraid I will make a fool out of myself".

**Gaming Experience Survey** Following Dye et al. (2009), we asked students to list the 10 games they had played the most frequently in the past 12 months. Using this, students were classified as action game players or not.

### Design and Procedure

The study used a pretest–intervention–posttest design. Students were seated at lab tables mostly in pairs, though some students were alone. Students were pseudo-randomly assigned to one of two game versions (predictive or real-time) in each class. **79** students played the real-time game and **64** played the predictive game. Assignment was not random because students were allowed to sit in their typical seats and pairs of students seated together were placed in the same condition. This prevented students from seeing the alternate game version and allowed them to consult one another if they chose. All students worked individually. Before playing the game, students completed three separate tasks that were integrated with the game content: the physics pre-test (adapted from the FCI), the ANT, and the mental rotation task. After the pre-tests, students played the their version of the game. The content of the game levels roughly corresponded with one or more of the aforementioned categories of questions on the FCI-based test.

Students played the game for approximately three days of class time and completed different numbers of levels in this period according to their abilities. Several simple tutorials were included and two questions were included within the first 10 levels of the game to help students connect the material in the game to Newton's Laws.

Students completed the questionnaire on current motivation (QCM) after playing the first level of the game and the game engagement questionnaire (GEQ) after playing approximately 38 levels. Students were asked to stop playing after approximately 20 minutes on the third day. After playing, students first completed the FCI, ANT, and the mental rotation post-tests, then completed the gaming experience survey and provided feedback about the game.

## Results

### Initial Equivalence of Student Groups

The distribution of students classified as action gamers on the gaming experience survey did not significantly differ by across the game version groups (predictive vs. real-time). Furthermore, game type groups did not significantly differ prior to treatment in terms of any subscales on the physics understanding test or the ANT (i.e., Alerting, Orienting, or Executive scores).

### Measures of Motivation and Engagement

A univariate ANOVA was conducted with GEQ scores as the dependent variable and game version as a between-subjects variable. There were no significant differences between student engagement ratings across the predictive ($M$ = 45.25, $SD$ = 8.09) and real-time ($M$ = 44.27, $SD$ = 5.96) game versions, $F(1, 124) = .62$, $p = .43$, $\eta_p^2 = .01$. Additionally, separate univariate ANOVAs were conducted with QCM components as dependent variables and version as a between-subjects variable. The univariate ANOVA for

QCM "probability of success" showed a significant difference between versions, $F(1, 139) = 46.57$, $p < .0001$, $\eta_p^2 = .25$. Students in the real-time game had significantly higher estimates ($M = 5.00$ , $SD = 1.08$) than students in the predictive game ($M = 3.45$, $SD = 1.62$). Thus, it appears that students in the real-time game version may have had higher achievement motivation to start. To note, the QCM challenge component was dropped from covariate analyses due to a large correlation with the interest component, $r(139) = .61$, $p < .0001$.

## Student Gains and Version Comparisons

**Physics Understanding** A repeated-measures MANCOVA was conducted with test administration (pre vs. post) as a within-subjects factor. Game version (predictive vs. real-time) was included as between-subjects factors. Each question type (vectors, acceleration, friction, mass, and gravity) was entered as a separate dependent measure. The multivariate analysis showed that overall learning gains were non-significant from pre- to post-test, $F(5, 137) = 2.27$, $p = .05$, $\eta_p^2 = .08$. Separate univariate ANOVAs for each question type were examined with the same factors as above. These tests showed that only the vectors question type showed small but significant learning gains, $F(1, 141) = 6.55$, $p = .01$, $\eta_p^2 = .04$, from pre- ($M = .22$, $SD = .26$) to post-test ($M = .29$, $SD = .29$). No interactions with game version were significant for any of these tests, so our hypothesis of an overall advantage for the predictive game was not supported.

**Attention Networks (Baseline and Network Scores)** A repeated-measures ANOVA was used to evaluate baseline RT (neutral trials) between test administration times. Game version was included as a between-subjects factor. This test did show a significant effect of test administration, $F(1, 100) = 36.27$, $p < .0001$, $\eta_p^2 = .27$, with faster post- ($M = 542$, $SD = 91$) than pre-test ($M = 582$, $SD = 90$) RTs. The interaction between test administration and version was not significant, $F(1, 100) = .20$, $p = .66$, $\eta_p^2 = .002$. A similar ANOVA with baseline accuracy showed no significant effects.

Following this analysis, individual repeated measures ANOVAs were used to compare gains in network scores. We calculated network scores from difference scores among median RTs following Rueda et al. (2004): Executive score = incongruent - congruent trials, orienting score = spatial - single cue trials, alerting score = double - no cue trials. Test administration was included as a within-subjects factor and game version was included as a between-subjects factor. The ANOVA for alerting scores showed that scores significantly increased, $F(1, 100) = 27.48$, $p < .0001$, $\eta_p^2 = .22$, from pre-($M = 5.96$, $SD = 36.52$) to post-test ($M = 44.46$, $SD = 58.71$) administration. The ANOVA for orienting scores showed that scores significantly increased, $F(1, 100) = 100.88$, $p < .0001$, $\eta_p^2 = .50$, from pre-($M = -33.75$, $SD = 46.54$) to post-test ($M = 18.53$, $SD = 43.08$) administration. Additionally, there was a significant interaction between test administration and game version for orienting scores, $F(1, 100) = 7.46$, $p = .007$, $\eta_p^2 = .07$. This interaction reflected that the differences (post-pre) in orienting scores were larger for the predictive version ($M_{Diff} = 74$, $SD_{Diff} = 55$) than the real-time ($M_{Diff} = 42$, $SD_{Diff} = 60$) version.

Finally, the ANOVA for executive scores showed that scores significantly increased, $F(1, 100) = 139.40$, $p < .0001$, $\eta_p^2 = .58$, from pre- ($M = 32.95$, $SD = 36.22$) to post-test ($M = 96.82$, $SD = 55.20$) administration. These findings do not support our second hypothesis. In fact, the only difference between the two game versions we observed was in the opposite of the predicted direction (with larger gains in orienting scores for the predictive game).

**Attention Networks (Omnibus ANOVA, RTs and Accuracy)** To compare the specific effects of cues and flankers, separate repeated-measures ANOVAs for RTs and for accuracy were conducted. However, given these analyses are not of primary importance to our research questions, the details of these analyses are not reported here. We note three important results from these analyses, however. First, no interactions involving game version were significant. Second, main effects for accuracy ANOVAs were similar to those for RT ANOVAs. Finally, we observed spatial cues reducing congruency effects, which has been observed other ANT studies. Furthermore, this effect was greater for the pre-test.

## Covariate Analyses of Student Gains

**Attention Networks (Gaming Experience)** A univariate ANOVA was conducted to evaluate baseline RT differences on the ANT pre-test between recreational action game players and others. Recreational action game playing was included as a random factor. Action game playing did not influence baseline RT in this comparison, $F(1, 81) = .01$, $p = .92$, $\eta_p^2 < .001$. Following this, separate univariate ANOVAs were conducted for each ANT network score. None of the network scores were significantly different for action game players: alerting scores: $F(1, 81) = .03$, $p = .87$, $\eta_p^2 < .001$; orienting scores: $F(1, 81) = 3.17$, $p = .08$, $\eta_p^2 = .04$; and executive scores, $F(1, 81) = .01$, $p = .93$, $\eta_p^2 < .0001$. Orienting was the only component to approach significance [action game players ($M = -27$, $SD = 37$), non action game players ($M = -45$, $SD = 49$)]. Overall our results did not corroborate those of Dye and colleagues. However, we did observe a marginally larger pre-test orienting score for action game players.

**Physics Understanding with Covariates** First, to determine how baseline measures of attention influenced learning gains, separate repeated-measures MANCOVAs were conducted for each game version. Test administration (pre vs. post) was included as a within-subjects factor. ANT

pre-test network scores (alerting, orienting, and executive) were included as covariates. Each question type (vectors, acceleration, friction, mass, and gravity) was included as a separate measure. Neither multivariate nor univariate tests showed any significant effects of the covariates for either game version. Thus, our fourth hypothesis, that ANT pre-test scores will be more closely correlated with learning gains for the real-time game was not supported.

Following the above analyses with ANT pre-test scores, a similar analysis was conducted including difference scores between the ANT pre- and post-tests, aggregate GEQ scores, and QCM component scores (probability of success, anxiety, and interest). First, separate repeated-measures MANCOVAs were conducted for each game version. For the real-time game, there was a significant interaction between test administration and ANT orienting score in the multivariate test, $F(5, 45) = 3.31$, $p = .01$, $\eta_p^2 = .27$. None of the other effects for the real-time game were significant in the multivariate test.

Because we were interested in the specific effects for each question type, univariate tests were explored as well. For the real-time game, the interaction between test administration and ANT orienting gains was significant for the vectors question type, $F(1, 49) = 6.09$, $p = .02$, $\eta_p^2 = .11$, and for the friction question type, $F(1, 49) = 6.38$, $p = .02$, $\eta_p^2 = .12$. The interaction between test administration and ANT executive gains was significant for the vectors question type, $F(1, 49) = 5.17$, $p = .03$, $\eta_p^2 = .10$, and for the friction question type, $F(1, 49) = 4.87$, $p = .03$, $\eta_p^2 = .09$. Partial correlations with difference scores controlling for other covariates showed that gains on vectors and friction questions *increased* with *smaller* ANT orienting, $r(47) = -.33$, $p = .02$, and executive gains, $r(47) = -.31$, $p = .03$.

For the predictive game, no effects were significant in the multivariate test. In unvariate tests for the predictive game, interactions with test administration were significant for the mass question type with the QCM anxiety, $F(1, 29) = 4.98$, $p = .03$, $\eta_p^2 = .15$, and GEQ score, $F(1, 29) = 4.85$, $p = .04$, $\eta_p^2 = .14$. Gains on the mass question increased with increasing QCM anxiety, $r(27) = .38$, $p = .03$ and GEQ engagement, $r(27) = .38$, $p = .04$. Similarly, gains on the gravity question increased with increasing QCM interest scores, $F(1, 29) = 5.83$, $p = .02$, $\eta_p^2 = .17$. These findings partly support our fourth hypothesis that increased motivation would support greater physics learning gains, however this was limited to the predictive game.

Finally, the predictive game showed a significant interaction between test administration and ANT executive gains for the friction question type, $F(1, 29) = 4.39$, $p = .045$, $\eta_p^2 = .13$. Gains on the friction question *increased* with *smaller* executive gains, $r(27) = -.36$, $p < .05$. Together, the differences in correlations between learning gains and ANT gains for the real-time and predictive games support our fifth hypothesis.

## Discussion and Conclusions

Overall, few of our initial hypotheses were supported: Players did not demonstrate better learning with the predictive than with the real-time game (hypothesis 1), changes in attention network scores were not greater for the real-time game (hypothesis 2), scores on the ANT pre-test did not predict learning gains for either version (hypothesis 4), and action videogame players did not have higher initial network scores (hypothesis 6). However, we did observe that motivation was correlated with learning gains, at least for the predictive game (hypothesis 3), and we did find that changes in ANT network scores had different relationships to learning gains across the two game versions (hypothesis 5). The remainder of this section is devoted to discussing specific findings of interest.

Perhaps the most interesting finding from the above analyses is that there was a robust negative correlation between participants' orienting/executive ANT gains and physics understanding gains in the real-time game. ANT scores increased from pre- to post-test for both game version groups, suggesting that students may have had more attentional resources available to distribute attention after playing either game version (see Dye et al., 2009). However, the greater the ANT gains, the smaller were the learning gains observed in the real-time game. One interpretation of these findings is that learning gains for the real-time game were greater for those students that gained less in terms of available attentional resources though real-time game play. There may be competition for resources between learning to spread attention quickly and widely in the real-time game and resources for extracting discipline-specific content from the game.

Another notable finding is that there were no overall differences in learning between the real-time and the predictive game. Despite the additional load presumably imposed by the real-time game, learning was equivalent. Several possible explanations will be explored in future work. Students might simply replay levels more often in the real-time game, so that load limitations are overcome. Additionally, the real-time game may have certain advantages over the predictive game. One possible advantage is that students are not required to anticipate or visualize the results of cumulative force applications to form a coherent plan – students implement plans piecemeal, as needed. Each decision can be made relative to the current direction of motion and about how each force will alter the current trajectory. Furthermore, in the real-time version, students get immediate feedback about whether each action undertaken results in an expected outcome.

For the predictive game, multivariate tests showed a somewhat greater influence of motivation and engagement, such that greater motivation/engagement was correlated with larger learning gains. One possibility is that performance on the predictive game was influenced by motivation due to the time gap between planning, execution/observation, and revision. If students failed to use what they observed to inform a subsequent placement phase,

then they may have adopted something more like a trial-and-error approach at each placement phase. However, the real-time game delivered just-in-time feedback on choices, which may have facilitated identifying incorrect actions even with lower motivation.

Another interesting finding was the interaction between game version and test administration for ANT orienting scores. Considering orienting/executive scores were both larger for game players in the Dye study, we might expect to see larger orienting scores for the real-time game because the rapid responses required game are more similar to those required in action games. However, we observed the opposite (greater orienting score changes for the predictive game). In the predictive game, (1) there were additional visual landmarks (forces placed by the student) to monitor as the ship approached and (2) attention could be devoted exclusively to orienting to relevant landmarks in the observation phase (as forces were not being selected). Such differences may account for gains in ANT orienting scores. Interestingly, these gains in orienting scores did not correlate with learning gains for the predictive game. This could strengthen the claim that orienting gains were obtained from improving monitoring of relevant landmarks during motion, which one would not expect to influence physics learning.

A final point involves the comparison of individuals classified as action game players to other students. Dye and colleagues (2009) showed that action game players had higher scores on orienting and executive ANT components and faster baseline RTs (but with equal accuracy). In contrast to these prior findings, we found only a marginal relationship between prior gaming experience and ANT orienting scores. These differences may be due to differences in the form of the ANT administered. Another difference that may have contributed was our testing the ANT in a classroom whereas Dye et al. tested in the home. Despite these differences, it is worth noting that our participants showed increased scores from pre- to post-test in the direction expected from Dye et al.'s results for recreational playing. Thus, it does seem that playing our game may induce changes in attentional networks.

One limitation of this study is that there was no baseline condition with which to compare the game version treatments. Therefore, gains on the physics assessment and in the components of the ANT could result from a testing effect. Preliminary results do indicate that EGAME produces larger physics learning gains than a control game with adult participants. Future research will need to address this issue.

A second limitation of this study involves the prototype nature of the versions of the EGAME game at the heart of this study. EGAME is being continually improved based on these and other findings, but the game is still a work in progress. Our assumption (underscored here) has been that without scaffolding, formal learning gains will be minimal. Two future plans involve (1) introducing feedback based on the game play and (2) incorporating dialog interactions to support explicit articulation through self-explanation and directed questioning. The results of the current study are an important step toward integrating basic research on cognition and learning with applied research informing the design of digital games for learning.

## Acknowledgments

This material is based upon work supported by the NSF under Grant No. 1119290.

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