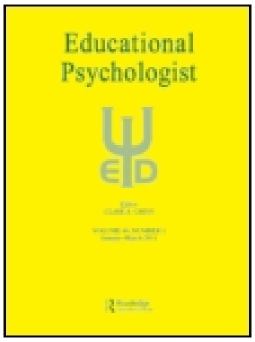

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Digital Games and Learning: Identifying Pathways of Influence

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Digital games and gamelike contexts have become an integral part of young people's lives, and scholars have speculated about their potential to engage and enhance children's learning. Given that digital games are complex systems, we propose that different aspects of game features and game play might influence learning in different ways. Drawing on developmental and educational psychology theory and research, the article identifies 4 potential pathways of digital game influence: time, formal features, content, and context of use. Research findings from games and other technologies are presented to provide support for each pathway. The conceptual framework presented in the article will help to ensure learning from, with, and within games.

Digital games and game-based contexts have become an integral part of young people's lives (Rideout, Foehr, & Roberts, 2010), and children are being exposed to games at younger and younger ages (Common Sense Media, 2013). Recent surveys suggest that teachers are becoming more positive about integrating computer games in their teaching; among 16,000 teachers in the United Kingdom, 35% reported that they were using computer games and 60% reported that they would consider using them in the future (Williamson, 2009). Although earlier reviews of the research on learning gains from serious games produced mixed or inconclusive results (Egenfeldt-Nielsen, 2009; Kafai, 2006), more recent meta-analyses have concluded that compared to conventional instructional methods, games may result in more learning gains (Clark, Tanner-Smith, & Killingsworth, 2013; Wouters, van Nimwegen, van Oostendorp, & van der Spek, 2013). But, to more effectively harness their potential, we need a better understanding of the mechanisms by which games might influence learning. Indeed, we need more research using Mayer's (2014) value-added approach to identify specific game features that contribute to the effectiveness of a game for learning (Wouters et al., 2013).

In this article, we present a "pathways of influence" approach that identifies some of the different pathways via which digital game use can mediate children's learning. We draw on developmental and educational psychology theory and research to present a conceptual framework to understand and study the effects of using games, virtual worlds, and other game-based contexts in educational settings. Our goal is to identify technology-based variables, as well as use-related variables that play a role in the academic, cognitive, and socioemotional learning from, with, and within games.

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DIGITAL GAMES AS CULTURAL TOOLS

The theoretical foundation of this article is Vygotsky's (1978) proposal that children's learning and development occur in a social context. In other words, children learn from interactions with other people—parents, siblings, peers, and teachers—as well as from interactions with the tools provided by the culture or context. A central element of his theory is that higher mental functions emerge from interactions with available psychological tools such as language, counting systems, algebra, and writing. That is, cultural artifacts mediate cognitive development. Subsequently, sociocultural theorists have expanded the term *cultural tools* to include the paintbrush, computers, and calendars, and they expect that interactions with these tools play an important role in cognitive development (John-Steiner & Mahn, 1996). Of relevance here is Greenfield's (1994) seminal proposal that action video games are a cultural artifact, and thus we can expect them to influence learning and development. Furthermore, she has posited that cognitive socialization is the process by which cultural tools impact processing skills (Greenfield, 1990). Greenfield (1994) noted that form and content are separate dimensions of video games and that we could expect effects stemming from thematic content as well as the formal features or symbol systems of video games.

Drawing on these theoretical ideas, Subrahmanyam and Greenfield (2008) proposed that different media use different symbol systems, for instance, radio uses auditory representations; television uses auditory, iconic, and visual representations; and computer games use auditory, iconic, visual, dynamic, and spatial representations. Repeated use of a medium and practice with the particular representational systems used by it will help to internalize different sets of representational skills. Examination of extant research has confirmed this and has shown that use of different media forms impacts different cognitive skills and processing of information; thus, video game playing was found to lead to short-term increases of spatial skills, auditory representations led to better imagination, and audiovisual representations led to better recall (Subrahmanyam & Greenfield, 2008).

PATHWAYS OF INFLUENCE

To effectively utilize games in education, it is important to identify the psychological mechanisms by which they can potentially influence learning. A first step toward uncovering the mechanisms underlying learning is to acknowledge that games are multidimensional and complex (Wouters et al., 2013) and have their own unique representational systems. In addition, they can be used in different kinds of ways for different amounts of time. Consequently, different game elements or features and different aspects of their use likely influence learning in different ways. Thus, it is important to identify variables related to game features and game use that can serve as pathways through which games influence learning outcomes. In other words, each pathway of influence can help to capture game features or aspects of game play that have the potential to mediate learning. Although these different factors likely act simultaneously during game play, identifying potential pathways of influence reiterates that multiple mechanisms underlie learning from game play.

Viewing video games as tools with particular representational systems provides one pathway by which games can influence learning. For other possible pathways, we turn to the "pathways of influence" approach, which has identified some pathways (e.g., time and content) through which computer use might impact the development of academic, cognitive, and social skills (Subrahmanyam & Greenfield, 2011; Tran & Subrahmanyam, 2013). Tran and Subrahmanyam (2013) focused exclusively on the implications of informal computer use and examined different aspects of such use, including use of the mouse and keyboard, educational software, computer/electronic games, and the Internet (e.g., websites, videos, and communication applications). Such informal computer use is more unstructured, is typically child driven, and primarily occurs within homes, although it also occurs in museums, free play times in preschool classrooms, unstructured class time in schools, and after-school programs.

In this article, we have adapted Tran and Subrahmanyam (2013) to describe the pathways or game-related variables that can potentially influence learning outcomes in educational settings. In contrast to their focus on the informal use of different kinds of technology, this article focuses exclusively on digital games in formal settings, where game use is more structured and deliberate. As Gerber, Cavallo, and Marek (2001) noted, within such settings, "education takes place in an organized manner such that the learner and the teacher are placed together with the prescribed intent of promoting learning" (p. 535). Thus, teachers have set learning and curricular goals and determine how and when games are used. A major contribution of this article is that the original pathways approach has been refined to take into account these contextual elements of game use. Another contribution of the article is the marshalling of additional sources of evidence. For empirical support, Tran and Subrahmanyam drew only from studies examining young children's informal computer use and explicitly excluded studies that examined technology use that was part of the curriculum. Because informal learning is relevant to formal learning, we draw on relevant evidence from both formal and informal contexts for each pathway. In the next sections, we describe the following four pathways or game-related variables that are relevant to learning within formal settings: time with games, formal features of games, content of games, and context of use. For each pathway, we provide a brief description along with empirical evidence concerning its role in learning.

TIME, DIGITAL GAMES, AND LEARNING

The first pathway of game influence on learning centers around the variable of time. Here we consider classroom time with games in terms of two dimensions: time spent on that particular activity and time taken away from other potentially important activities. As Wouters et al. (2013) noted, games are complex learning environments involving multiple variables and multiple events occurring at different locations. Thus learning gains from games may accrue only after a certain amount of time has been spent on it. The second dimension considered here has been labeled the time displacement hypothesis (Nie & Hillygus, 2002; Straker, Pollock, & Maslen, 2009); on this view, time spent with games can serve as a pathway of influence by displacing other activities that either contribute to or impede learning.

Time spent with games has been one of the most commonly used measures to describe and study technology use. On the question of informal technology use, the enormously influential 2010 Kaiser Report revealed that 8- to 18-year-old youth in the United States spend 7 hr 38 min daily using a variety of entertainment media (Rideout, Foehr, & Roberts, 2010). After television and music, computer and video games are the most frequently used technologies, and respondents in this survey reported that they spent on average 1 hr 13 min playing electronic games each day. In a 2013 survey of U.S. K–8 teachers ($n = 694$) conducted by the Joan Ganz Cooney Center for the Games and Learning Publishing Council, 74% reported that they used digital games for instruction and 55% said they did so weekly (Takeuchi & Vaala, 2014). Only 9% reported that they used them every day. The survey report did not specify how much time was spent using games for instruction, and we did not find other survey data that addressed this question. In the meta-analysis by Wouters et al. (2013), studies with one session reported that they ranged in time from 18 min to 3 hr, and studies with more than one session reported a range of three to 40 sessions; there were no details regarding the actual length (in time) of the sessions.

With regard to empirical evidence concerning the relation between informal game time and learning, controlled studies have found improvements in reading ability and school readiness as a result of daily (15–20 min) home use of developmentally appropriate educational software by low-income children (Li, Stanton, & Atkins, 2006) and struggling readers (Karemaker, Pitchford, & O'Malley, 2010). Other research on informal time use suggest small but positive associations (Attewell, Suazo-Garcia, & Battle, 2003; Borzekowski & Robinson, 2005; Fish et al., 2008; Li & Atkins, 2004; Van Scoter, 2008) between computer time (which includes games time) and academic and school performance; of importance, moderate (weekly) use was associated with better performance, in contrast to infrequent (monthly or less) and excessive (daily) use. For formal settings, the meta-analysis by Wouters et al. (2013) revealed that multiple sessions of gaming were more effective than single sessions. When compared to conventional instruction methods, single gaming sessions were not more effective than single sessions involving conventional instruction methods; however, multiple sessions were more effective for gaming than for conventional instructional methods. Although this study indicates that there may be an optimal amount of gaming time required for learning gains to occur, the analysis only looked at the number of sessions and did not specifically examine the total time spent with serious games, nor did it examine how the time was divided between serious games and more conventional instruction.

The data regarding the time displacement hypothesis presents a murkier picture. After a review of the research on informal computer use including games (Attewell, Suazo-Garcia, & Battle, 2003; Hastings et al., 2009; Hofferth, 2010; Lanigan, Bold, & Chenoweth, 2009), Tran and Subrahmanyam (2013) concluded that computer use primarily displaced other screen-based activities that were largely solitary or minimally interactive. However, time spent on video game playing has been found to be negatively related to school competence (Hastings et al., 2009), suggesting that game time, at least at home, may come at the cost of activities that contribute to school competence. In schools where game time is initiated mostly by teachers, games could affect learning by displacing conventional activities that students find less appealing, thereby enhancing student motivation. Contrary to this possibility, the meta-analysis by Wouters et al. (2013) concluded that serious games did not have motivational benefits compared to conventional instruction methods. In sum, the first pathway by which games can influence learning is via the variable of time, in particular the time spent with games within educational settings. Less clear is whether there are benefits or costs because of the displacement of other classroom activities as a result of game time.

FORMAL FEATURES OF DIGITAL GAMES AND LEARNING

The second pathway of influence involves the formal features of games. We begin by describing the three features of interactive media; then we identify some of the characteristics of the formal features of games, followed by a description of how formal features serve as a pathway of influence and mediate learning. The section concludes with empirical evidence that demonstrates the role of formal features in bringing about learning. The formal language of interactive media is one of their fundamental elements, along with the hardware and content. With regard to digital games, hardware refers to the particular physical platform via which a game is played, whether a computer, a mobile device, or a specialized gaming platform such as a Microsoft Xbox. The content of a medium refers to the thematic content of the message delivered by the formal features, such as the particular topic focus (e.g., history vs. math). The formal features of a medium include the audiovisual production features of that medium and are essentially the "language" via which it conveys the thematic message of the content. For instance, some of the formal features of television include fast action and pace, zoom in and zoom out, fragmented spaces, logical gaps, and close-ups (Subrahmanyam & Greenfield, 2008).

To understand how formal features may serve as a pathway of influence for learning, we note that form and content are independent dimensions of digital games and other media forms (Greenfield, 1994). The formal features of a medium also include the representational systems utilized by it; different media use different representational systems such as auditory, enactive (action-based), iconic (image-based), or symbolic (symbol-based) representations (Bruner, Olver, & Greenfield, 1966; Subrahmanyam & Greenfield, 2008). For instance, radio is an audio medium and television is a largely audiovisual medium that uses audio, text, and moving images. Digital games use all of these representations and in addition are spatial, iconic, and dynamic, with many events occurring simultaneously at different locations on the screen (Schrader, Lawless, & McCreery, 2009; Subrahmanyam & Greenfield, 2008). Furthermore, games embody these different representational systems in the context of "goal-directed activity with instantaneous feedback" (Greenfield, 1994, p. 4).

To grasp the content or message of a medium, a user has to "know" or decode the particular representational systems used by that medium. This requires the skill of representational competence, which Sigel and Coking (1977) defined as the recognition that different representational modes can stand for a common referent. Representational competence is involved when we recognize that a map of a game world hand-drawn on paper represents the same game world as an interactive digital map with icons and images from that world and that both are two-dimensional representations of a three-dimensional game world. Although both representations refer to the same entity, content translations from one medium to another often result in changes to the meaning (Greenfield, 1993). When listening to a play via the radio, we may attend to characters' words and emotions, whereas when viewing the same play on television, we might attend to physical appearance and actions drawing very different meanings or conclusions. From an educational standpoint, this may mean that students who read about a topic in a textbook and listen to a lecture about it, compared with students who play a digital game on the same topic, might focus on very different aspects and as a result arrive at different interpretations about it.

Because a user has to decode the representational forms of a medium to grasp its message, repeated use of that medium can lead to its particular symbol forms becoming internalized mental representations for the user and enhance those particular representational skills (Salomon, 1979). Greenfield (1984, 1993) has referred to the process by which cultural tools mediate the development of processing skills as cognitive socialization. According to her, media, and in particular interactive media such as action video games, have become important tools of cognitive socialization over the last 50 years. Extending these ideas, Subrahmanyam and Greenfield (2008; 2011) have proposed that different media forms utilize different representational processes and repeated use of a medium contributes to the development of those particular representational skills. Game playing can thus result in the internalization of the representational systems used thereby leading to the formal features of the game serving as a pathway of influence. In the next paragraphs, we review some of the empirical evidence in support of our proposal that the formal features and representational systems of a medium mediate learning.

We start with research on the relevant formal features from print and television before turning to digital games. Print is the oldest of media forms, and it is largely symbolic in nature, wherein letters and words have an arbitrary relation to their referents (Subrahmanyam & Greenfield, 2008). Research has shown that exposure to books and book reading plays a critical role in the development of emergent literacy skills (Scarborough & Dobrich, 1994) and is related to vocabulary (Chall, Jacobs, & Baldwin, 1990; Cunningham & Stanovich, 1991). Based on a review of a large body of research comparing learning from text with and without pictures, Kozma (1991) concluded that, especially for poor readers, recall is increased by the use of pictures with text and in particular when the pictures are related to central themes, new ideas, or structural relationships covered in the text. According to him, one possible reason for this is that compared to words, pictures and images are more similar to objects and events and thus help students construct mental models of the concept. A central feature of digital games and game-based simulations are iconic and dynamic representations, and we revisit this element in later paragraphs.

In contrast to print, radio uses audio, whereas television uses audio and visual features, as well as stationary and moving text, pictures, and diagrams (Kozma, 1991). Research also suggests that these differences may impact the processing and retention of the message. For instance, among preschool children, recall is better when information is presented visually versus aurally (Hayes & Birnbaum, 1980). Greenfield and colleagues compared the effect of radio and television by presenting elementary school children with either an audio or video version of children's stories narrated with the identical soundtrack. The two media forms had different effects on different processing tasks: Participants who heard the audio version demonstrated better imagination in a story-ending task, whereas those who saw the video showed better recall of the material that they were presented with (Greenfield & Beagles-Roos, 1988; Greenfield, Farrar, & Beagles-Roos, 1986). This finding shows that television viewing may provide children practice with visual representations and thus have positive effects on learning and recall, but at the same time it may also be less stimulating for imaginal representations (Subrahmanyam & Greenfield, 2008). However, there are indications that for transfer to occur there should be a match between modality of presentation and modality of retrieval (Calvert, 2001; Greenfield et al., 1986).

Research suggests that other formal features of television also have effects on cognitive processing and learning. Wright and Huston (1983) concluded from a review of the research that fast action and pace are perceptually salient and help to draw and hold attention. Their review suggested that the effect was independent of program content and held even when violent content was separated from perceptually salient formal features. Other perceptually salient features that have been found to facilitate learning and comprehension include character vocalizations and moderate action levels (Calvert et al., 1982), as well as close-ups and logical gaps (Salomon & Cohen, 1977). According to Salomon (1976), television incorporates a range of symbolic codes, and combinations of codes can have unique effects on cognitive skills and processes and influence information processing and learning. Although Salomon's proposal was made in the context of television, it is also relevant to digital games.

There is now a small but solid body of evidence attesting to the effects of specific games on the development of the particular cognitive and representational skills that they require (Subrahmanyam & Greenfield, 2008, 2011; Tran & Subrahmanyam, 2013). Much of this research is on the earlier generations of action video games; although current games have superior graphic, sound, and multiplayer capabilities, their fundamental grammars have remained unchanged, and so are still relevant and discussed here (e.g., Dye, Green, & Bavelier, 2009; Greenfield, DeWinstanley, Kilpatrick, & Kaye, 1994; Tahiroglu et al., 2010). These studies have demonstrated that electronic game playing can have positive effects on cognitive skills such as attention, spatial and iconic representational skills, and executive function skills, all of which have implications for learning. Specifically, spatial and iconic representational skills have been implicated in performance in STEM disciplines (Uttal & Cohen, 2012) and for the development of general problem-solving skills (Lager & Bremberg, 2005). Spatial visualization ability is critical to successfully navigating hierarchical systems within electronic information contexts (Downing, Moore, & Brown, 2005), a key element of general digital literacy skills.

As noted earlier, most action video games are fast paced and require the player to keep track of multiple events at different points on the screen and to select and choose a response while inhibiting a response to other events occurring simultaneously at other points on the screen. This feature of electronic games taps into the skill of selective attention (focusing on one stimulus to the exclusion of others) and divided attention (attending to two or more stimuli at the same time). Greenfield et al. (1994) examined the effect of video game experience by manipulating the probability (equal or unequal probabilities) with which an icon occurred at two locations on the screen. They found that expert video game players responded more quickly than novices to both high- and low-probability positions of the icon. Moreover, after 5 hr of playing a game (*Robotron*), participants showed improvement in the reaction time, but only for the low-probability target position. Other research has confirmed that video game players have better developed attention skills than non–video game players (Dye et al., 2009). Greenfield et al.'s (1994) finding regarding expert players and Dye et al.'s (2009) finding regarding video game players are correlational. Thus it is possible that gamers have better attentional skills to begin with, and those with poorer attentional skills may not be drawn to games and/or do not perform well when they do play games. Evidence showing a more causal role for games comes from research that has demonstrated the beneficial effects of game playing on attentional (Green & Bavelier, 2003; Tahiroglu et al., 2010) and visual-processing skills (Green & Bavelier, 2007). From a review of well-designed video game training studies of non–video game players, Green, Li, and Bavalier (2010) concluded that training with action video games enhances processing; moreover, they noted that in two studies, training-related enhancements were found even when participants were tested again some time later after the completion of training, indicating the longer term nature of video game effects. It is important to note that such effects are contingent on the game utilizing the particular skill to be developed; in the study by Green and Bavelier (2003), improvements in attentional skills were only found after playing *Medal of Honor*, a battle game where a number of entities are simultaneously engaged in a variety of actions all over the screen. No improvements were found after playing *Tetris*, a dynamic puzzle game in which one event occurs at one place on the screen.

Another set of cognitive skills that are utilized in digital games are spatial representational skills, which are considered a suite of skills (Pellegrino & Kail, 1982) entailed in judging speeds and distances, mental rotation, spatial visualization, and dealing with two-dimensional images (of three-dimensional space). Computer applications of all kinds, and in particular action video games, utilize spatial representational skills of a hypothetical two- or three-dimensional space (Subrahmanyam & Greenfield, 2008). As with attentional skills, studies have shown that repeated practice with games produces short-term increases in selected spatial skills (De Lisi & Wolford, 2002; Lager &

Bremberg, 2005; Okagaki & Frensch, 1994; Subrahmanyam & Greenfield, 1994). In a training study by Subrahmanyam and Greenfield, where participants were given 2¼ hr of practice with a video game, children who played the action game *Marble Madness* showed significant improvement in anticipating targets and visualizing paths, whereas those who played the word game *Conjecture* did not. Although participants who had lower spatial skills at the start of the study improved, they still did not catch up to those who showed strong spatial skills at the start of the study. Finally, initial spatial skills positively predicted final video game performance, further confirming that video game play taps into spatial representational skills, as well as develops them (Subrahmanyam & Greenfield, 1994). Greenfield and colleagues also found that skill in playing the game *The Empire Strikes Back* predicted performance on a mental paper-folding task, which measures the ability to visualize three-dimensional movement from a two-dimensional display; according to the authors, the game in question utilized this spatial skill (Greenfield, Brannon, & Lohr, 1994). The researchers also found that better players of this game performed better on a classical mental paper-folding task. Positive effects of playing the video game *Tetris* have also been found for mental rotation (De Lisi & Wolford, 2002; Okagai & Frensch, 1994).

All of these studies assessed spatial skill performance in the laboratory. There is evidence that informal game play is also related to real-world skills. For instance, video game skill assessed in the laboratory and self-reported action video game playing predicted performance in laparoscopic surgery (errors and speed of doing the surgery), more so than either actual experience with laparoscopic operations or years of training (Rosser, 2007). It is likely that action video game experience prepared the surgeons for navigating and operating in a three-dimensional space by using information presented on a two-dimensional screen with very little tactile feedback (Greenfield, 2009). It is important to note here that such transfer is specific: We can expect to find benefits for particular skills only if the skills are utilized in the game and the effects will not accrue from just playing any computer game. Note for instance that playing Tetris did not improve attentional skills (Green & Bavelier, 2003) but did improve mental rotational skills (De Lisi & Wolford, 2002; Okagai & Frensch, 1994). Except for the study by Rosser et al. (2007) involving laparoscopic surgeons, most of the studies we have described here assessed spatial skills using computerized tests in the laboratory; it may be that transfer of skills is more likely to occur if the contexts of training and assessment are more similar. In one study involving surgical novices, participants who trained on a three-dimensional first-person shooter game performed significantly better on a simulated endoscopy task compared to those who trained on a two-dimensional version of the game (Schlickum, Hedman, Enochsson, Kjellin, & Felländer-Tsai, 2008). Thus, virtual reality games may present an opportunity for greater transfer from games to non-game and other real-world settings.

In addition to spatial representational skills, video games also use iconic or analog representations, wherein people, objects, events, and other entities are represented via images—static or dynamic—that resemble their referents. Effective navigation within digital games requires the user to "read" and "interpret" these representations. In fact, successful game playing hinges on the player grasping the meaning of images as words are used sparingly. Early research indicated that experience with iconic images in video games can benefit iconic representational skills. In a cross-cultural study carried out in Rome and Los Angeles, Greenfield and colleagues found that after playing the game *Concentration* on the computer, participants used more iconic and fewer symbolic representations in their answers compared to participants who played the same game in a conventional board format. Representational skill was assessed by asking participants questions about images of video displays from *Rocky's Boot*, an early educational logic puzzle game to teach circuit design and Boolean logic (Greenfield et al., 1994). The results of this study suggest that effects transferred to both the comprehension and production of iconic representation in an unrelated paper-and-pencil task that used similar representational modes.

The final set of skills that we consider here are general cognitive skills such as executive functions and visual spatial working memory, which are relevant to cognitive functioning across a range of content domains and problem-solving tasks. Training studies have been conducted using computerized tasks; although not the same as digital games, the tasks, such as a joy stick controlling an animated cat to predict trajectories and resolve conflicts, contain formal features similar to those used by games. Such computer-based training has been found to improve executive function skills (Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005), as well as visual spatial working memory (Thorell, Lindqvist, Bergman Nutley, Bohlin, & Klingberg, 2009). Of interest, in the Rueda et al. (2005) study, training not only benefited executive function skills but also produced significant increases in overall IQ. Similarly, Thorell et al.'s (2009) study assessed training effects on visual spatial working memory, but benefits were also found for verbal working memory. In contrast, early studies on the first generations of games mostly looked for and documented specialized effects related to specific skills utilized in the games. These newer training studies are among the first to suggest that electronic game playing may lead to more generalized cognitive gains that could be brought into play across a range of educational tasks and contexts.

The foregoing research supports our contention that the formal features of games can mediate learning during game play. Another way that formal features can serve as a pathway may come from opportunities to design and produce games/content that require an even more advanced and sophisticated understanding of the representational systems and formal features. In a small sample study, Kafai gave participants (elementary school students and preservice teachers) the opportunity to design computer games to teach fractions (Kafai, Franke, Ching, & Shih, 1998); the games could have their own game worlds, characters, storylines, and other design features. Based on an analysis of the games designed by the participants, Kafai speculated that the students developed sophisticated and complex representations of the content matter. Another example of such hands-on learning comes from the work of Ito and Bittani (2009), who have described the work of Japanese anime fans, who are part of interest-driven online communities wherein learning is primary. For instance, they create subtitles on Japanese animation, and the communities help to promote and develop sophisticated technical skills in a graduated fashion using feedback and scaffolding from fellow members. Anime fans progress from consumption to production and eventually to precocious professionalism, which involves manipulating the formal features of interactive technologies.

Other formal game elements that could influence learning include their goal-directed nature and immediate feedback. According to Prensky (2005), key elements of an electronic game are goals, which serve as an incentive to push a player in the face of repeated failure. Similarly, Gee (2008) noted that video games such as *Half-Life 2, Rise of Nations, SWAT4, Morrowind: Oblivion*, and *World of Warcraft* entail goal-directed experiences. Research by Blumberg (2000) has shown that process goal instructions facilitated video game performance, revealing that players' goals can have implications for learning from game play. Goal-directed flight simulator games have been successfully used in military training and sports video games have the potential to help learners learn from sophisticated virtual sequences (Fery & Ponserre, 2001). The goal-directed aspect of games has also been used effectively in healthcare settings to enhance patients' knowledge about their disease and treatments; for example, research suggests that a psychoeducational game called *Re-Mission* designed to involve young cancer patients in their own treatment was effective both in increasing knowledge about cancer and in improving treatment adherence (Beale, Kato, Marin-Bowling, Guthrie, & Cole, 2007; Kato, Cole, Bradlyn, & Pollock, 2008).

In addition to incorporating goal-directed activities, games also provide reinforcement, maintain records of behavioral change, and provide feedback (Griffiths, 2002). With regard to learning, feedback provides an assessment of progress by motivating a performer to put more effort, stay focused, and strive to progress toward goals to attain the task (Garris, Ahlers, & Driskell, 2002). In a study by Erhel and Jamet (2013) using a digital learning game called *ASTRA* about aging-related diseases, results suggested that there was deeper learning when the instructions stressed *ASTRA*'s educational focus versus entertainment focus. In a second experiment, the researchers found that even when instructions emphasized the entertainment and gamelike nature of the multimedia program, regular feedback about performance motivated participants to process the educational content and resulted in deep learning. Another study of educational video games by Delacruz (2012) suggested that one should find ways to motivate students to use provided feedback through the use of incentives. The results suggested a higher normalized score on math items and stronger intrinsic motivation when students were given the incentive to use feedback. Of interest, research findings indicate that even when a person loses a game, it can be intrinsically motivating if the player receives positive feedback for the effort put into the game (Vansteenkiste & Deci, 2003).

In sum, the second pathway by which games can influence learning is through their formal features. At a very basic level, repeated use of games and practice with their particular representational systems and formal features can help students develop related attentional, representational, and cognitive skills. At a more advanced level, learners may have to go beyond game playing to achieve higher order learning and conceptual outcomes. This is likely because designing and creating games and other content may force learners to engage with their formal features at a deep level. Thus, teaching children coding and programming may provide potential representational benefits from manipulating the formal features when coding and creating computer games. Finally, other formal features that can influence learning include goal-directed activities and immediate feedback.

CONTENT OF DIGITAL GAMES AND LEARNING

The third pathway of influence of digital games is through their content, which is the message or theme delivered by the formal features (Subrahmanyam & Greenfield, 2008). As with formal features, interacting repeatedly with particular games may help to internalize their messages or themes, thus helping game content to serve as a pathway for learning. Some dimensions of content include academic topics such as math (e.g., fractions) or history (e.g., civil war); other dimensions of game content that can mediate learning include fantasy and social themes such as sharing, helping, and aggression. Much of the research has actually focused on game content, as it seems an intuitive first point to examine the educational benefits of games.

Although not the primary focus of our article, we begin by addressing questions related to aggressive and other social content in games as they are relevant to the question of content effects. Not surprisingly, there is a vast literature on these topics given concerns surrounding violent content in media more generally and video games in particular. We refer the reader to publications by Whitaker and Bushman (2009) and Anderson et al. (2010) for theoretical reasons as to why we might expect effects from playing violent video games. The research on violent video game play is quite robust, and a comprehensive review of the research by prominent scholars in the field concluded that "research on violent television and films, video games, and music reveals unequivocal evidence that media violence increases the likelihood of aggressive and violent behavior in both immediate and long-term contexts" (Anderson et al., 2003, p. 81). With regard to susceptibility to these effects of video games, a subsequent meta-analysis by Anderson et al. (2010) yielded weak evidence for cultural differences between Eastern and Western countries and no evidence for sex or age differences. For an alternative perspective on these conclusions, see Ferguson and Kilburn (2010). Research suggests that nonviolent, pro-social content might also have short-term and long-term effects on pro-social behaviors (Gentile et al., 2009; Huang & Tettegah, 2010). Health-related games have also been studied, and again the evidence suggests that such content is effective in promoting changes in health behaviors (Beale et al., 2007).

Games with educational content are referred to by various names, including instructional games, entertainment, edutainment, or serious games. Subrahmanyam and Greenfield (2011) noted that the premise of most games in this genre is that the gaming context and the hands-on approach of "learning by doing" will lead to greater student engagement and learning. In contrast to the research on the effect of aggressive themes in media including video games, recent reviews regarding the evidence of content effects of games in educational contexts have not yielded consistent results. Kafai (2006), who has done some innovative work in the area of designing games for learning, noted that research has not shown consistent academic benefits. In their chapter describing a review of the research on this topic, Sherry and Dibble (2009) concluded that the idiosyncratic nature of the studies make it very difficult to draw any conclusions and generalizations. For reviews of research on the gains from using specialized educational software in the classroom compared to more traditional instruction by the teacher, the reader is referred to publications by Glaubke (2007); Lieberman, Bates, and So (2009); McCarrick and Li (2007); and Räsänen, Salminen, Wilson, Aunio, and Dehaene (2009).

More systematic surveys and studies have led to similar conclusions. After reviewing 20 studies on this topic, Egenfeldt-Nielsen (2009) concluded that although students do learn from computer games and also like the in-classroom use of games (Egenfeldt-Nielsen, 2009), "the support for saying something more valuable is weak" (p. 268). A longitudinal study based on a national sample of first-, fourth-, and sixth-grade classrooms and conducted under the auspices of the U.S. Department of Education found no statistically significant difference between classrooms that used reading and mathematics software with classrooms that did not do so (Dynarski et al., 2007). Although not strictly games, most educational software is similar to games in their formal features and gamelike contexts, and so the results are relevant here. With regard to science-based simulations and games, a recent report concluded that although there was moderate evidence that simulations promote interest in science, the evidence did not indicate any effects on other learning goals; furthermore they report that the evidence was inconclusive with regard to the benefits of games for science-based learning (Honey & Hilton, 2011). The meta-analysis by Wouters et al. (2013) reported greater learning for language- than for biology- or mathematics-based games.

Another gamelike environment is that of virtual worlds, and their immersive nature may have the potential to engage young learners in learning activities and help to develop critical thinking and problem-solving skills (Hu, 2010). Kafai and colleagues have examined the learning outcomes in a participatory simulation study, in which a virtual experience was connected to a science topic using a virtual world (Neulight, Kafai, Kao, Foley, & Galas, 2007). The virtual world in question was *Whyville*, which is designed for 8- to 16-year-olds, who engage in science and social activities within the online context (Fields & Kafai, 2010). Students in two sixth-grade classrooms experienced a "virtual" epidemic of an infectious disease called Whypox. At the same time, the students learned about natural infectious diseases for their science unit. The researchers used a pre- and posttest to assess students' understanding of natural disease. The comparison suggested that although student understanding of natural disease was improved, it was not fully biological, and the students' explanations appealed to prebiological mechanisms (e.g., mechanical transfer of disease through contact) rather than truly biological explanations (e.g., biology of germs or white blood cells).

Although research regarding the benefits of game content within educational settings is sparse, studies on informal uses within the home, after-school, and preschool settings has revealed benefits, especially for children and youth who may be at risk (Tran & Subrahmanyam, 2013). For instance, daily use of an online educational site (Headsprout Early Reading) for an 8-week period yielded gains in reading and oral language skills in a group of low-income preschool children (3 to 4 years of age; Huffstetter, King, Onwuegbuzie, Schneider, & Powell-Smith, 2010). The study was conducted at a Head Start Center, but the use of software occurred in a mobile computer lab and mimicked the more informal use common in homes. Simultaneously the children received in-class literacy instruction that paralleled the software training, indicating the potential for in-home use of educational content in games that is linked to in-class curriculum. Similar benefits have been found from informal computer-based training in a gamelike context for reading skills in dyslexic children (Magnan & Ecalle, 2006), as well as for children with low numeracy skill (Räsänen, Salminen, Wilson, Aunio, & Dehaene, 2009). In sum, the messages and themes of games may serve as a third pathway for learning. There is considerable evidence demonstrating learning pathways from aggression and pro-social content. However, evidence with regard to the effects of game content on academic learning outcomes has not produced a clear picture, and it appears that gains may depend both on the particular academic subject (language arts vs. science) and the level of the learner.

CONTEXT OF USE AND LEARNING

A fourth pathway of influence for digital games is the social context of use. In other words, learning gains from games may depend upon the context of use, in particular the social settings within which games are played. Here the learning pathway stems from the opportunities for social engagement provided by games (Tran & Subrahmanyam, 2013). The meta-analysis by Wouters et al. (2013) revealed that those who played serious games individually or in a group learned more than those who did not play games; but of importance, those who played in a group showed greater learning gains than those who played alone. In addition to learning and academic gains, games and online game contexts can also provide opportunities to interact, collaborate, and even compete. Collaboration is an important 21st-century skill and is an element assessed in the new Common Core standards, and we consider some of the ways that games can be used to provide opportunities for social engagement and interaction. Computer games could serve as the impetus for social interaction, especially when players encounter difficulties or challenges. Additionally, they can be used to encourage users to cooperate, negotiate, and collaborate; for instance, research with computers in preschools suggests that computer use fostered social interactions among children, especially when computers were shared (McCarrick & Li, 2007). Similarly, within elementary schools, more computers in the classroom may reduce interactions; in contrast, preschool children collaborate with each other even when each has his or her own computer (Willoughby et al., 2009). Although the idea of one computer per child is often touted, these results suggest that as with computers, games might encourage interaction, collaboration, and competition when students have to share the hardware or work together in the game.

Collaboration when playing computer games may also help children develop important real-world social skills such as negotiating with other players about roles and responsibilities. In fact, data suggest that gaming is more likely to be a social activity. Among 6- to 10-year-olds in one study, 44% reported playing alone compared to 54% who reported playing with another person (33% with a sibling, 11% with friends, and 10% with a parent; Hastings et al., 2009). Earlier research has also indicated that game playing may have positive benefits for social skills and relationships (Subrahmanyam, Kraut, Greenfield, & Gross, 2001). With the advent of the Internet and online gaming, such social interactions can occur virtually with offline friends as well as strangers.

Research suggests that collaboration and competition over computer games may yield learning and academic benefits via enhancements to student motivation. In one study, teams of students in three secondary schools in Amsterdam played *Frequency 1550*, a digital game set in medieval Amsterdam. The study authors were primarily interested in the motivational role of gaming, and they reported that students showed flow while engaged in activities within the game (Admiraal, Huizenga, Akkerman, & Dam, 2011). Relevant here is their finding that engagement in group competition was related to their learning: The more the students were engaged in group competition, the more they learned about the medieval history of Amsterdam. For a college-based programming course, Burguillo (2010) used game theory and students participated in a competition in which they used a software platform to create a game. Using survey data, the author concluded that friendly competitions can be motivating to students and increase their course performance.

Similarly Ke and Grabowski used a pre- and posttest design to compare fifth graders' performance in mathematics between game-playing (cooperative or interpersonal competitive) and no-game-playing (drill) conditions. Participants in the gaming conditions played *ASTRA EAGLE*, a series of web-based computer games for mathematics. Controlling for individual differences, results suggested that game playing was more effective than drills, and participants in the cooperative game playing condition had the most positive attitudes toward mathematics (Ke & Grabowski, 2007). In general, multiplayer online role playing games such as *World of Warcraft* provide many opportunities for collaboration, teamwork, and leadership; it appears that leadership within these informal settings is challenging and time-consuming and incorporates many of the features of leadership in offline settings (Reeves & Malone, 2007; Williams et al., 2006). In sum, the fourth pathway by which games can promote learning stems from the particular settings within which they are used. That is, the learning gains from games—both academic and real world—may depend on whether they are played solitarily or in a group, in collaboration, or in competition with peers.

DISCUSSION AND CONCLUSION

In this article we presented a "pathways of influence" approach to provide a conceptual framework to study and understand how digital games and gamelike contexts can mediate learning. Although games have been touted for their potential in education, the empirical evidence to date has been mixed and contradictory. When learning gains have been obtained, it is not always clear what element or elements of the learning setting—the game, the instructor, or the context of play—were responsible. By identifying aspects of electronic games and game use that may be important and providing evidence in support of their role, we have presented a framework that can be useful for researchers, educators, and game designers seeking to harness the potential of digital games for learning. Our framework is situated within Vygotsky's notion of cultural tools and views digital games as a cultural artifact (Subrahmanyam & Greenfield, 2008). Influenced by prior work that has sought to identify variables that mediate the learning gains from informal computer use (Tran & Subrahmanyam, 2013), we described four potential pathways by which digital games can potentially influence learning outcomes in educational settings: time, formal features, content, and context of use.

Although time use has been an oft-used metric for all kinds of media use, we need survey data that present a fuller picture of the extent to which teachers incorporate digital games in their classroom instruction, the number of sessions and amount of time spent with games, and the particular instructional activities they may displace. Although it appears that multiple in-class game sessions are more effective for learning (Wouters et al., 2013), very few studies have systematically investigated the relation between instructional game time and learning. In fact, this may be one reason that research on games and learning has yielded mixed and inconclusive findings. Even more important, we need randomized controlled trials to identify the number and duration of game sessions that are most effective at producing learning with a particular type of game. Studies must also examine game time compared with instructional activities, especially in the context of the particular instructional activities they may displace. Optimal game time may also depend on the particular game genre, content/topic, students' grade level, and informal gaming/screen time outside school, which varies as a function of age, race/ethnicity, and gender (Rideout et al., 2010).

A related point is whether learning gains are assessed immediately at the end of game use or assessed after a lapse of time. From an experimental perspective, this means that researchers should manipulate both instructional time with games and time when learning gains are assessed. Doing so will help to identify learning gains from short- versus long-term use, as well as identify instructional game use that produce short- versus long-term learning gains. Although instructional game time is an important variable, what one does with that time is equally important, and in order to study the learning from, with, and within games we have to analyze the formal features and content of games, as well as their context of use.

Our analysis of the formal features of games drew from earlier research on television (Calvert, Huston, Watkins, & Wright, 1982; Salomon, 1976; Wright & Huston, 1983), as well as the first generation of video games (Greenfield, 1984, 1994). We described the formal language of games, including the representational systems utilized such as spatial and iconic representation, as well as other elements such as goal-directed activities and immediate feedback. Repeated use of digital games should provide practice with the symbol systems and formal features they utilize and should lead to gains in selected cognitive and representational skills. We also presented evidence from studies that attest to short- and long-term benefits to cognitive skills as predicted by this proposal (Green et al., 2010; Subrahmanyam & Greenfield, 2008, 2011). Future research should adopt the value-added approach identified by Mayer (2014) to systematically manipulate formal features of games to better understand their learning consequences. More work is needed to understand how the representational and cognitive gains from game playing may relate to academic and other learning gains within the classroom. Research must also systematically compare the gains from game playing with game design involving the actual manipulation of formal features.

Game content is another important element of games. Much of the extant research on digital learning that has focused on game content has yielded disappointing results with regard to learning and educational outcomes. One possible explanation for this is that some kinds of academic content such as language arts and math benefit more from game playing and the repeated opportunities for engaging with the content that they present. In contrast, other content areas such as science might require the more hands-on engagement provided by game design activities. Future research must investigate these alternative possibilities. The fourth pathway centers around the context of game use, and the evidence presented suggests that mindful use of games using collaboration or competition can foster both academic learning, as well as help develop important 21st-century skills. Of course, we need to better understand when game play in group settings or game play in more solitary settings might be more effective.

To better understand the link between games and the learning that ensures from game play, researchers should first create taxonomies of their formal features, content, and contexts of use. For formal features, this could include the different types of representations that must be learned in a game, the different types of goal-directed activities, and the different types of feedback. Future studies should then incorporate experimental designs to systematically manipulate these variables to assess their impact on learning outcomes. Given the complexity of games and game worlds, this is no easy task, but is essential to better understand their potential role in learning. Equally important are the mechanisms by which game features and constellations of game features impact learning. According to Wouters et al. (2013), games may produce learning via changes to cognitive processes and motivation. Green et al. (2010) speculated that video game play leads to changes in processing as a result of increased physiological arousal, incremental increases in task difficulty and variability in input, and even activation of cortical regions that are sensitive to reward and reinforcement. They also suggested that one possible mechanism underlying these changes is via the shaping of neural networks to become better at extracting statistical information about the learning task. Research on the mechanisms of learning is still in its infancy, and these proposals are largely preliminary. To harness the potential of games for learning, future research must seek to identify the mechanisms, including neural mechanisms via which games produce learning.

Although we presented and discussed each pathway separately, it is very likely that the different pathways interact with each other during actual game play and the nature of their interaction mediates learning. This may also be the reason that research on the content effects of games has yielded mixed results, as most studies have looked at games within a domain and have not taken into account other features of games. We suggest that a more fruitful approach for research would be to compare the learning potential of the different formal features of games and the combination of form, content, and context of use rather than comparing learning from digital games with more traditional teacher-based instructional modes. For example, action video games with spatial representational symbol systems in a solitary play setting might be more effective for learning certain kinds of content, whereas games utilizing other kinds of representational systems in a collaborative context might be more effective for other kinds of content.

Our conceptual framework provides a first step to systematically analyze features of games and game use that could mediate learning, but more work needs to be done. The four pathways and their characteristics described here are by no means an exhaustive list, and it is important to identify other features that could be critical for learning. One potential element is that of game hardware. Recent advances in technology include multiplayer online games, virtual reality, and touchscreen apps and games, and it is important to consider how the hardware might interact with game features to foster learning. More research is needed to understand the role of motivation as a mechanism underlying game influences and to examine whether different game features are better for different kinds of content and learning. Much of the extant research has focused on short-term effects, and we know very little about long-term effects of digital games and how they may be moderated by the different pathways of game influence. Transfer is another important issue, and most of the research reviewed in this article examined only short-term transfer, often measured in similar digital/technological contexts. An important question is whether some game features produce greater transfer to other offline academic contexts as well as offline real-world settings. For instance, virtual reality games and virtual worlds may more easily promote transfer of learning to real-world situations, and research should compare their effectiveness for learning in different domains. Learner characteristics might also be important, and age and differences in learning styles and representational skills could moderate the impact of the pathways that we identified here. Finally, we did not consider teacher variables (e.g., attitudes toward and experience with games) that might moderate the effects of games. As technology becomes even more integral in the lives of digital youth, it is important to analyze and understand how game features, use, and learner and teacher variables may mediate learning and transfer.

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