“Critic-proofing” of the Cognitive Aspects of Simple Games

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Abstract:

This paper posits the use of computer games as cognitive development tools that can provide players with transferable skills suitable for learning in the 21st century. We describe a method for categorizing single-player computer games according to the main cognitive function(s) engaged in by the player during gaming. Categorization was done in collaboration with a neuropsychologist, academic researchers, and research assistants. Twelve research assistants, mostly domain novices, were trained to categorize games according to a cognitive matrix developed by the neuropsychologist. They also categorized the games, and evaluated and commented on the relevance of the neuropsychologist’s categorization of the games. Through the process of “critic proofing,” computer games were reliably classified into primary and secondary cognitive categories, and the team was able to identify problems with both the categorization of certain games and the definitions of some of the cognitive functions in our cognitive matrix. Such an approach allowed for the identification of under-populated cognitive categories in the project’s existing repository of games, and for further development of the cognitive representation framework, information useful for both researchers and designers in the gaming industry.
Keywords: Computer Games, Cognition, Learning, Reliable Coding, Critic-proofing.

Introduction

In this paper, we describe our approach for identifying and categorizing simple, single-player computer games that are “cognitively responsible.” This term was generated by Martinovic and Whent in 2011, specifically to describe simple, single-player computer games that utilize several aspects of cognition in the player (e.g., visual perception, memory, executive function). Using this term means that we are avoiding the addictive qualities of computer games (e.g., limit on play time) and are considering only games that are not connected to social networks (with associated risks, e.g., privacy); we are considering games that are meant to have an educational and/or cognitive benefit—aspects which we are exploring without definitive answers yet; and that we are using games that are subject to education and psychology expert review and critique. By coming up with the concept, we extended existing taxonomies that classify single-player computer games according to genre (e.g., action, puzzle), level of interactivity, or difficulty (e.g., Apperley, 2006; Van Eck & Hung, 2010) to include categories that relate to the cognitive functions the player engages in during gaming. This method is used as part of a larger research and development project[1] described in Whent et al. (2012) in which we plan to involve and evaluate children aged 6 to12 in playing computer games that we deem cognitively responsible.

Our working hypotheses in this multi-year study are that:

(a) The player's performance while playing cognitively responsible computer games may help identify his/her cognitive strengths and weaknesses;

(b) Repeated playing of games that are in the player's weaker cognitive areas will help the player improve his/her cognitive processes; and

(c) The gaming results can be used to determine further human or software intervention (e.g., recommending which other games to play; enriching day-to-day living with additional and targeted cognitive experiences).

While these hypotheses are guiding our research, in this paper we describe the groundwork that was completed in order to set a stage for addressing these and other fundamental premises, which shall inform future game developments. To summarize, our research examined the concept of game play as a cognitive development tool with possible applications for a broader audience than just children.

[1] This ongoing project has been funded by NSERC, OBI and FedDev, and SSHRC.

The literature has shown that training and learning that include purposefully selected computer games can provide players with transferable skills, support lifelong learning, and enhance their reasoning (Bottino, Ferlino, Ott, & Tavella, 2007) and digital skills (Beavis & O'Mara, 2010; Owston, Wideman, & Brown, 2009). The problem is that while millions of children play computer games daily (and often compulsively), many parents fear that their children are engaged in activities that may be detrimental to or at least ineffective for their social and cognitive development. Some parents deliberately avoid having computers at home, while others restrict access for their children out of fear that they will use computers to play games rather than for educational purposes (Dance, 2003).

While it is obvious that computer games engage players cognitively, the specifics of how gaming relates to cognitive development, the games' attributes (i.e., aspects of a game that support learning and engagement), and what is involved in the gaming activity (e.g., how the player's personality, gaming interface, and other factors interact) are far from being well understood. To support children's healthy emotional, cognitive, and learning development, Lieberman, Fisk, and Biely (2009) suggested that more research was needed to understand these areas of development in children when they play computer games. Rebetez and Betrancourt (2007) called for "an empirically based classification of games, depending on their potential effects for an educational purpose, [and for the development of] a unified research paradigm and methodologies to carry on reliable research on video games" (p.131). Furthermore, Boyle, Connolly, and Hainey (2011) suggested that research into gaming should include psychologists who "can help in exploring and systematising the characteristics of different games and in helping to understand the different kinds of enjoyment and potential for learning linked to specific game characteristics" (p. 72).

In line with these recommendations and to alleviate misconceptions among parents and the general public about the utility of computer games, our multidisciplinary team of educators, computer scientists, and psychologists explored and systematized the characteristics of simple games available at www.DiscoveryGames.com (Whent, 2012), as well as assessing both their suitability for helping to create cognitive profiles of the players and the potential effects these games may have for improved cognition. Cognitive abilities (e.g., auditory, visual, conceptual, speed, and executive; see also Appendix A) affect one's reading, writing, doing mathematics, and communicating effectively. According to Crouse (2010), a child who is lacking in visual processing ability may have problems with mathematical calculation and reasoning as well as with writing mechanics. Remediation may be recommended in such cases, with the child playing more games in his or her weak categories, in addition to any other interventions that may be undertaken by parents, teachers, and/or psychologists.

Computer Games, Child Cognition, and Learning

Statistics Canada (2010) reported an increase in the amount of daily time Canadians spent playing video games from 1 hour 48 minutes in 1998 to 2 hours 20 minutes in 2010. According to Rideout, Roberts, and Foehr (2005), in the U.S., children aged 8 to10 spent more than an hour a day playing video games.

The literature, however, is not unified in its reports and analysis of the social and cognitive consequences of such trends (Martinovic, Freiman, & Karadag, 2011). On one hand, a literature review of computer games from behaviourist, cognitive, constructivist, educationist, and neuroscience perspectives (Yusoff, Crowder, Gilbert, & Wills, 2009) identified aspects of these games that supported learning and engagement, such as incremental learning, sequencing of actions, scaffolding, feedback, rewards, and learner control. Moreover, playing computer and video games has lately been recognized as a valid cognitive activity, as such play affects the player's capability to self-regulate, make right decisions, and problem solve (Bogost, 2007; Gee, 2007).

At the same time, computer games can be addictive and may overload the limited capacity of working memory in children (Tardieu & Gyselinck, 2003) and increase the risk of poor school performance (Chan & Rabinowitz, 2006). Today's children are believed to have a shorter attention span than earlier generations and to need immediate answers (Pedró, 2006), which may be a consequence of the extensive propagation of video games. Since the main features of many video games are quick reaction time (Castel, Pratt, & Drummond, 2005) and immediate feedback (Gentile, 2011), these games may reinforce the inclination towards fast, focused, and repetitive actions that result in direct and limited learning in a short time.

One documented benefit of playing computer games is improved visual intelligence (Gardner,1983) which may be particularly relevant for subject areas where one needs to manipulate images on a screen, such as science and technology (Subrahmanyam, Kraut, Greenfield, & Gross, 2000). Computer-based games may enhance hand–eye coordination, visual scanning, auditory discrimination, and spatial skills (DeLisi & Wolford, 2002). Moreover, this emphasis on visual information processing may be connected to a significant increase in average non-verbal scores in various psychological tests across all groups tested (Subrahmanyam et al., 2000). A comparative study of children aged 10 to 11 who played two different computer games—one with strong visual content and the other text-based—showed that playing the first game improved spatial performance, while playing the second did not (Subrahmanyam & Greenfield, 1994). Repetitive game playing may increase young (preschool) children's working memory (Thorell, Lindqvist, Nutley, Bohlin, & Klingberg, 2009); mental rotation accuracy

(DeLisi & Wolford, 2002); and spatial rotation, iconic skills, and visual attention (Subrahmanyam, Greenfield, Kraut, & Gross, 2001)[2].

Playing purposefully designed computer games may have a positive effect on learning for children in a wide range of ages (Gee, 2005). Because playing computer games involves integration of touch, voice, music, video, still images, graphics, and text (IBM, 1991), children learn to interact with an environment geared to a variety of intelligences (e.g., linguistic, logical, spatial, kinaesthetic, musical; Gardner, 1983). Video games emphasize problem-solving and recursive practices (Gee, 2007) as well as entertaining players through successive challenges of increasing difficulty. Players of computer games achieve automaticity in an enjoyable way, which can be related to findings from neurological research that identify practice and emotion as an important element of learning (e.g., Zull, 2004). In addition, Beck and Wade (as cited in Bogost, 2007, p. 240) maintain that the "videogame generation" (i.e., those born after 1970) is uniquely positioned to use meta-cognitive skills obtained through video game playing (e.g., reflecting on the immediate situation, analyzing choices and comparing odds, and finding the right strategy).

Different computer games affect children differently. Pillay (2002) employed both quantitative (i.e., completion time and number of correct solutions) and qualitative (e.g., cognitive strategies used, such as goal-directed searches and/or making inferences) measurements to investigate the impact of two recreational computer games on the performance of 14- to16-year-old children in a series of computer-based instructional tasks. The author found that playing recreational computer games may influence performance in subsequent computer-based educational tasks and concluded that although recreational and educational games may

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[2]For extensive list of perceptual, cognitive, behavioural, affective and motivational outcomes of

have different goals, the commonality in their structure was what mattered. For example, after playing a recreational game that involved multiple use of a linear, cause-and-effect approach, the players tended to employ means–end analysis and a step-by-step approach in an educational game, even when that method was not appropriate. Pillay suggested that children would benefit from playing different types of games (e.g., recreational, educational) because by playing them, children would develop a repertoire of cognitive schemas that they could later use in various learning tasks.

Theoretical Framework

In this section, we introduce aspects of *activity theory* (e.g., Kaptelinin, 1996) that provide a lens through which we can look at playing computer games. Our intent is to consider all aspects of gaming—the player, the computer game, and how the game is played—that can help us understand how an individual interacts with a game. This is important because, as Jonassen and Rohrer-Murphy (1999) state, alteration of the nature of human activity caused by use of the software may transfer into the specific mental development of the software user. Hence, relating a player's characteristics to the characteristics of the games being played, and thus better understanding the fit that can be established between the two elements, will contribute to a more reliable use of games in the evaluation and improvement of the player's cognitive skills.

In activity theory, the central triad of any activity consists of a *subject* (e.g., a player), an *object* (e.g., a game to play) and a *tool* (e.g., a computer; Bellamy, 1996). Here the player does not relate to the game directly, but rather does so indirectly through the computer. Motivation to be immersed in the story, achieve a skill, and/or compete with the computer (see Radoff, 2011) drive the player towards the achievement of the goals (Bedny & Karwowski, 2007), which may

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playing computer games, see Connolly, Boyle, MacArthur, Hainey, and Boyle (2012).

be of dual nature: the conscious, desired result of his/her actions, such as winning the game and having fun, and the cognitive component of gaming, such as learning and gaining skills. For example, while the player's goal may be to win over the villain or gain 100 points, the cognitive outcome may be the development of problem-solving skills, memorizing a song, or developing confidence for doing some mental calculations. While the game conditions and levels change, the player changes, too, by developing a skill or learning. It should be noted, however, that the player's motivation to play may diminish in time if the game is not suitable or fun, especially where the cognitive challenge does not match the player's ability.

The view of gaming activity as consisting of a subject–tool–object–outcome construct helped us both to associate the player's cognition with the features of the computer game and to recognize that the outcome of play may be to exercise a particular cognitive function of the brain and to develop a certain cognitive skill. To conceptualize the game mechanic in an illustrative (but non-exhaustive) way, we have adapted the conventional diagram of activity theory (Figure 1) and extended it to include additional components (see Appendix B) stemming from the literature review.

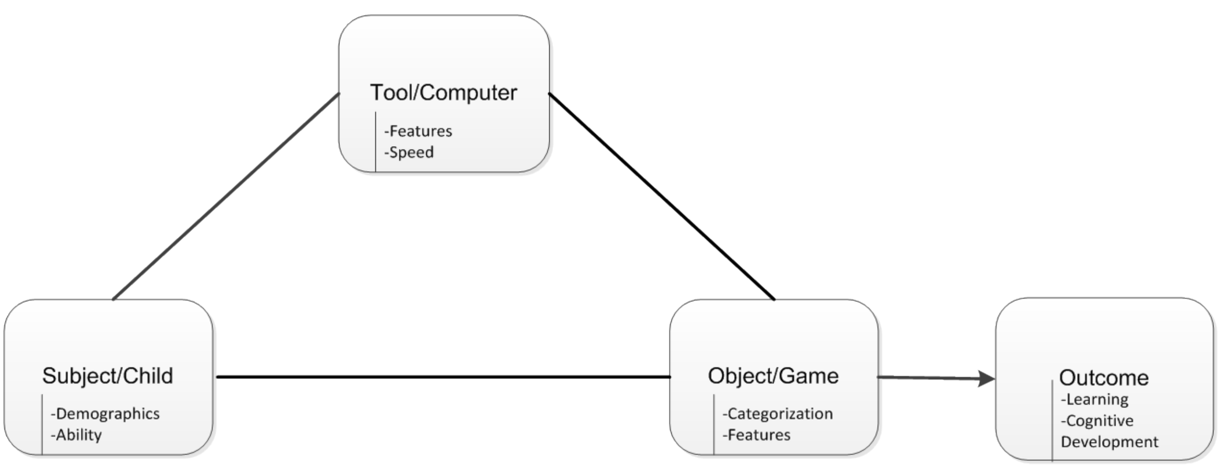

Figure 1. Components of activity with their essential aspects.

At the same time, cognitive development and learning happen in one's social environment and through the opportunities created in the context of activity. Vygotsky (1978) defined the Zone of Proximal Development (ZPD) as a difference between the actual and potential developmental level of a child accomplished with a help of others. For Newman and Holzman (1993) the ZPD is the proper unit of analysis for understanding learning and cognitive development, and their relationship. The ZPD is for our study both a tool and a result (Guy, 2005)—constructing and observing gaming situations and relating them to learning and developmental change in children cannot be done in isolation; the family, school, and other relevant social aspects have to be also included to help us grasp how games could add to educational practice. For these reasons the gaming engine that we are developing and testing also requires input from parents/caregivers to obtain information that is used for building a learning profile of the child, the information that will be used when suggesting to the child which games to play next, and then following his/her progress in time.

Research Method

We performed a qualitative analysis of our inventory of 221 games to determine the primary and secondary cognitive skills addressed by each game. These simple, single-player games are available through the Online Training and Education Portal (OTEP Inc., http://otep.com/) web site. The manufacturer categorized the games in the following way: action–puzzle (n = 26), action (n = 29), logic (n = 34), puzzle (n = 34), shooting (n = 5), sports (n = 5), memory (n = 19), strategy (n = 13), educational (n = 17), typing (4), and unidentified (n = 35) games. However, these distinctions were neither detailed nor precise enough to be used by a software engine to create a cognitive profile of the player of each kind of game. For our purposes, therefore, we had to reliably re-categorize these games according to the primary and secondary cognitive skills exercised by players during play.

The research method we opted for was inspired by Livingston, Mandryk, and Stanley's (2010) method of the *critic-proofing of games*. Both of these methods—ours and that of Livingston et al.—can be used to critically evaluate a computer game at any point during its development. In its original form, critic-proofing is a heuristic evaluation method (see Nielsen, 1997), such that it is based on a small group of evaluators reviewing game usability issues in comparison with the established usability heuristics (e.g., how the game controls work and how they align with controls employed in other games of the same genre). Evaluation can cover any aspect of user experience for which heuristics exist, such as for a game being 'fun' or 'playable.' Nielsen recommends three to five evaluators who would independently from each other inspect the software to ensure unbiased evaluation. Only after the evaluation is complete, the evaluators can meet to discuss the outcomes. Throughout this process, they are accompanied by an observer who may take notes and answer questions.

In Livingston et al.'s (2010) approach, the heuristic evaluation method is extended with steps in which the game is first categorized by genre and its final ratings are based on an empirical analysis of evaluators' reviews. The critic-proofing approach has been criticized as not always appropriate for children's products by MacFarlane and Pasiali (2005), who made the case that adults may not perceive problems that children might have in using products, or on the other hand, might judge issues as severe, while children might be largely unaffected by such problems.

As opposed to Livingston et al. (2010), who used the critic-proofing method to assess the usability/playability of a game and find the game's shortcomings, we sought to reliably categorize games in our repository according to the cognitive skills they engaged in the player.

Accordingly, we used two types of evaluators: (1) an expert in cognition theory, and (2) a group of research assistants, young adults who were inclined to play computer games. Our approach incorporated both empirical and inspection methods employed in game studies (e.g., Pinelle, Wong, & Stach, 2008): (1) empirical methods because the games were categorized based on the evaluation tools given to players; and (2) inspection methods because among our players, we also had evaluators skilled in cognition theory. Our methodological approach consisted of four main steps (see Figure 2):

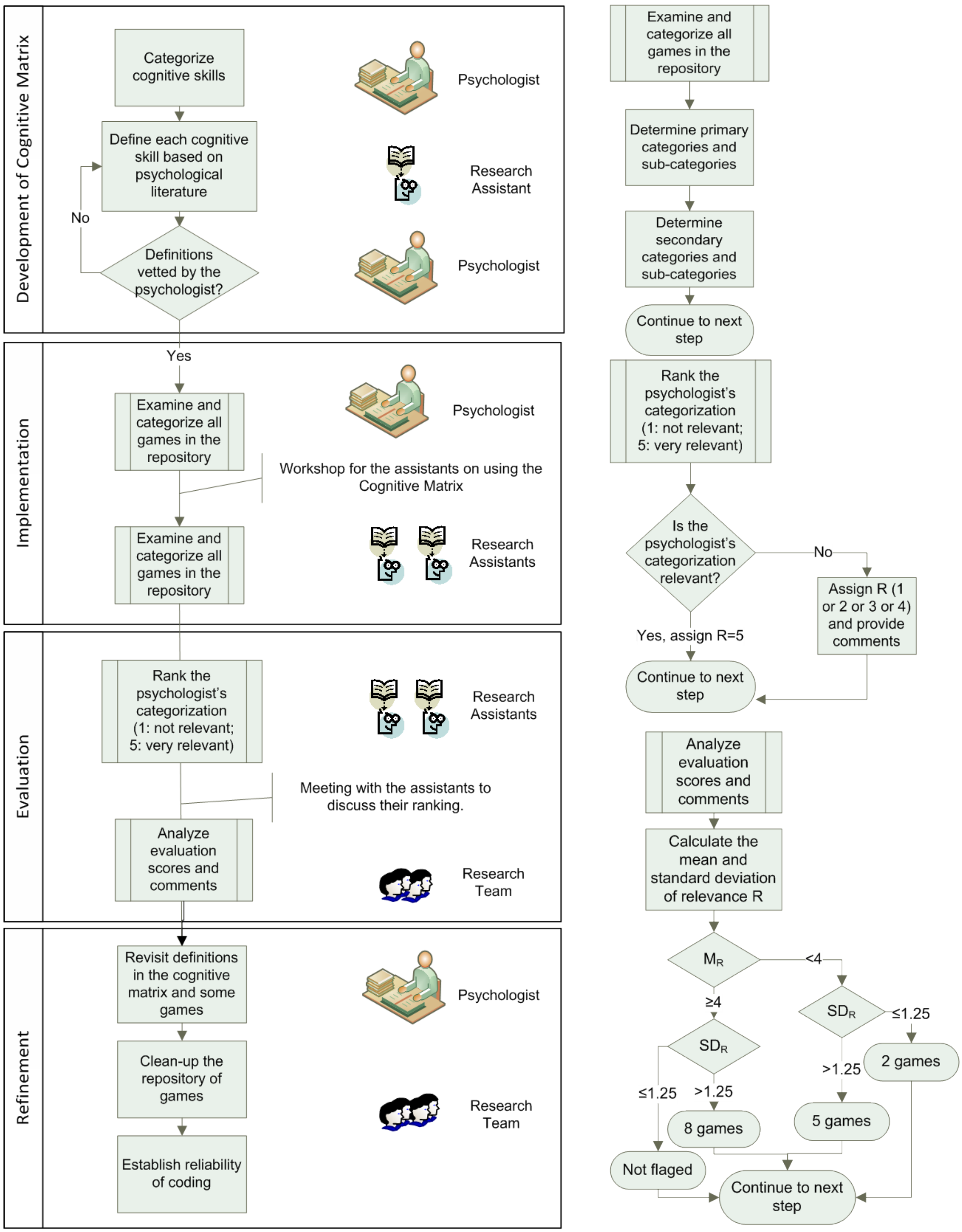

Figure 2. Methodology, with task details, for establishing the reliability of games categorization.

Step 1. Development of a cognitive matrix (see Table 1 and Appendix A).

a. Categorization of cognitive skills was developed for OTEP Inc. by a clinical neuropsychologist (henceforth referred to as the psychologist). There were 9 main cognitive categories, each containing subcategories (43 in total).

b. A research assistant examined the psychological literature to find definitions for each identified cognitive category. These definitions were vetted by the psychologist and became part of the cognitive matrix.

Table 1

An Excerpt from the Cognitive Matrix for One Cognitive Category and Its Subcategories*

Cognitive Category	**Cognitive Subcategories**
100: Visual Perception The ability to perceive and interpret information in the visual field.	A) Matching Shapes—distinguishing identical shapes from similar or different shapes. B) Visual Tracking—following a moving target with the eyes (PsycNet, 2012). C) Movement Detection—detecting either an object moving relative to its surroundings or the surroundings moving relative to an object. D) Colour Perception—perceiving colour accurately. E) Spatial Judgement—understanding the arrangement of items in 2D or 3D space; manoeuvring around or towards such items (Cognifit, 2012).

*The cognitive category/sub-category ID, title, and description are presented; the complete matrix contains 9 cognitive categories and 43 subcategories with definitions (see Appendix A).

Step 2. Implementation

a. The psychologist examined games from the repository. For each game, he determined the primary and secondary categories, as well as their subcategories (see Table 2 and Figure 3). Initial conceptualization here is that the game is thought to exercise the 'primary' category to a greater extent than the 'secondary' category, but both are tapped.

b. The researchers organized a one-hour workshop for the 12 independent raters (paid undergraduate and graduate research assistants from three academic departments [psychology, education, and computer science], henceforth referred to as the assistants) to describe the categorization task, clarify the cognitive categories and subcategories, demonstrate the evaluation of several games, and answer questions.

c. The assistants played all the computer games in the repository and, referring to the definitions in the cognitive matrix, selected a primary and secondary cognitive category/subcategory for each game.

Table 2

Primary and Secondary Cognitive Categories/Subcategories for Two Games in the OTEP Inc. Repository

Game	Primary Cognitive Category	Cognitive Subcategory	Secondary Cognitive Category	Cognitive Subcategory
Building Blocks (puzzle game, see Figure 3)	100: Visual Perception	A) Matching Shapes	500: Executive Functioning	C) Problem Solving
Bricks Squasher (action game, see Figure 3)	300: Visual Motor	A) Visual Motor Integration	100: Visual Perception	B) Visual Tracking

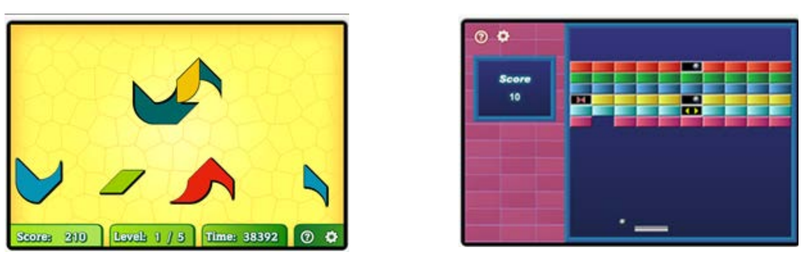

Figure 3. Screen shots of two games: *Building Blocks* (left) and *Bricks Squasher* (right).

Step 3. Evaluation

a. The assistants were told how the expert (i.e., the psychologist) had classified each of the games. They were then asked to rank the expert's categorization for relevance on a 5-item Likert scale (from 1 = Not Relevant to 5 = Very Relevant). If they felt that the psychologist's categorization was not relevant, they were asked to provide comments to back their opinion.

b. After the assistants completed their evaluation, we organized another one-hour meeting with them to discuss any issues they had with the clarity of the definitions or instructions on how they should categorize the games, the games they played, or their decision-making processes. The games that received the most variation in categorization were played in front of the group so that the group could discuss them and determine why their categorizing had produced such diverse values.
c. After all the Likert scores were in, a descriptive analysis was conducted.

Step 4. Refinement

a. Based on the assistants' feedback, the psychologist re-investigated and re-categorized the games that were identified as problematic. In addition, the definitions were clarified if the entire team (the psychologist and the assistants) felt that they may have been confusing.
b. Based on the cognitive matrix, the researchers determined reliability scores for the categorization of computer games in the OTEP Inc. repository.

Data Analysis and Results

Data analysis was also conducted in several stages. The data from the implementation phase (a to c: the psychologist's and the assistants' categorization of games) were inputted into Excel along with the data from the evaluation phase (a and b: the assistants' perceived relevance of the psychologist's classification of games [on the scale: 5 = Very Relevant, 4 = Mostly Relevant, 3 = Relevant, 2 = Somewhat Relevant, and 1 = Not Relevant]).

Initial Analysis

The initial analysis took into account the relevance rating assigned by the research assistant raters. We identified as problematic those games with a low average relevance rating (Low M_R, meaning that the assistants, on average, gave a low relevance R to the expert's categorization) and/or a high standard deviation (High Standard Deviation of R—SD_R, meaning that the assistants' relevance value R diverged from the Mean R—M_R value) of the average relevance rating. There were five games that satisfied both conditions (Low M_R and High SD_R), eight games with a High SD_R only, and two games with a Low M_R only, for a total of 15 problematic games. In these evaluations, we considered relevance R to be low if the average relevance M_R fell below 80% of the maximum Likert score of 5. We assumed standard deviation SD_R to be high if it reached values over 1.25, which is higher than the rough estimate of standard deviation as one fourth of the range of possible scores (i.e., (5-1)/4=1).

The team discussion considered such questions as: What was so different about these 15 (problematic) games? Were the categories confusing? Were the games difficult to play? Why the noted discrepancy in relevance (as judged by different assistants) and/or the disagreement between assistants (i.e., low inter-rater agreement)?

We also looked into the comments provided by the assistants. Some comments described the games as too difficult or too confusing. One assistant stated: "I don't understand 500A [Executive Function/Inhibit] or I don't understand the game." In fact, four games were categorized by the psychologist as 500A, but the assistants did not see them as such. For example, they considered reaction time in these games as more relevant than inhibition of the reaction: "Speed of processing is the most relevant because the game is based on reaction time," one of the assistants commented. We concluded that the 500A subcategory "Inhibit" may have been particularly tricky for the assistants, who seemed to have downplayed the importance of inhibition of reaction in comparison to the speed of reaction. Another subcategory that proved to be tricky was 200A: Visual Attention/Selective Attention; while its definition specified the ability to attend to certain stimuli while ignoring others, many assistants felt that the gamer had to process all of the information in the game to be able to focus on certain features. This led some assistants to consider other subcategories in the place of Selective Attention. In our discussions and team meetings, we also considered other aspects that may have made the evaluation process problematic for some assistants, such as clarity of definitions in the cognitive matrix, as well as instructions for the assistants.

For example, the action game *Mars Lander* proved to be difficult for many of the assistants and caused some disagreements in categorization and relevance rankings. The goal of this game is to land a spaceship in a landing area. However, players must control the speed of the ship; if it lands too quickly, it will crash. To move the spaceship to the right, the gamer must hold the left arrow key; to move the ship to the left, the gamer must hold down the right arrow key; to move the spaceship upwards, the gamer must hold the down key. This game proved difficult to categorize for a few reasons: (1) the game itself was difficult, (2) the instructions for the game were difficult to understand (see Figure 4), and (3) the definition of "500A: Executive Function/Inhibit," which was identified as the primary category by the psychologist, was confusing to many of the assistants. These misunderstandings affected the choice of cognitive categories as well as the assistants' ranking of the relevance of "Inhibit" for this game.

Figure 4. Instructions for playing *Mars Lander* and a screenshot of spaceship landing.

Another problematic area concerned the multiple cognitive activities involved in some games. For example, *Mars Lander* was perceived by the assistants as requiring 500: Executive Function/Inhibit, 300: Visual Motor/Visual Motor Integration, 100: Visual Perception/Visual Tracking, and 100: Visual Perception/Spatial Judgment. Thus, it may have been difficult for assistants to choose the most relevant cognitive (sub)category. The assistants may also have perceived games differently from each other, contributing to their disparate categorization and relevance decisions. We decided to focus on the primary cognitive category/subcategory and to analyze and employ the identified secondary categories for auxiliary benefit when using the games for the purpose of cognitive training.

Second Round of Analysis

We then colour-coded the games according to the equivalent ranking measures reported in Table 3. These analyses and categorization were intended to supply each game with a rank that would provide a numeric representation of the relative ease with which the assistants could decide on the primary category and clarity of the rater classification (i.e., face validity) plus the accuracy and relevance (i.e., construct validity) of the primary cognitive category assigned to the game. The assistants' percentage of agreement with the (expert) psychologist's initial classification(s) of the games into cognitive categories was calculated before they were told the expert's classification. The percentage reported refers to the percentage of the 12 assistants who rated the primary cognitive category the same as the expert.

The percentage of agreement ranged from 25% (i.e., 3 of the 12 assistants) to 100% (i.e., 12 of the 12 assistants). The average perceived relevance ratings across all 12 assistants ranged between 5.0 (i.e., all thought the expert's classification was Very Relevant to the game) and 2.6 (i.e., on average, assistants perceived the expert's classification of the game was between Somewhat Relevant and Relevant). To establish the ranking of the games on a scale one-to-ten, the existing range of ratings was divided into equal-interval ranks in the following manner: Interval Width = (Range)/9 [i.e., (5.0 - 2.6)/9 = .27].

The average of the rankings was calculated from the equivalent ranks corresponding to each assistant's initial percentage agreement with the expert's categorization and that assistant's average perceived relevance. Using this average rank, we colour-coded the games in the following way (see Table 3): Blue (Very Relevant/Equivalent Rank = 1; 7 games), Green (Mostly Relevant/Equivalent Rank = 2, 3, 4, 5; 150 games), Amber (Relevant/Equivalent Rank = 6, 7, 8; 49 games), and Red (Somewhat Relevant/Equivalent Rank = 9, 10; 15 games).

Table 3

Ranking for the Rater's Agreement and Perceived Relevance and the Colour-coding of the Games.

Raters' % Agreement	Equivalent Rank*	Raters' Perceived Relevance (Interval Width =.27)		Equivalent Rank**	Colouring of the Games Based on the Average Rank
0	1	.0	Very Relevant	1	1 (blue)
92	2	4.7		2	2 (green)
83	3	4.5		3	3 (green)
75	4	4.2		4	4 (green)
			Mostly Relevant		
67	5	3.9		5	5 (green)
58	6	3.7		6	6 (amber)
50	7	3.4		7	7 (amber)
42	8	3.1		8	8 (amber)
			Relevant		
33	9	2.8		9	9 (red)
25	10	2.6	⇩	10	10 (red)
			Somewhat Relevant Not Relevant		

Note: Equivalent Rank* is based on the Raters' % Agreement; Equivalent Rank** is based on the Raters' Perceived Relevance.

For example, the action game, *Bricks Breaking II*, was categorized by the expert as 200A (Visual Attention/Selective Attention). However, only about 50% of the assistants selected 200A as its main cognitive category, which resulted in a low equivalent rank of 7 for this game. The assistants, on average, also found the expert's classification Mostly Relevant, which resulted in the equivalent rank of 5. These two ranks produced an average ranking of 6, which identified this game as Amber, meaning a game with a poor score or rank.

While it was the collective decision to remove Red games from the repository, it was expected that most of the Amber games would remain after some intervention, such as the expert reclassifying the game, the programmers redesigning the game, or the team simplifying/clarifying the operational definitions of the cognitive categories. Both the Green and Blue games showed very good (or perfect) inter-rater reliability and did not suggest further action.

Table 4 contains the overall means, standard deviations, and range of assistants' agreement, perceived relevance, and rankings of the games.

Table 4

Overall Means, Standard Deviations, and Range of Raters' Agreement, Perceived Relevance, and Ranking

N = 221 Games	*M*	*SD*	*Spread of Values*
Raters' % Agreement	74.88	14.68	25 – 100
Equivalent Rank*	4.00	1.76	1 – 10
Raters' Perceived Relevance	4.69	.33	2.6 – 5.0
Equivalent Rank**	2.32	1.28	1 – 10
Average Rank	3.16	1.36	1 – 9.5

Note: Equivalent Rank* is based on the Raters' % Agreement; Equivalent Rank** is based on the Raters' Perceived Relevance.

Based on our analysis, the overall categorization of the games according to their primary cognitive function reached a rounded 75% (*SD* = 15%) rater agreement. After the Red games were removed, the agreement was 77% (*SD* = 13%). When only the Blue and Green games remained, the agreement reached 82% (*SD* = 9%).

Discussion

As we looked into computer game play through the lens of activity theory, our literature review and analytic approach allowed us to zoom into the characteristics of subject, tool, object, and outcomes of the activity. Appendix B presents the activity triangle (see also Figure 1) with more detailed, although non-exhaustive aspects of the four components of gaming activity. Since we focused on the cognitive aspects of play, the diagram (see Appendix B) shows how the combined characteristics of a player, a computer, and a game may produce different outcomes, such as helping a player develop certain cognitive and motor skills, and experience physiological arousal.

Identifying the main differences between computer games in a rigorous, analytical way is necessary if gaming research is to move beyond the mostly arbitrarily determined genres used by the gaming industry and provided on the packaging. Some classifications are more obvious than others: games can be multi-player or single-player games, and they can target certain populations of players (e.g., according to age, gender, skill, ability, interest). So far, there have been attempts to classify single-player games according to their goal/outcome (e.g., as educational, therapeutic, or entertaining) or according to the expectations of the target players, such as:

- action games, requiring fast reaction time, eye–hand coordination, and reflexes;
- simulation games, requiring specific domain knowledge about the system;
- strategy games, involving planning, decision-making, and execution and adjustment of actions;
- adventure games, requiring the player to overcome a series of obstacles;
- role-playing games, allowing the player to identify with the protagonist; and
- puzzle games, involving logical reasoning (Van Eck & Hung, 2010).

Van Eck and Hung consider gaming as problem solving; they argue that while games are more than just a problem-solving exercise, it is difficult to imagine a game that does not incorporate problems to be solved. Their claim exemplifies the difficulties that research on the classification of computer games faces—difficulties that range from developing standards in clear and plain language that aid in describing and evaluating game categories and heuristics, to implementing these standards on games that may be very diverse and complex.

Although computer games, as categorized by their manufacturers, may fall into one of the six categories stated by Van Eck and Hung (2010), we cannot for the purpose of our research use such activity-based broad categorizations to identify the specific cognitive functions engaged by the player. For example, both *Brick Squasher* and *Mars Lander* were classified as action games, but each engaged different cognitive functions according to our classification: Visual Motor

(300A) and Executive Functioning (500A) respectively. Thus, we developed a classification method that was inspired by Livingston et al. (2010) critic-proofing games approach. Our method identified the four steps of developing distinct cognitive aspects in single-player simple computer games:

1. Development of a matrix by an expert. Developed by a psychologist, OTEP Inc.'s cognitive matrix is grounded in the cognition literature. It consists of 9 main cognitive categories (e.g., visual perception, auditory processing, executive function, social cognition) and 43 subcategories belonging to the various main categories (e.g., visual tracking, selective attention, auditory perception, semantic memory).
2. Implementation of coding by both expert(s) and non-experts. About 200 games in the OTEP Inc. repository were coded by research assistants, independent game raters, and the psychologist, with each game being assigned a cognitive primary category/subcategory and a secondary category/subcategory;
3. Evaluation of the relevance of the expert's categorization of the games from Not Relevant (1) to Very Relevant (5). The raters' agreement with the expert's classification (Strongly Agree being rank 1 and Least Agree being rank 10) and their perceived relevance of the expert's ranking of the games (Very Relevant being 1 and Not Relevant being 10) were analyzed. The average rankings for both relevance and agreement were used to determine the colour assigned to each game: Blue (1), Green (2–5), Amber (6–8), and Red (9–10). The seven games rated Blue showed not only extremely good agreement between the expert's and non-experts' cognitive category assignments but also very high ratings of relevance; these games appear to highly endorse that the cognitive function tapped by playing the game is "what's on the label."

Another 150 games were coded Green because of very good agreement and ratings of relevance; some of these games were assigned an additional cognitive category if at least one-third of the raters attributed that category to the particular game. This, along with a similar evaluation we conducted of the expert-identified secondary cognitive categories, suggested that a particular game might require a degree of this additional cognitive function to perform well, offering potential additional therapeutic benefit.

4. Refinement of the categorization. The games with controversial categorization (Amber or Red) were reviewed by the psychologist to either clarify the definitions of the categories or re-categorize the games. The reliability scores of the categorizations based on the cognitive matrix were determined. While 49 Amber games alerted the expert that alternative categorization might be prudent, 15 Red games were removed because their initial categorization raised too many questions or inconsistencies (see Table 5).

Table 5.

Performance of Cognitive Classifications across Computer Games Classified as Primarily Tapping this Cognitive Function.

Cognitive Classification	*N*	% Blue or Green	% Red
Semantic Memory	4	100%	0%
Spelling	8	100%	0%
Working Memory	19	100%	0%
Colour Perception	3	100%	0%
Visual Tracking	2	100%	0%
Mental Maths	11	100%	0%
Math Concepts	4	75%	0%
Reasoning	20	85%	0%
Matching Shapes	8	75%	0%
Problem Solving	36	78%	3%
Planning	24	71%	0%
Visual Motor Integration	16	56%	0%
Counting & Quantity	2	100%	0%
Visual Motor Speed	8	75%	13%

Spatial Perception	22	55%	5%
Selective Attention	17	41%	18%
Episodic Memory	2	50%	0%
Theory of Mind	1	0%	0%
Expressive Language	1	0%	0%
Math Numerosities	3	33%	67%
Music Perception	3	0%	67%
Inhibit	6	17%	67%
Organization	1	0%	100%

N = Number of computer games classified as this primary cognitive category.
% Blue or Green = Percentage of computer games with higher 'Average Rank' overall, which were colour-coded blue or green.
% Red = Percentage of computer games with lower 'Average Rank' overall, which were colour-coded red.

A clear pattern appears to emerge from the Table 5. Certain cognitive functions (e.g., Semantic Memory, Working Memory, and Colour Perception) were successfully attributed to computer games. This would appear to suggest that the operational definitions of these particular cognitive functions and these particular computer games were unambiguously clear to trained raters using the Cognitive Matrix for the purpose of classifying these games. At the other extreme, several cognitive classification categories did not perform so well (e.g., Math Numerosities, Music Perception, and Inhibit), either because these cognitive classification definitions are less clear in the Cognitive Matrix, games that appear to utilize these cognitive functions actually do not or are too ambiguous themselves, or a combination of both of these.

As the computer games analyzed in this study were not originally developed for the purpose of identifying the engagement of a particular cognitive function, we have much to learn regarding what attributes or components made about half of our classifications very successful. This may have at least in part to do with the ease of clearly defining a cognitive construct, the quality of writing of the item to make it accessible to the lay public, and the computer game itself which does not possess too many competing/ambiguous demands, poor instructions, or a combination of all of these.

If we are to design computer-based teaching, training, or rehabilitation programs, we would hope to reflect this quality and efficacy of the computer games designed or used for this purpose, and be able to have a sense of what cognitive function(s) the computer game primarily or secondarily exercises. For example, the middle of Table 5 contains the so-called 'executive functions,' Reasoning, Problem Solving, and Planning. Much has been written on these cognitive functions in attempt to understand them and their complex natures; indeed, even if there is actually a distinct nature to each different from the other, or rather if they are powered by general intellectual ability. Though it is beyond the scope of this paper to cover these constructs in depth, it may be said that each requires a useful mental framework or way of conceptualizing a problem, ability to learn from mistakes and experience, generation and consideration of options, foresight, and so forth. Given this level of complexity, it appears promising that a cognitive attribute could be so successfully assigned to a computer game.

Although we applied this classification method to each of the 221 games in our collection, we do not claim that players of other similar games will necessarily experience the same cognitive challenges/opportunities. Our experiment established that our simple single-player games to a certain degree do reliably match up to a certain type of cognitive challenge. So even though our method is not seamlessly transferrable to the categorization and evaluation of other games, we believe that it demonstrates an approach that one can use to categorize computer games using different (albeit not necessarily cognitive) taxonomies and colour-coding the games based on the level of achieved relevance. Therefore, our methodology draws from Rebetez and Betrancourt's (2007) call for empirical and reliable research on computer games, as well as it gains from the expertise of psychologists, which was suggested by Boyle, Connolly, and Hainey (2011). Other researchers can use this model to guide their decision-making processes in recommending existing games or developing new games. The correctness of our approach was validated through the high percentage of agreement between experts and non-experts as well as by the recursive manner in which both the definitions of the coding categories were refined and the games were colour-coded.

Conclusions

This paper presents an approach for identifying primary and secondary cognitive categories of simple, single-player computer games that are "cognitively responsible" (such that are intended to benefit the player's thinking processes). Reliable categorization of such computer games could be then used to interpret the player's gaming scores and possibly to identify areas of cognitive strength or weakness. This process could lead to recommendations on how to adjust the difficulty level of each game to strengthen cognitive functioning or suggest which games to play.

The method and results described in this paper are relevant to researchers and developers of computer games who can (1) use our cognitive matrix when developing, testing, or evaluating some of their games, and (2) build upon our categories to include more options that would cover multi-player games, for example. Evaluators of computer games can use our critic-proofing approach to assess the compliance of their games with standards they use. Our contribution is also relevant to the gaming industry that is looking for worthwhile and fun games that allow or encourage players to exercise their cognitive skills, such as thinking, decision making, processing speed, learning new skills and/or information.

Our approach helped us to identify problems that raters may have with particular cognitive categories, a difficulty to be expected. Indeed, the literature recognizes the complexity of cognitive training interventions and research because of multiple confounding factors (e.g., increased familiarity through test-retest conditions, rather than true improvements in cognition;

or difference in motivation of players to persevere on the game task, especially if the game is too easy or too difficult). Since in our ongoing research, we are trying to establish if there are gaming-related gains in a player's cognition, we need to identify "success factors" (Jolles & Crone, 2012, p. 3) for this to happen, at the same time taking into account that these factors will be largely context-dependent. Individual differences (see Mayer, 2003)—including such factors as age, ability, education, and previous experience with gaming and motivation; the types of games and their playability; and the length of the intervention—all need to be taken into account. So far we have tentatively identified cognitive processes involved in playing simple, single-player games—with very good initial results in terms of both reliability and face and construct validity—as well as detecting potential problems with this approach that may be at least partially remediated.

The next step in our research will be to correlate cognitive profiles of game players formed through more traditional means (e.g., psychological tests) with the profiles we developed based on their gaming performance. With this, we hope to check our first hypothesis, namely that the player's performance during playing cognitively responsible computer games may help identify his/her cognitive strengths and weaknesses. In this way, early and seamless (e.g., while playing fun games) identification of cognitive strengths and weaknesses in children should be possible. Using the player's profile (including the cognitive one) and his/her current interests, motivation, and skill, as well as the game genre, the game's cognitive dimensions, and other game and computer hardware features, we hope to suggest strategies that can increase player motivation and lead to positive outcomes (which will address our second and third hypotheses). Scaling down the difficulty level of game play when necessary or changing the genre to prevent mental and physical fatigue may result in the player's interest being maintained to achieve favourable effects. Prescribing specific games to children who possess a relative strength in the primary cognitive category of the game may support maintaining the child's interest and motivation, while the secondary cognitive category of the same game is prescribed for remedial purposes. Generally, having tools to create a cognitive profile of the user on the fly would allow for more personalized and dynamically changing online services that can adjust to a child's needs and ever-changing cognitive capabilities.

Nowadays, educators are aware that learning happens in and across different contexts, and they are increasingly looking for engaging activities that allow for transfer and cross-fertilization of knowledge. Such activities may be found in playing single- or multi-player games on the computer, gaming console, or online. Raising awareness of different aspects of computer games and potential contribution of such games to the cognitive development of children can inspire parents, educators, psychologists, and the computer gaming industry to collaborate, and may support inclusion of appropriate computer and video games as learning resources in schools and youth centres.

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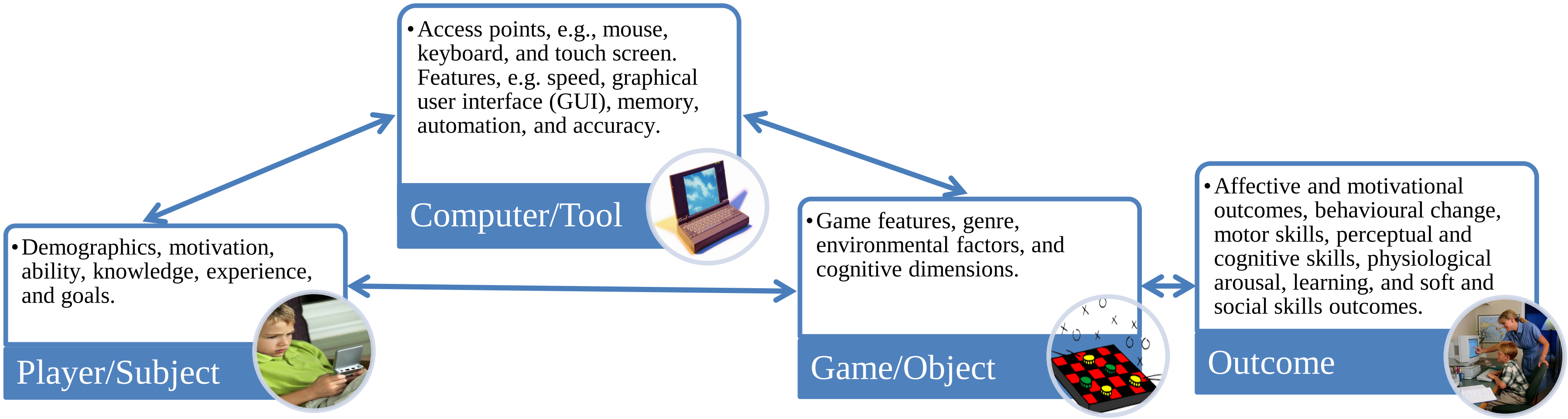
APPENDIX A: COGNITIVE MATRIX.

Cognitive Category	Cognitive Subcategory
100: Visual Perception The ability to perceive and interpret information in the visual field.	A) Matching Shapes—distinguishing identical shapes from similar or different shapes. A) Visual Tracking—following a moving target with the eyes (PsycNet, 2012). B) Movement Detection—detecting either an object moving relative to its surroundings or the surroundings moving relative to an object. C) Colour Perception—perceiving colour accurately. D) Spatial Judgement—understanding the arrangement of items in 2D or 3D space; manoeuvring around or towards such items (Cognifit, 2012).
200: Visual Attention The ability to focus on visual information.	B) Selective Attention—focusing on and responding to certain stimuli while ignoring other stimuli or information (Lefton, Brannon, Boyes, & Ogden, 2008; Matlin, 2009; PsycNet, 2012). A) Sustained Attention—focusing on or attending to one or multiple stimuli for an extended period of time (PsycNet, 2012). B) Divided Attention—simultaneously focusing on or attending to two or more stimuli that may use different perceptual modalities and being able to respond to each appropriately (Matlin, 2009; PsycNet, 2012).
300: Visual Motor The ability to coordinate physical actions with what is seen.	C) Visual Motor Integration—integrating both visual and motor capabilities in order to complete certain tasks. D) Visual Motor Speed of Processing—speed of processing information that requires both visual and motor capacities.
400: Auditory Processing The ability to detect and understand sounds.	A) Hearing and Auditory Discrimination—being aware of, detecting, or identifying sounds (PsycNet, 2012). B) Music Perception—identifying or simply perceiving differences in musical features (e.g., pitch, melody, rhythm, and harmony). C) Auditory Attention—paying attention to sound and focusing on certain acoustic signals.
500: Executive Function A cognitive system that controls and regulates cognitive activities.	A) Inhibit—actively suppressing some mental representations or withholding one's natural responses (Engelhardt, Nigg, Carr, & Ferreira, 2008; Wolfe, 2004). B) Working/Short-term Memory—memorizing information that is currently being (or recently has been) processed or used and which lasts a brief amount of time; coordinating current mental activities (Matlin, 2009; PsycNet, 2012).

	C) Problem Solving—determining strategies that will lead to a desired goal or completion of a current task when a solution is not obvious because of missing information (Lefton et al., 2008; Matlin, 2009; PsycNet, 2012). D) Flexibility—adjusting thoughts, actions, perspectives, or attention in response to changing tasks or environmental demands (Ionescu, 2012). E) Reasoning—thinking logically and coherently in order to solve problems, evaluate situations, or reach conclusions. F) Planning—working out steps to achieve a future goal. G) Organization—bringing order to objects/activities or material being learned. H) Behaviour Regulation—inhibiting or controlling one's behavioural responses according to a given situation (Kalpidou, 1998). I) Initiation—getting started on an activity.
600: Memory The ability to remember things.	A) Episodic Memory—memorizing information recently learnt; memorizing personal events or episodes that occurred in one's life, as well as information about the time at which these occurred (Lefton et al., 2008; Matlin, 2009). B) Semantic Memory—memorizing information learnt in the past; memorizing factual or general information about the world, including knowledge about word meanings and relations (Lefton et al., 2008; Matlin, 2009; PsycNet, 2012). C) Procedural Memory—memorizing how to do things involving perceptual, motor, and cognitive skills (Lefton et al., 2008; Matlin, 2009).
700: Acquired Cognition Abilities that develop over time and with practice.	A) Expressive Language—understanding and expressing oneself using language (a system of symbols, usually words, that conveys meaning and has rules for combining symbols to generate an infinite number of messages). B) Vocabulary—knowing word meanings. C) Grammar—knowing words and sentence structure, as well as rules for generating clear sentences and phrases (Lefton et al., 2008; Matlin, 2009; PsycNet, 2012; Yule, 2010). D) Reading Vocabulary—recognizing words in a language through reading. E) Phonics—reading and pronouncing words after hearing human speech (PsycNet, 2012). F) Reading Fluency—reading smoothly and quickly, while understanding the material being read. G) Reading Comprehension—understanding what is being read. H) Spelling—spelling words correctly.

	I) Math Numerosities—identifying the number of items in a set. J) Counting and Quantity—counting and identifying quantities of items. K) Mental Maths—doing calculations or solving math problems in one's head. L) Shapes—perceiving and detecting the form or shape of objects (PsycNet, 2012). M) Math Concepts—understanding principles "concerning numbers, their relations, and mathematical operations performed on them" (PsycNet, 2012). N) Writing—presenting contents in writing in a clear and well-structured way as well as being able to express oneself in a varied and personal manner appropriate to the audience and situation (Skolverket, 2012).
800: Social Cognition The ability to perceive and understand aspects of the social environment.	A) Understanding Emotion (Empathy)—recognizing others' emotions and conveying that understanding to someone, while showing compassion, sympathy, and concern (Baron, Branscombe, & Byrne, 2008). B) Theory of Mind—perceiving how the mind works; sensing one's mental state, thoughts, attitudes, beliefs, and/or emotions, as well as the mental state, etc. of others.

APPENDIX B: NON-EXHAUSTIVE DETAILS OF COMPUTER GAMING ACTIVITY COMPONENTS[3].



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[3] **Player.** Demographics may include age, education, culture, socio-economic status, opportunities (e.g., for access to computers and games previously), and health status. Motivation may be to become immersed in the story, compete with an opponent, develop skills, and learn. Motivation can be intrinsic or extrinsic, and includes pleasure, relaxation, leisure, and challenge. Other factors include knowledge, experience (e.g., prior development of sensory and motor skills through particular experiences/support), ability (e.g., IQ; see Mayer, 2003), and goals (e.g., to win over villain).
Computer. Digital tools differ in their features and in how the games are played on them.
Game. Game features include playability, story line and sequence of actions, scaffolding, feedback, learner control, and existence of an adversary. Genres include action, puzzle, adventure, simulation, logic, sports, memory, strategy, role-playing, and educational games. Environmental factors include multi-modality, online access, short response time, and immediate feedback. Cognitive dimensions are given in our Cognitive Matrix (see Appendix A).
Outcome. Affective and motivational outcomes include engagement, preference, and enjoyment; behavioural change includes stimulated reflection, recall, and argumentation; changes in motor skills include manual dexterity and multitasking-automaticity; alterations in perception and cognition include mental rotation ability, enumeration accuracy, recall, and hand-eye coordination, speed of processing, short-term memory, finding the right strategy, and analyzing choices; physiologically, players experience increased heart rate, blood pressure, and skin conductivity; other outcomes include learning and developing social skills (see Connolly et al., 2012).