This is a pre-print version of the paper to appear in the Journal of Cognitive Technology

Design of digital cognitive games: Some considerations

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Digital games that are used for purposes other than pure entertainment are growing in popularity. These include games that engage the player in making sense of climate change patterns, learning about complex mathematical structures, and investigating public health policies. Such games function to mediate, facilitate, support, and/or develop high-level cognitive activities, such as problem solving, planning, learning, and analytical reasoning, and are referred to in this paper as digital cognitive games (DCGs). Despite their growing popularity and recognized potential, the design of DCGs is often not well-informed by current research in relevant domains. This paper draws from research in the cognitive and learning sciences, game studies, and human-computer interaction design, to examine some components of DCGs that significantly influence cognitive processes, and thus affect the performance of cognitive activities. These include game content and its visual representation, interaction design and the core mechanic of DCGs, and interactivity of DCGs. Each component is discussed, and an existing DCG is briefly analyzed. An awareness of these components would benefit designers if DCGs are to achieve their desired cognitive effects and intended outcomes.
Keywords: Digital Games, Video Games, Game Design, Learning, Cognitive Technologies, Cognitive Activities

INTRODUCTION

There is a growing body of research suggesting that playing digital games can enhance the performance of cognitive activities (Blumberg & Ismailer, 2009; Green et al., 2006; Sedig, 2007). Furthermore, digital games are increasingly being targeted towards purposes other than pure entertainment. In addition to their motivational properties, they are also being conceptualized as cognitive technologies (McDaniel & Vick, 2010). Already digital games are being used to facilitate such activities as making sense of climate change patterns, analyzing economic policies, learning about mathematical representations, reasoning with decision trees and complex structures, and exploring health issues (for some examples, see: Belman & Flanagan, 2010; Gros, 2007; Ke & Grabowski, 2007; Rowhani & Sedig, 2009; Haworth et al., 2010; Linehan et al., 2011). However, despite their potential for enhancing and developing cognitive activities, and despite their growing popularity, the design of digital games is often not well informed by human-computer interaction research, nor current research in the cognitive and learning sciences (Barr, Noble, & Biddle, 2007; Rambusch, 2010; Sedig, 2008). Studies in these areas indicate a relationship between design decisions and the performance of high-level cognitive activities such as learning and problem solving (e.g., Chmiel, 2010; Habgood & Ainsworth, 2011; Sedig, 2007, 2008; Sharritt, 2010; Svendsen, 1991). In addition, existing design frameworks tend to focus on general principles (e.g., see Dipietro et al., 2007; Wilson et al., 2009; Sedig & Haworth, 2012) which, while useful for design, do not allow for a systematic understanding of the relationship between design decisions and cognitive effects. Therefore, it is difficult to consistently design digital games to achieve their full potential for enhancing the performance of high-level cognitive activities (Haworth & Sedig, 2011). Rather than being concerned with all digital games, this paper is concerned with a particular category of digital games—digital cognitive games (DCGs)—whose primary function is to mediate (i.e., facilitate, develop, and/or promote) the controlled, reflective, effortful, and/or mindful performance of high-level cognitive activities. This paper combines and integrates research from game studies, cognitive and learning sciences, and human-computer interaction design to discuss some components of DCGs that influence cognitive processes, and are thus essential considerations for the design of effective DCGs.

The structure of the paper is as follows. Before discussing design considerations, some recent trends and advances in the learning and cognitive sciences, as well as the basic characteristics of DCGs, are discussed. Next, some important components of DCGs are discussed; these include game content, representations, interaction, core mechanic, and interactivity. Subsequent to this, a brief design scenario is presented. The final section summarizes the paper and provides suggestions for future research.

Learning and cognition

Towards the end of the twentieth century, epistemological shifts and technological advances stimulated researchers and educators to expand their conceptions of learning and learning environments (Land & Hannafin, 2000). Indeed, learning theories developed over the past two decades have asserted that higher-order thinking and the performance of high-level cognitive activities, such as problem solving and planning, are vital components of learning (Jonassen, 2011). For example, a learning activity may involve solving a problem, making sense of a body of information, planning some future actions, and/or making decisions; that is, it may involve any number of high-level cognitive activities. Accordingly, in this paper, learning is considered as a high-level cognitive activity that may have any number of other cognitive activities embedded within it.

Concurrent to epistemological shifts in the learning sciences, cognitive science researchers began to posit that cognitive processes are fundamentally influenced by one's surrounding environment. Evidence began to suggest that cognition not only is situated within social and contextual settings, but also is embodied and distributed across the brain and its external environment. For example, Kirsh and Maglio (1994) studied people playing *Tetris*, and discovered that cognitive processes during gameplay were extended into the external environment through the performance of epistemic actions—actions performed to facilitate mental operations rather than to achieve physical or pragmatic goals. Further research into human cognition has demonstrated that the external environment not only mediates and facilitates cognitive processes, but also is an integral component of what can be understood as an extended and distributed cognitive system (see Clark, 2008). When playing a game, cognitive processes are distributed across the player and the game. Cognitive activities emerge from the interactions among the components of the system—that is, the player and the game. Consequently, the unit of analysis of learning and other cognitive activities that games mediate *must be the player-game cognitive system*. That is, to examine if and how games support learning, the player and the game must be viewed as a distributed cognitive system, and not as isolated entities.

Digital cognitive games

Games have been defined in many different ways over the years. In this paper, a game is defined as a system in which players engage in artificial conflict, defined by rules, resulting in a quantifiable outcome (Salen & Zimmerman, 2004). A digital game, then, is a subset of general games which operates on electronic, computational devices or platforms. In other words, digital technology that is interactive necessarily mediates the play of a digital game, whereas such mediation is not a necessary characteristic of games in general.

Digital Cognitive Games (DCGs) are digital games that facilitate, support, and/or promote the performance of reflective, mindful, controlled, and/or effortful high-level cognitive activities. While playing a digital game, the player may be engaged in cognitive activities—such as problem solving or learning—using habitual, automatic, and/or trial-and-error mental strategies, but not necessarily thinking in a reflective or controlled manner. If, on the other hand, a digital game is intentionally designed such that the player is reflecting on his actions, thinking carefully about the task at hand, and/or engaging in deep mental processing of the information, then the game is considered a DCG.

When the primary cognitive activity of a DCG is learning, it can also be called a learning game, educational game, or serious game. However, DCG is a broader term since the primary cognitive activity may be something other than learning. For example, a digital game that engages the player in contemplation of social justice issues would be a serious game, but may not be a learning game or a DCG. A digital game in which the player learns and develops mathematical skills would be a learning game or an educational game, but it could also be a DCG. However, a digital game in which the player navigates through a maze—but must engage in reflective planning to do so—would be a DCG, but may not be considered a learning game or a serious game. This paper will focus on DCGs, as we are interested in the components of digital games that influence cognitive processes during the performance of high-level cognitive activities, irrespective of the content with which such processes are engaged. These same ideas can be applied to learning and educational games that are also DCGs, and thus will benefit researchers and designers of such games.

DESIGN CONSIDERATIONS FOR DCGs

This section will briefly examine some components of DCGs that fundamentally influence cognitive processes, and thus affect learning outcomes and the performance of cognitive activities. Considering these components when designing DCGs can enable a systematic design process in which design decisions are based on a conscious understanding of their cognitive effects. These components include game content, representations, interaction, core mechanic, and interactivity.

Game content and representations

Historically, educational content of games has been overemphasized at the expense of other essential components, leading to many poorly designed games that did not achieve their intended learning outcomes (Habgood, 2007). While content is certainly important, research in cognitive science has demonstrated that the manner in which content is represented, rather than the content *per se*, significantly influences cognitive processes (e.g., see Zhang & Norman, 1994). In fact, since the only access the player has to content is through representations at the visually-perceptible interface of the game, from the player's perspective the *representation is the content* (Cole & Derry, 2005). Designers must consider not only the content that is being provided to the player, but also the manner in which the content is represented. Moreover, it is often the case that game content can be represented with different representational forms that are informationally equivalent but computationally non-equivalent. That is, although different representations may depict the same content, each may require differing amounts of cognitive effort for processing and interpretation. While performing cognitive activities, cognitive processes are distributed across mental representations of the player and visual representations of the DCG; as a result, designers must carefully consider representation design and how design decisions impact cognitive processes and activities (e.g., see Sharritt, 2010).

Interaction and the core mechanic

An essential characteristic of DCGs is the interaction that takes place between the player and the DCG. Interaction is often discussed in the context of high-level pedagogical considerations, such as whether the DCG promotes constructivist learning, goal-based learning, cognitive apprenticeship, and so on. In this paper, however, interaction refers to lower-level individual instances of action and reaction between the player and the DCG, such as a player performing an action and a shape rotating as a result. At this level, interaction design is concerned with low-level action-reaction considerations, such as whether and how a DCG allows the player to rearrange tiles, transform shapes, move through a game space, and assign behaviors and/or properties to game entities, and the cognitive effects of such interactions. Much research demonstrates that design considerations at this level of interaction have significant effects on cognitive processes (e.g., see Sedig & Parsons, 2013).

A DCG often includes interactions that are not essential to playing the game, such as pausing or saving the state of the game. Although such interactions may be performed, there is typically a core set of interactions that are essential for proper gameplay and are repeated throughout the game. This core set of interactions occurs again and again to form a cycle, and can be referred to as the core mechanic of a game (see Sicart, 2008). For example, in the game *Tetris*, the basic interactions are rotation and movement of a shape, and these are repeated over and over and form the core mechanic. In DCGs, the core mechanic is the cyclical pattern of interaction that binds the player and the game into an integrated cognitive system. Consequently, it is primarily through the core mechanic that the player accesses and engages with the content of the DCG. Moreover, it is primarily through the core mechanic that the player and the DCG are tightly coupled into an integrated cognitive system, resulting in the emergence of higher-level cognitive activities. The core mechanic can therefore be considered the *epistemic nucleus* of the DCG. Consequently, this component must be designed with a conscious awareness of how cognitive processes of the player are affected.

Interactivity

High-level cognitive activities, such as learning, emerge from the sustained interaction between the player and the DCG that is enabled by the core mechanic. As a result, the quality of this interaction is a critical determinant of the quality of the cognitive activities that emerge from the interaction. While interaction refers to action and reaction, interactivity, by adding the suffix 'ity', refers to the *quality of interaction* (Sedig & Liang, 2006). The authors are currently developing a framework that identifies and characterizes a number of elements that collectively give structure to each individual interaction in the context of DCGs. Each element has different operational forms, and varying the operationalization of these elements can significantly impact interactivity. As an individual interaction has both an action and a reaction component, the elements that affect interactivity can be categorized into action elements and reaction elements. To illustrate, let us examine one action element and one reaction element. One element of action that has been identified as affecting cognitive processes is *agency*, which is concerned with the metaphoric way through which the player expresses an action. Two operational forms of agency are: verbal and manual. If the agency of an action is verbal, the player expresses an action using his 'mouth', as though speaking to the DCG, such as by typing a command into a console. If the agency of an action is manual, the player expresses an action using his 'hands', as though reaching into the interface and grasping and manipulating representations, such as using a mouse cursor to click and rotate an object. A study by Svendsen (1991) demonstrated that the operational form of this action element significantly influenced cognitive processes during the performance of a problem solving activity. One reaction element that has been identified as affecting cognitive processes is *activation*, which is concerned with the commencement of reaction after the player has committed an action. Three operational forms of activation are: immediate, delayed, and on-demand. If activation is immediate, the reaction occurs instantaneously after an action is committed. If activation is delayed, an action is committed and then a span of time passes before the reaction occurs. If activation is on-demand, the reaction only occurs once the player requests it. This element of reaction can be operationalized to promote different degrees of mental effort and engagement with the underlying content. For example, if activation is delayed, the player may be forced to engage in deep, reflective thought before committing an action, since the feedback from the action (i.e., the reaction) is not immediate.

DESIGN SCENARIO

This section will examine the design considerations of a particular DCG in order to demonstrate how the above components may be integrated and considered in the design process. The DCG in question requires the player to find a path through a maze that leads to an exit, while passing through several checkpoints along the way. Thus, to properly play the game, the player must identify possible paths and checkpoints, analyze them, make decisions about which path to take, and plan a course of action. The manner in which the components are designed affects how much cognitive effort is required to identify paths, how easily the player can assess the suitability of a path, how much the player is encouraged to reflect before making decisions, and so on. Each component and its different design options are discussed below. An exploratory study that was previously conducted with the DCG is also briefly mentioned to provide empirical support.

Content and representation

One crucial design decision is how the content of the game (e.g., the player, the maze space, paths through the maze space) should be represented. Three possibilities, each with different effects on cognitive processes, will be discussed. First, the paths could be represented in a grid-like fashion and the player's current position could be represented as an avatar, which is typical of many maze and puzzle games (Figure 1). This representation forces the player to exert cognitive effort to identify implicit, hidden paths, and to determine their suitability. A second option is to represent the paths explicitly with a tree diagram (Figure 2). Positions in the maze can be represented as nodes in the tree, and paths can be represented as links between the nodes. With this representation, the player is not required to expend much cognitive effort to identify paths, as they are explicit and visible, and can instead focus cognitive resources on analyzing the paths to determine which one is the best to follow. A third option is to use both representations simultaneously, so that the cognitive effects of each may be combined.

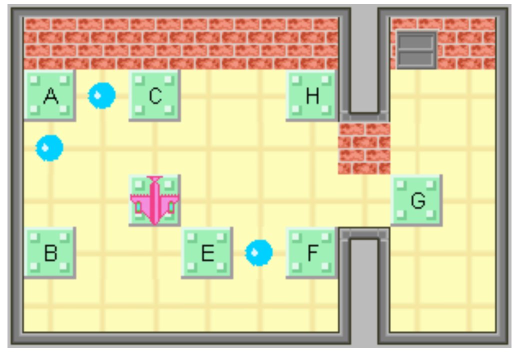

***Figure 1*. An implicit representation of paths through a maze.**

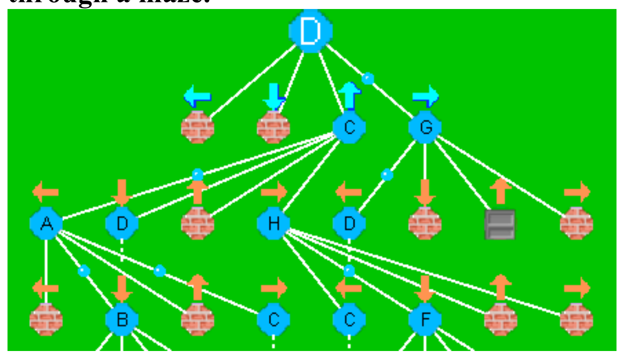

***Figure 2*. An explicit representation of paths through a maze.**

Interaction and core mechanic

The main action that the player performs in this DCG is to move through a path in a maze. Thus, an important issue for designing interaction is to determine the way in which the player can follow a path through the maze, while integrating this interaction with a chosen representation for the paths. Assuming that the paths are represented as a tree diagram, interaction could be designed in the following manner. For the action component, the player selects one of the root node's immediate children as the next step in the path. For the reaction component, the tree changes such that the selected node becomes the tree's new root node. Both these two components are repeated in a cycle, until the player has passed through all checkpoints and has selected the goal node. The selecting of nodes to form the path through the maze would thus constitute the core mechanic of the DCG. Alternatively, use of the grid-like representation would alter the design of the core mechanic, and interaction design would be concerned with moving an avatar around the grid. For the action component, the player could assign a direction to the avatar. For the reaction component, the avatar could move in the assigned direction until it reached some point at which it would stop. The core mechanic is thus the cycle of assigning directions to the avatar, and it moving accordingly through the maze.

Interactivity

For interactivity design, each structural element of an interaction can be examined and operationalized according to the desired cognitive effect. To exemplify this in light of the DCG currently being examined, consider the interaction discussed in the previous section in which the player assigns a direction to an avatar. The two previously discussed interactivity elements, *agency* and *activation*, which are concerned with action and reaction respectively, will be discussed.

The *agency* element of the action could be operationalized such that the player is given four directional buttons to click (i.e., manual agency). Doing so would assign the button's corresponding direction to the avatar. Alternatively, the agency element could be operationalized such that the player types a command, such as 'north', to assign a direction (i.e., verbal agency). The *activation* element of the reaction could be operationalized such that each time the player assigns a direction to the avatar it immediately moves in the assigned direction (i.e., immediate activation). On the other hand, the player could queue a series of directions for the avatar, then at some point select a button to initiate the reaction such that the avatar would move in each of the queued directions in the order in which they were assigned (i.e., on-demand activation). As discussed in the interactivity section above, each of these would have different effects on the cognitive processes of the players.

Evaluation

An exploratory study was conducted using multiple versions of this DCG to determine whether different design decisions affected decision making (see Haworth, Tagh Bostani, & Sedig, 2010 for a detailed discussion of the study). In the study, four versions of the DCG were developed. In version one, both a grid and a tree diagram were used to represent the paths, and the player interacted with the DCG by selecting nodes in the tree. In version two, interaction was changed so that the player assigned a direction to the avatar. In version three, the player could interact with the DCG either by selecting nodes or assigning a direction. In version four, only a grid was used to represent the paths, and the player interacted with the DCG by assigning a direction to the avatar. The results of the study indicated that participants who played version one referred to the tree diagram to extract paths in difficult mazes, showed more awareness of the consequences of their decisions, and avoided choosing paths that would be detrimental to their progress. Participants who played versions two and three paid less attention to the tree diagram, and spent more effort extracting paths from the grid. Participants who played version four showed more difficulty in determining the correct path. The researchers concluded that the different ways of designing interaction and representation components of the DCG did have an effect on the way in which participants analyzed their possibilities and made decisions regarding the best path to take.

Although the results indicate that such design decisions do affect the cognitive processes of players, only two of the components discussed in this paper—interaction and representation—were studied. A brief discussion of this study has been included simply to provide additional empirical evidence that the consideration of at least these two components is necessary. Future studies can examine the other components and their relationships in more detail.

SUMMARY

As recent theories of learning and instruction promote more situated and active learning strategies, DCGs have the potential to take a more important role in educational settings. To do so, however, their design must be well informed by relevant research. This paper has drawn from research in the cognitive and learning sciences, game studies, and human-computer interaction design, to examine some components that are important to consider in the design of DCGs. Representation design, interaction design, design of the core mechanic, and design for interactivity, have all been discussed in terms of their cognitive impacts. Future research in this area will hopefully elaborate on these components and integrate them into more comprehensive design frameworks. Although design of DCGs until now has typically been ad hoc and/or based on anecdotal evidence, the development of such research can assist designers in making systematic design decisions that are based on an awareness of their cognitive effects. As a consequence, DCGs can be consciously designed to engage particular cognitive processes and to achieve intended cognitive outcomes.

AUTHOR NOTES

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