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Title Page

BrainQuest: The use of motivational design theories to create a cognitive training game supporting hot executive function.

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Abstract

For children to yield greater mental performance abilities in real world settings, training approaches should offer practice in problems which have an affective component requiring social interactions, and be motivating over a sustained period. Current cognitive training games often overlook the important relationship between cognition and emotion, characterised by 'hot executive function', and correlated with fundamental academic and life outcomes. Here, we present robust qualitative evidence from a case study which documents the social relationships, motivation and engagement of a class of ten-year-old children who used an active smartphone cognitive training game called BrainQuest in their physical education lessons over a period of 5 weeks. Game design elements which are intended to move beyond simple gamification of cognitive tests are presented, along with a discussion of how these design elements worked in practice. The paper also presents and discusses the impact of the game upon the cognitive and emotional regulatory skills, characterised by executive function skills, based on the findings of this initial work. We conclude with recommendations for the designers of cognitive training games in the future and discussion of appropriate research methods for future gamification studies.

Keywords:

Gamification; motivational theory; game design; cognitive training games; executive functions

Highlights

- Cognitive training games gamify cognitive tests using extrinsic game design elements
- Creating engaging and emotive user experiences may improve training outcomes
- This paper presents a novel smartphone game to foster cognitive and regulatory skills
- An initial mixed-methods evaluation suggests the game can sustain engagement over time
- The game provides efficacious and continued cognitive and emotional regulatory challenges

1. Introduction

1.1 Overview

This paper explores the design and evaluation of a new game, called BrainQuest, for training 'executive functions' (EF), a series of cognitive and emotional regulatory skills which are required in nearly every facet of everyday life, particularly in novel circumstances (Diamond, 2013, 2012). In the paper we give an overview of the current short-comings in cognitive training game design practices and review the executive function construct, before describing the gamification approach to BrainQuest, the results of a 5-week initial evaluation of the game, and the implications of our findings for future cognitive training game design and gamification approaches. We seek to answer the following research questions, (RQ1) to what extent does the use of motivational game design theories affect the engagement value of a serious game for executive function? and (RQ2) what evidence is there to suggest an engagement-focused training game can challenge and improve executive function?

1.2 Cognitive Training Games & Gamification

Although 'cognitive training games' (CTGs) seek to improve player cognitive skills through computerized tools, they have so-far failed to provide evidence supporting their real-world effectiveness (Simons et al., 2016; Morra & Borella, 2015; Hambrick, 2014; Redick, 2013; Shipstead et al., 2012, 2010). This may be because their primary design method, the gamification of cognitive assessments (Melby-Lervåg et al., 2016; Mishra et al., 2016; Simons et al., 2016), may not always afford user experiences which remain inherently engaging over time (Seaborn and Fels, 2015), nor train the range of skills congruent with many real-world challenges of cognition (Green and Bavelier, 2012). However, by considering design practices advocated by motivational game design theories (Mishra et al., 2016; Morra & Borrella, 2015), there may be a way to improve on current gamification practices in cognitive training games.

Recently, there has been an explosion in 'brain training games' in which academic studies exploring the effects of cognitive training have evaluated commercial ventures seeking to enable improvement (and monetization) of players' cognitive skills through computerized tools (Simons et al., 2016). Examples of brain training games, also referred to as 'Cognitive Training Games' (CTGs), include Cogmed, Nintendo Brain Age, Lumosity, Peak, and Posit Science BrainHQ. They have recently gained serious marketing traction with $715 million annual sales in the digital brain health software recorded in 2013 and predicted to surge to $3.38 billion by 2020 (Simons et al., 2016; Worland, 2014).

Despite their commercial breakthrough, there is scepticism about the quality of the scientific evidence which underpins marketing claims: specifically, generalisation from in-game performance to real-world cognitive gains (Simons, 2016; Morra &[1] Borella, 2015; Hambrick, 2014; Redick, 2013; Shipstead et al., 2012, 2010). There are several methodological objections, e.g. the absence of an active control group, or unmatched comparison group (Mankin, 2016; Simons, 2016; Melby-Lervåg et al., 2016; Baniqued, 2014; Melby-Lervåg & Hulme, 2013; Redick, 2013; Shipstead et al., 2012), absence of adjustments for multiple measures (Makin, 2016; Redick, 2013), and lack of study power (Melby-lervåg, et al., 2016). While these issues are arguably easily rectifiable, others are more problematic on the grounds of game design (Mishra et al., 2016;).

Training games with a strong evidential base to improve cognitive abilities and emotional regulation would be beneficial for learners. Enhancing these abilities may yield many 'learning to learn' and 'classroom skills', such as organisation; time-management; concentration; reflection; goal setting, as well as improving social interactions with peers (Ponitz et al., 2008; Diamond, 2007; Meltzer, 2007;

[1] http://www.cogmed.com/, http://brainage.nintendo.com/, https://www.lumosity.com/, http://www.peak.net/, https://www.brainhq.com/

Saracho & Spodek, 2007; Brook & Boaz, 2005; Howse, et al., 2003; Blair, 2002). Such capacities may contribute to real-world improvements in both a learner's academic and personal lives (Diamond, 2012; Diamond et al., 2007). Nevertheless, many current designs seem far removed from the real world and have a rather narrow contextual relevance (Green and Bavelier, 2012). The prevailing CTG design approach is to gamify lab-based and individualistic cognitive assessments into a training task, by including visuals, scoring and reward systems (Simons, 2016). Often players show significant improvements on the gamified training tasks themselves or the specific cognitive assessments upon which they were created, but show neither improvement on other cognitive assessments of theoretically similar skills nor any real-world improvements (Simons, 2016; Shipstead et al., 2012).

Therefore, cognitive assessment gamification may not be the correct approach. In serious games research, gamification often seems to result in a superficial attempt to capture user interest that fails to sustain engagement over time (Habgood & Ainsworth 2011; Bruckman 1999). For CTGs, user engagement is fundamental to their success as continual practice of cognitive skills is vital to make improvements (Mishra et al., 2016; Morra & Borrella, 2015; Diamond, 2012). Furthermore, although cognitive assessments are somewhat able to isolate cognitive skills so they can be assessed, training skills in isolation is a misguided approach because we rarely use individual cognitive skills when performing real-world tasks (Mishra et al., 2016; Melby-Lervåg et al., 2016; Redick, 2013; Melby-Lervåg & Hulme, 2013).

The role of emotion must also be considered and authors, such as Metcalfe and Mischel (1999), have long proposed the impact emotion can have on human behaviour and cognition. In their exploration of executive function (EF), Zelazo and Carlson (2012) expand on this concept by defining 'cool' and 'hot' derivatives. Cool executive function is emotionally neutral and used in situations requiring a purely cognitive response, such as exercising motor control to regulate movement or decision making based purely upon logic (Zelazo & Carlson, 2012; Kerr & Zelazo, 2004). Meanwhile, hot executive function is elicited in contexts which are affective, involve emotion, motivation, or the consideration of social factors, and are no longer purely cognitive (Zelazo & Carlson, 2012; 2008; Kerr & Zelazo, 2004). The environment of CTGs are characteristic of the purely cognitive assessments which they gamify (Green & Seitz, 2015). For example, users participate in individual assessments of cognitive skills where many of the emotional influences listed appear absent. However, this is not representative of the real world where there are situations requiring both cool and hot EF, and where emotions may affect behaviour and where human may have to interact with each other (Zelazo & Carlson, 2012; De Luca & Leventer, 2008; Kerr & Zelazo, 2004). Thus, this may limit the ability of CTGs to prepare users for real world tests of cognition.

2. Background and Related Work

2.1 Serious Games & Gamification

Few studies have focused on designing cognitive training games that avoid the pitfalls of current gamification practices. Though it does not address every shortcoming of cognitive training games, such as the absence of emotionally affective skills like hot executive function, the Neuroracer cognitive training game (Anguera et al., 2013) was able to address the issue of player engagement. The Neuroracer team identified the importance of making games motivationally engaging to encourage repeated practice and, thereby, designed Neuroracer to resemble an entertainment video game in which the user controls a virtual car driving through a fantasy world using a console controller (Anguera et al., 2013). However, the game also presented a cognitive challenge. As the player controlled the car's speed and direction, they were intermittently presented with a series of signs which they had to respond to according to a predefined rule. The idea was that controlling the car while responding to signs required multitasking skills. Despite implementing CTG design decisions recommendations to increase user engagement (Mishra et al., 2016), Neuroracer's ability

to capture engagement was not evaluated. Therefore, understanding the value of engagement in CTGs requires urgent consideration.

It is difficult to balance serious goals and fun in the creation of serious games. As stated by Winn et al. (2008, p.3), *"Making a good game is hard. Making a good serious game is even harder. The reason it is so difficult is that rather than simply trying to optimize the entertainment aspect of the game or the so-called fun factor, one must also optimize to achieve a specific set of serious outcomes"*. Hence, the success of gamification utilized in serious video games suffers from the fact that the underlying serious activities or goals may not necessarily be fun for all end users. This can be particularly difficult when creating games for children (Read, 2015). By simply layering game-design content upon serious activities, the gaming element becomes *"a separate reward or sugar-coating"* for the user to derive engagement, rather than the core game mechanics (Habgood & Ainsworth, 2011, p.5).

CTGs typify this approach by gamifying laboratory tests of cognition (Green & Seitz, 2015) which are designed with the primary goal of capturing cognitive skill rather than providing an engaging user experience. For example, most cognitive tests are designed for periodic benchmarking (Rabbitt, 2004) rather than high frequency use which may benefit from motivational design. Consequently, the mechanics of cognitive assessments may be unlikely to easily translate into engaging gameplay, despite the best efforts of designers. Furthermore, these issues pertain to the serious games genre as whole, where even games possessing the efficacy to facilitate learning or the delivery of a serious message largely fail to generate enduring engaging gameplay experiences (Wouters et al., 2013), at least compared with traditional instruction. As there are no mechanical differences between entertainment and serious games, there is a strong rational to analyse the underlying serious game design processes – specifically, dominant gamification practices.

The process of creating 'fun' through gamification can also be challenging. Many games have common elements which are universal to many video games, board games, quizzes, or sports (Chorney, 2013; Rosas et al., 2003). It is often these elements which are utilized in gamification (Chorney, 2013). One criticism of many gamification approaches is the widespread narrow adoption of cheap extrinsic motivators, whereby the user is offered a reward in exchange for engaging in an activity (Richter et al., 2015; Habgood & Ainsworth, 2011). In games, extrinsic motivators are often presented as reward-based systems: points; leader-boards; trophies; badges; or prizes (Richter et al., 2015; Deterding et al., 2011)**.** When extrinsic motivators are the primary source of motivation involved in an activity, they can be a powerful source of short or even medium-term motivation (i.e. for encouraging someone to initially begin an activity), especially for personality-types who enjoy competition (Mellecker et al. 2013; Zagal et al., 2005; Locke & Latham, 2002). However, long-term efficacy of purely extrinsic motivators appears less successful (Richter et al., 2015; Butler, 2013; Hecker, 2010; Nicholls, 1984) and they often fail to preserve motivation over time (Richter et al., 2015). Nevertheless, it has been argued that extrinsic motivators can be more useful when used in partnership with intrinsic motivators, whereby, one is motivated by their enjoyment of the activity rather than to simply receive a reward alone (Rigby & Ryan, 2011; Ryan et al. 2006; Ryan & Deci, 2000; Deci & Ryan, 1985a; 1985b). Thus, given the positive impact of sustained engagement upon learning (Read, 2015), it is important that serious game designers learn know the difference and the longevity of these different types of motivation.

2.2 Motivational Game Design Theory

Game designers focused on creating sustainable engaging user experiences believe that intrinsic motivation should take precedence over extrinsic motivation (Ng, 2012; Teixeira, 2012; Peng, 2012; Rigby & Ryan, 2011; Silva, 2010). To be intrinsically motivated, the motivational stimulus comes from within the person and may be affected by their personality or values (Rigby & Ryan, 2011; Ryan et al.

2006; Ryan & Deci, 2000; Deci & Ryan, 1985a; 1985b). However, there are some common intrinsically motivating properties, identified in the works of Ryan and Deci on 'Self-Determination Theory' and 'Cognitive Evaluation Theory' (Richter et al., 2015; Ryan et al. 2006; Ryan & Deci, 2000; Deci & Ryan, 1985a; 1985b), and more recently applied to video games through Rigby and Ryan's 'Player Experience of Needs and Satisfactions' (PENS) model (Rigby & Ryan, 2011). According to these models, intrinsic motivation can be sustained by satisfying three key human needs: *competence*, *autonomy*, and *relatedness*. These three needs were key influences on this work in this paper and are central to the design and evaluation of the BrainQuest game, later described.

Competence is the need for challenge and feelings of self-efficacy (Ryan et al., 2006). We must routinely test our skills by attempting ever greater and more complex challenges (Schell, 2014; Rigby & Ryan, 2011). While many successful video games can facilitate the improvement of skills, albeit often contextually specific skills, they can support a user's thirst for challenge through variable difficulty (Schell, 2014; Rigby & Ryan, 2011; Costikyan, 2005; Lepper & Malone, 1987; Malone & Lepper, 1987). The level of challenge experienced should be at an optimal level which is perceived difficult but is achievable (Schell, 2014; Rigby & Ryan, 2011; Csikszentmihalyi, 1990; Lepper & Malone, 1987; Malone & Lepper, 1987). Regardless of whether the user succeeds or fails, feelings of competency may still be fostered through positive and meaningful feedback (Schell, 2014; Rigby & Ryan, 2011).

Autonomy is the need for control or willingness of choice during an activity (Ryan et al., 2006). It is the freedom to make choices based on one's volition, to exercise control, to pursue interests or values, and the empowerment of self-expression (Rigby & Ryan, 2011; Hunicke et al., 2004; Costikyan, 2005; Deci & Ryan, 1985a; 1985b). Nevertheless, creating opportunities for choice allows us to exert control more frequently (Rigby & Ryan, 2011; Lepper & Malone, 1987; Malone & Lepper, 1987). Games can satisfy the need for autonomy by empowering players to make choices over strategies or solutions to challenges or between different activities (Rigby & Ryan, 2011). Autonomy can also be exercised by control over one's identity, such through playing style and decision making (Rigby & Ryan, 2011) – e.g. strategies employed, goals undertaken, or choices made.

Relatedness is characterised by the way *"humans inherently seek to be connected with others and feel that they are interacting in meaningful ways,"* (Rigby & Ryan, 2011, p. 65-69). In games relatedness is usually satisfied by experiencing companionship which is supported both cognitively and empathically through the pursuit of common goals, providing opportunities to receive attention, and seeing the impact of one's actions upon other players (Rigby & Ryan, 2011). Relatedness in video games can help positively impact or sponsor new relationships by giving players things to do together and provide individuals with reasons to communicate (Rigby & Ryan, 2011; Costikyan, 2005; Hunicke et al., 2004; Lepper & Malone, 1987). Relatedness may be felt most strongly through cooperative play which can extend feelings of competence in situations where it is possible to achieve with the help of another, what would otherwise be impossible alone (Rigby & Ryan, 2011). However, it may also be present in 'constructive competition', whereby challenging oneself against others creates an opportunity to test and increase one's skills, to learn from more gifted opponents or to exhibit one's talents – each, in turn, increasing competence (Lepper & Malone, 1987; Malone & Lepper, 1987). Moreover, as each player is contributing to the feelings of competence of the other, it can support *"meaningful and supportive connections that are the hallmark of relatedness" (*Rigby & Ryan, 2011, p.78-79). Both competition and cooperation can promote positive social interactions (Bekker et al., 2010). Note, relatedness is often absent from cognitive training games (beyond extrinsic leader-board systems) which gamify cognitive assessments, as these tests attempt to benchmark the cognition of individuals.

The themes described by the pillars of competence, autonomy, and relatedness also complement, separate work exploring motivational game design, such as the work of Lepper and Malone (1987), Schell (2014), and Le Blanc's taxonomy (Hunicke et al., 2014). For example, echoing provisions for

competence, Lepper and Malone (1987) advocate the inclusion of variable difficulty levels to support the self-esteem of players with different abilities, as well as providing informative and constructive performance feedback. Moreover, autonomy also features, as Le Blanc's taxonomy further supports the power of self-expression (Hunicke et al., 2014) and that game outcomes should depend on the player's responses (Lepper & Malone, 1987; Malone & Lepper, 1987). With regards to relatedness, these models highlight the importance of interpersonal factors and encouraging intrinsic cooperation and competition, where players play together and may affect the outcomes of each other, thereby, creating further feelings of control over events (Lepper & Malone, 1987; Malone & Lepper, 1987).

These works also highlight some additional sources of intrinsic motivation, such as developing strong senses of fantasy and narratives (Schell, 2014, Hunicke et al., 2014, Lepper & Malone, 1987; Malone & Lepper, 1987). Fantasies should be intrinsic to the gameplay rather than used as a reward (e.g. fantasy animation should form part the gameplay and be integrated with serious content, rather than being presented separately as a reward, following serious content (Lepper & Malone, 1987; Malone & Lepper, 1987). Furthermore, fantasy and narratives should attempt to draw emotion from the user to immerse them (Lepper & Malone, 1987; Malone & Lepper, 1987). Sensory curiosity is another means of enhancing fantasy (Lepper & Malone, 1987; Malone & Lepper, 1987), through rich aesthetics, graphics and sounds (Hunicke et al., 2014), and discoverable content (Schell, 2014). Nevertheless, as stated by Schell (2014), sensory pleasure *"cannot make a bad game into a good one, but it can often make a good game into a better one"*, and this highlights why gamification must go beyond token inclusions of art work.

Although game designers are often polarised into partisan pro-intrinsic versus pro-extrinsic groups, the more balanced view, held by neutral commentators like Schell (2014), is that both types of motivation have their place in games. Moreover, they may be especially useful in serious games, with extrinsic motivators being used as a short-term 'hook' to encourage users to initially undertake a new activity, coupled with intrinsic motivators to encourage long-term repeated play. Meanwhile, some authors have highlighted the blurred lines in the intrinsic/extrinsic dichotomy, stating that extrinsic motivators may, in time, produce intrinsic motivation (Weiser et al., 2015; Kim et al., 2015; Schell, 2014). For example, leader-boards may facilitate rewarding and meaningful social interactions between peers (Weiser et al., 2015; Kim et al., 2015; Zagal et al., 2005; Locke & Latham, 2002). Such occurrences are congruent with Self-Determination Theory, where human motivation is presented along a continuum and where movement along the continuum is achievable (Ryan & Deci, 2000; Deci & Ryan, 1985a; 1985b). It seems clear, therefore, that the design of effective CTGs require designing for both intrinsic and extrinsic motivation, to engage users quickly but also sustainably over time.

2.3 Executive Function: Testing and Training Methodologies

This paper concerns the design of a game which aims to develop executive function (EF), a key series of interrelated cognitive and self-regulatory skills which are required in nearly every facet of everyday life and particularly in novel circumstances (Diamond, 2015; Diamond, 2013; Anderson et al., 2010; Rabbitt, 2004). EF skills begin developing from birth and continue to grow well into adulthood but are most crucial for children as they are associated with academic and life success as well as mental and physical health (Diamond, 2013).

EF is not a unitary concept and different skills may be used in different concentrations and combinations, depending upon the situation, making it hard to quantify or train abilities (Diamond, 2013; Rabbitt, 2004; Hughes & Graham, 2002; Burgess, 1997). However, EF ability can be measured through specialized cognitive testing batteries, in which a series of cognitive assessments test different combinations of the same EF skills. One well known assessment, pertinent to the work in this paper, is the BADS-C EF battery, which is targeted towards children and adolescents (Emslie, 2003).

As well as being able to assess EF ability levels, there is now evidence that these skills can be trained through targeted interventions using a diverse range of approaches, such as computer games, physical activity, and social play (Diamond, 2012; Diamond & Lee, 2011). In a review and synthesis of EF interventions, Diamond (2012) recommends that future EF training interventions, seek to directly train EF skills through cognitively challenging exercises but also support these routes indirectly through activities associated with EF ability (Diamond, 2012). These are activities which may: require physical activity (PA), given the positive effects of PA on cognition; involve social activity, as this builds emotional regulatory skills (an aspect of EF); and both facilitate feelings of competence and "fun", which can support EF performance but also ensure individuals sustain their training over time (Diamond, 2012). These pathways to enhancing executive functions overlap with the principals of game design described above.

3. BrainQuest System

3.1 Overview

BrainQuest is the active smartphone cognitive training game which is described and evaluated in this paper. The game seeks to challenge and improve executive function (EF) skills using a variety of complementary pathways used in previously successful training interventions and outlined by the work of Diamond (2012).

The game is targeted towards children aged between 10 and 13 years, who are at a crucial point of their EF development. For example, research suggests that children within the age range may be experiencing changes to various EFs, such as selective attention, set shifting, response inhibition and impulsive responding (Klimkeit et am., 2004), improvements in strategic planning and fluency (Luciana & Nelson, 2002; Korkman et al, 2001). There are also changes in hot EF, such as regulating emotions as children begin to understand social rules (De Luca, 2008; Baron-Cohen et al, 1999). 'Inhibitory control' (a core executive function which concerns the regulation of attentional, emotional, and motor control) is a "disproportionally difficult" task for children (Diamond, 2013, p. 141).

The plot of BrainQuest is about saving and stealing animals in a 'cattle rustling' scenario from the Wild West. Users assume one of 3 roles as they play the game together in an outdoor play space. The main role is designed to most exhaustively challenge EF, while the additional roles promote physical and social activity, as well as providing a dynamic and strategic problem for the user playing as a hero. Game activities have similar dynamics to playground games, involving the collection of tangible objects, stealing objects from opponents, and chasing opponents. The physical and digital worlds are bridged by using near-field communication (NFC) technology, which allows users to interact with real world items using their smartphones.

BrainQuest's 'task ordering rules' and 'task structure' closely resemble the rules and structure of an executive function assessment, called the Modified Six Elements (6E) - a test of planning, task scheduling, cognitive flexibility and performance monitoring which requires both attention and use of WM (Emslie et al., 2003). However, the game design first prioritised engaging user experiences before later integrating serious content, rather than gamifying as a layer on top of a cognitive test. User engagement is, therefore, at the core foundation of the BrainQuest's design and synthesizes motivational game design theories with user-centred design processes.

3.2 Current System

3.2.1 NFC Technology

BrainQuest packaged as an app for Android smartphone devices and employs an NFC-based interface. NFC or near field communication is a wireless connectivity technology facilitating short-

range communication between electronic devices or between an electronic device and scannable tags. In BrainQuest the technology is utilized using inbuilt smartphone NFC communication modules to communicate with scan-able NFC stickers attached to game objects (Figure 1). Thus, characteristic of mixed reality, the technology allows the user to integrate elements of real and virtual worlds – coupling objective performance measurement, historical data tracking, tailored challenge, engaging game fantasy, goal-setting, and meaningful feedback with PA and social interaction akin to real-world or playground games.

A video of the current system can be viewed in Gray (2015).



Figure 1. BrainQuest NFC Interface (Gray, 2017)

3.2.2 Player Roles and Play Space

Users in BrainQuest play in groups of 3 in the following roles: 'hero', 'cow rustler', and 'sheep rustler'. The hero must perform 3 different types of task, each of which has 2 subtypes – one involving cows, the other involving sheep. The task types undertaken by the hero are summarised in Table 1, and their representation on the BrainQuest user interface can be seen in Figure 2.

Hero Task	**Subtask**	**Description**
1. Return Animal Task	1. Return Sheep	Collect animals and return them to designated 'hero' animal pens. There are two different types of return task: one for returning sheep, one for returning cows.
	2. Return Cow	
2. Stop Rustler Task	3. Stop Sheep Rustler	Chase and catch the rustlers as they attempt to steal the hero's animals and take them to their 'rustler' pens. There are two different types of chase and catch task: one for sheep rustlers, one for cow rustlers.
	4. Stop Cow Rustler	
3. Save Animal Task	5. Save Sheep	Save animals who have been captured inside rustler pens. There are two different types of save task: one for saving sheep, one for saving cows.
	6. Save Cow	

Table 1. BrainQuest Hero Tasks

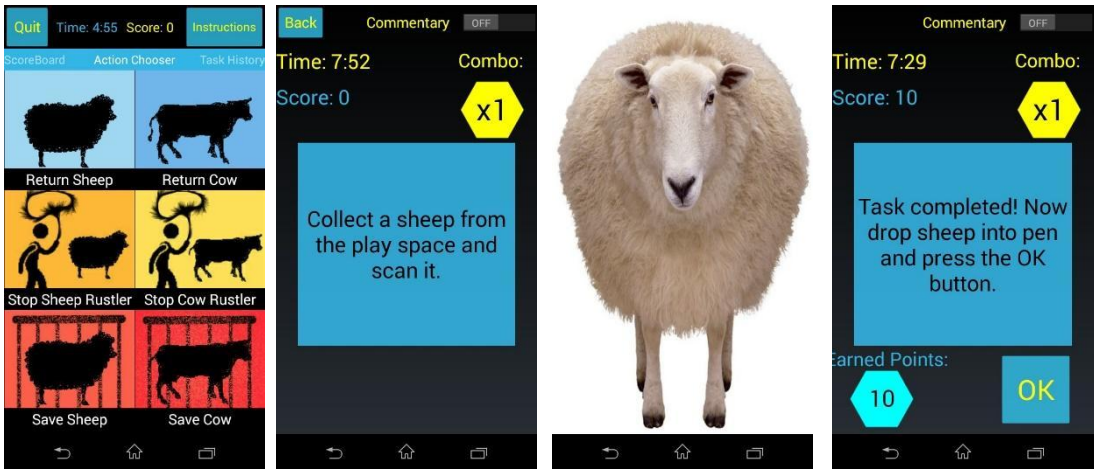


Figure 2. BrainQuest Hero User Interface (Gray, 2017)

Meanwhile, the rustlers are dedicated solely to stealing animals from hero animal pens - cow rustler steals cow, sheep rustler steals sheep. To do this they must perform shuttle runs around the perimeter of the play space, stealing hero animal from their pens one at a time. Following each 5-minute game, the 3 users switch roles.

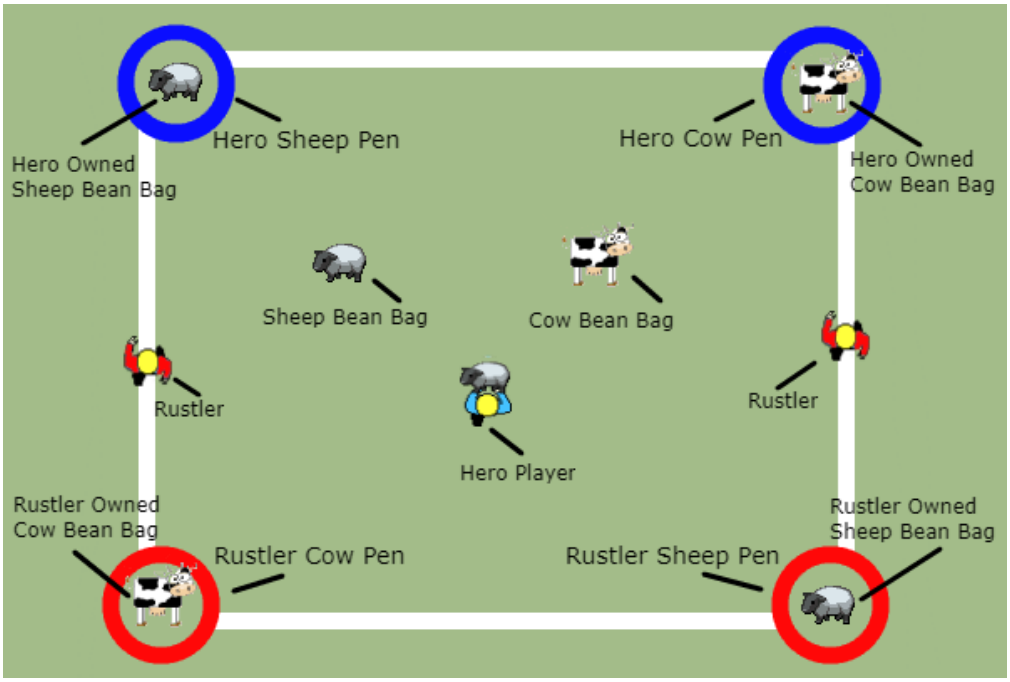


Figure 3. BrainQuest Play Space (Gray, 2017)



Figure 4. BrainQuest Play Space – Mock-up Diagram (Gray, 2017)

The play space (Figure 3, Figure 4) is an area of approximately 15 square metres consisting of the elements in Table 2.

Play Space Element	**Description**
Hero Sheep Pen	One blue hula hoop is the 'hero sheep pen'. The hero returns sheep bean bags from the middle of the play space to this pen one at a time. The hero may also capture sheep from rustlers and return it to this pen. Meanwhile, rustlers visit the pen to steal hero owned sheep bean bags.
Hero Cow Pen	The other blue hula hoop is the 'hero cow pen'. The hero returns cow bean bags from the middle of the play space to this pen one at a time. The hero may also capture cow bean bags from rustlers and return it to this pen.
Rustler Sheep Pen	One red hula hoop is the 'rustler sheep pen'. The rustlers use this pen to store sheep bean bags stolen from the hero sheep pen. The hero may visit the rustler sheep pen to rescue sheep bean bags.
Rustler Cow Pen	The other red hula hoop is the 'rustler sheep pen'. The rustlers use this pen to store sheep bean bags stolen from the hero sheep pen. The hero may visit the rustler sheep pen to rescue sheep bean bags.
Sheep Bean Bag	Multiple (6+ sheep) sheep bean bags are scattered around the play space. Each sheep has an NFC sticker on it which can be scanned by a player's smartphone.
Cow Bean Bag	Multiple (6+ cows) cow bean bags are scattered around the play space. Each sheep has an NFC sticker on it which can be scanned by a player's smartphone.
Hero Owned Bean Bag	Hero owned sheep and cow bean bags reside in the hero pens, having been previously collected from the play space or rescued from a rustler pen.

Rustler Owned Bean Bag	Rustler owned sheep and cow bean bags reside in the rustler pens, having been previously stolen from hero pens.
Pen Signs	Every hero and rustler pen has a sign on the outside which corresponds to visual stimuli presented on the BrainQuest interface, to guide the player to the corresponding physical location. To access the contents of a pen (to 'unlock') the pen, the player must scan the pen NFC tag using their smartphone.

Table 2. BrainQuest Play Space Setup

3.2.3 Rules and Scoring

The hero must perform their role while holding in mind and attempting to follow a set of task ordering rules which govern the number of points awarded for each successful task and present the challenge to EF skills that are translated from the 6E test. Note, a comparison of the 6E and BrainQuest rules can be found in Section 3.3.4. Hero Rules are shown in Table 3.

Hero Task Ordering Rule	**Example**
Rule 1: For each task choice, the hero must change task type.	If a hero player completes a 'Save Sheep' subtask, they must not repeat another task of the 'Save Animal' type for their next choice – i.e. not a Save Sheep, nor a Save Cow. Instead, they must undertake a subtask of the type 'Stop Rustler' or 'Return Animal'.
Rule 2: Within the 5-minute time limit, the hero must make sure that they have attempted all 6 subtasks while following Rule 1.	The hero player must have completed at least one instance of Return Sheep, Return Cow, Stop Sheep Rustler, Stop Cow Rustler, Save Sheep, and Save Cow within the time limit.

Table 3. BrainQuest Hero Task Ordering Rules

The scoring system awards the hero player 10 points multiplied by a combo bonus per successfully completed task. For every completed task that follows task ordering rule 1, the combo bonus is incremented by 1 until the user breaks the rule. E.g. the points awarded for completing one correct task in a row is 10 points (combo = 1), points awarded for completing 2 correct tasks in a row is 20 (combo = 2), points awarded for 10 correct tasks in a row is 100 (combo = 10). At this point, the combo bonus is reset to its initial value of 1. Furthermore, 100 overall bonus points are awarded for accurately following task ordering Rules 1 and 2.

The rustler rule is simple: they must earn as many points as possible within the time limit. Rustlers are rewarded 20 points for every shuttle run completed with an additional 10 points for successfully stealing an animal.

3.3 Creating an Engaging User Experience

3.3.1 Iterative User-Centred Design Process

User-centred design is a useful method for creating games which appeal to the interests and subsequently generate engaging content for end-users (Druin, 2002; Garrett, 2002). This is critical when taking a self-determination theory approach, as people are only intrinsically motivated for activities which are aligned with their own intrinsic interests (Ryan and Deci, 2000). Hence, the completed BrainQuest system, described in the previous section, was developed iteratively over a period of 18 months, in participation with Primary 7 classes (children aged 11-13 years) at a Scottish Primary school. There are multiple roles in which end-users can play in user-centred design, at various degrees of involvement but the research team decided that the role of 'informants' would be most suitable – where users contribute intermittently to technology design and evaluation at regular intervals (Druin, 2002).

BrainQuest's user-centred design process began with a detailed design workshop, involving a class of 25 Primary 7 pupils (aged 11-12 years), with the aim of generating game content (fantasies, themes, activities) ideas as well as to produce general feedback regarding previously experienced successful/unsuccessful game designs, and finally, establish some end-user requirements. The content generated by users provided concrete details regarding user interests, as well as validating certain recommendations proposed by the motivational theories. Insights included: the popularity of including a fantasy which featured farm-yard animals and a battle between good and evil/criminal forces – this spawned the animal rustling fantasy in BrainQuest; activities which included chase/catch dynamics, item collection, saving items from an adversary; support for different ability levels – validating the need for competence; facilitating both cooperative and competitive conditions – validating relatedness; and the inclusion of a leader-board function – validating the inclusion of extrinsic motivators.

Following the design workshop, the game was prototyped, before returning to a subset of the users to evaluate the implemented design and provide additional insights. Following each evaluation, aspects of BrainQuest's current design were refined and additional areas of functionality generated. This process was repeated for four iterations. A more detailed account of the user-centred design process and the evaluation sessions involved in the creation of BrainQuest can be found in Gray (2017).

3.3.2 Implementing Motivational Game Design Theory

The key pillars of Ryan and Deci's Cognitive Evaluation Theory (Rigby and Ryan, 2011; Deci and Ryan, 1985a), the work of Lepper and Malone (Lepper and Malone, 1987), and the contributions from the user-centred design process, all influenced BrainQuest's design. The game is founded upon intrinsically motivating design principles of fantasy, competence, relatedness, and the mechanics of popular playground games, and these were the focus of early game iterations. However, in later iterations, extrinsic motivators like leaderboards and trophy reward systems were included to complement the existing design.

Fantasy is a key aspect of the game, designed to immerse the users and appeal to their interests, and encouraged by both Lepper and Malone (Lepper and Malone, 1987) and Le Blanc's taxonomy (Schell, 2014; Hunicke et al., 2004). The chosen animal rustling theme has connotations of the Old West (Figure 5), which is enhanced by: (1) the graphics, sounds, and music which appear as a user scans one of the NFC-equipped objects to; (2) the tangible NFC-equipped objects themselves, in the form of beanbag cows and sheep; (3) the language used within the game – e.g. the "rustlers", "herding animals", "animal pen"; (4) the fact the game involves running around and chasing adversaries in the real world.

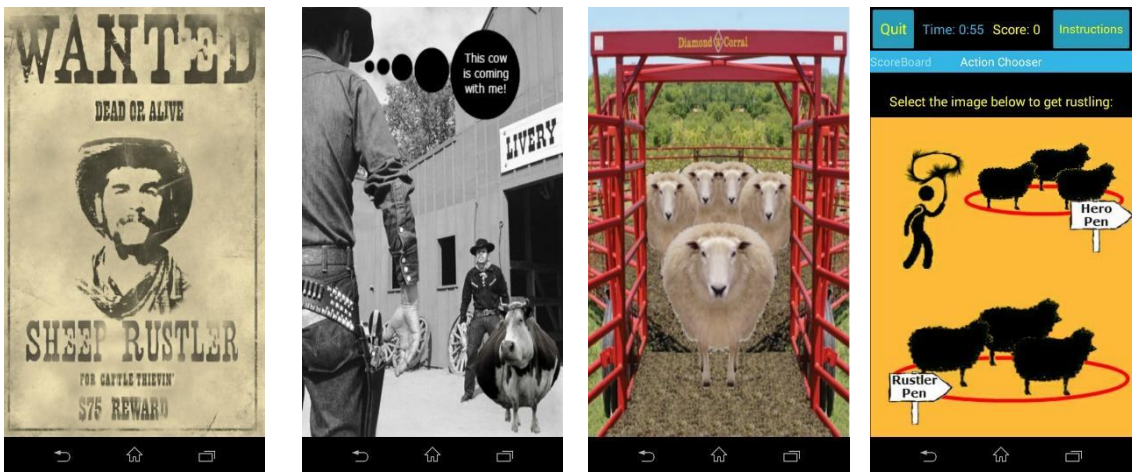


Figure 5. BrainQuest Fantasy Enhance Examples (Gray, 2017)

Competence is fostered by incremental challenge increases in response to user progress, the inclusion of multiple tools to support the user, performance feedback, the leader-board and trophy systems. There is a variable difficulty level system with 4 levels (Table 4) – Rookie, Professional, World Class, Legendary, each including different support tools (Figure 6) which are incrementally removed as the level increases. Users only move up when they have exhibited an ability to follow task ordering rules correctly and the variable difficulty forces users to reformulate their strategies at every incremental level increase. Furthermore, users of different abilities can play together with the interface adding personal layers of challenge without changing the group dynamic and preserving user feelings of confident. With the interface changes and additional human rustler variables, no two games should will be identical.

Rookie Difficulty (Level 1) Tools:	**Professional Difficulty (Level 2) Tools:**	**World Class Difficulty (Level 3) Tools:**	**Legendary Difficulty (Level 4) Tools:**
Task Choice Support Tool (EF Support)	Task History Stack (EF Support)	Task History Feedback	Task Randomizer (EF Aggravator)
Task History Stack (EF Support)	Task History Feedback	Written Instruction	Task History Feedback
Task History Feedback	Written Instruction	Audio Commentary	Written Instruction
Written Instruction	Audio Commentary		Audio Commentary
Audio Commentary			

Table 4. BrainQuest Difficulty Levels & Support Tools

The 'Task Choice Support Tool' supports following the task ordering rules by shading out the most recently completed task type, therefore, suggesting suitable tasks to choose. It helps to prevent players from breaking rule 1 (do not undertake the same task type in succession) but players must still hold rule 2 in memory to implement each of the 6 task types at least once. Together with the 'Task History Stack', the tool is designed to assist the user in learning how to strategize, plan, and utilize feedback during the activity.

The 'Task History Stack' allows players to view ordered lists of completed tasks, with previous tasks which conformed to task ordering rules written in green coloured font and tasks which broke the rules written in red. Although the stack does not explicitly suggest task choices, it reduces the amount of information required in working memory maintaining a list of previously completed tasks which players can use to inform new task choices. The stack is also present in the end of the game so players may view a record of their task choices and reflect on their performance.

Unlike the previous tools which attempted to reduce cognitive load and support working memory, the 'Task Randomizer' seeks instead to make decision-making harder for the user. This breaks the golden HCI rule of design consistency (Mandel, 1997), yet is necessary to challenge player cognition and is only used at the highest game difficulty level. The randomizer mixes up the order of the choice thumbnails on the Hero Task Selection screen following completion of a task. Therefore, it interferes with any expected mental representations of the interface (held in working memory) and encourages the user to think carefully before choosing their next task. Thus, it was proposed to require a degree of additional mental manipulation and attention, exercising working memory and inhibitory control towards a pre-potent (automatic and routine) response.

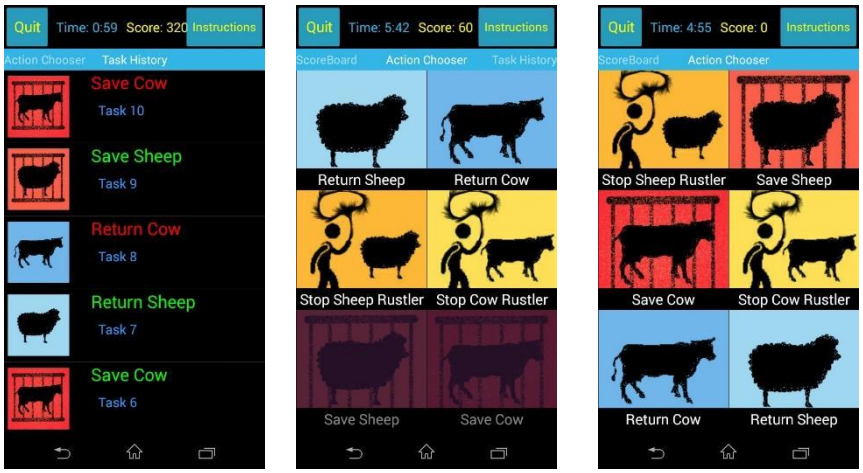


Figure 6. Task History, Task Shader, Task Randomizer Tools (Gray, 2017)

BrainQuest also makes use of some limited feedback systems to help players. There are on-screen written instructions and audio commentary to help teach users how to learn the procedures involved in each game task, and imagery which corresponds with the tangible real-world objects. Immediate feedback is given by the smartphone graphics and sounds associated with specific scenarios which reinforces the meaning of user actions while using the NFC scanning technology. Extrinsic motivators – a trophy system, a leader-board, and historical score centre of user statistics, were introduced to complement intrinsic design decisions (Figure 7). Though these are common gamification techniques, like the serious content, they were integrated late in the design process and only after the engaging game activities had been developed. It was hoped, these features could be used as an initial extrinsic motivational hook which could, over time, become intrinsic motivators, such as possible goals for users to achieve or encourage social interaction.

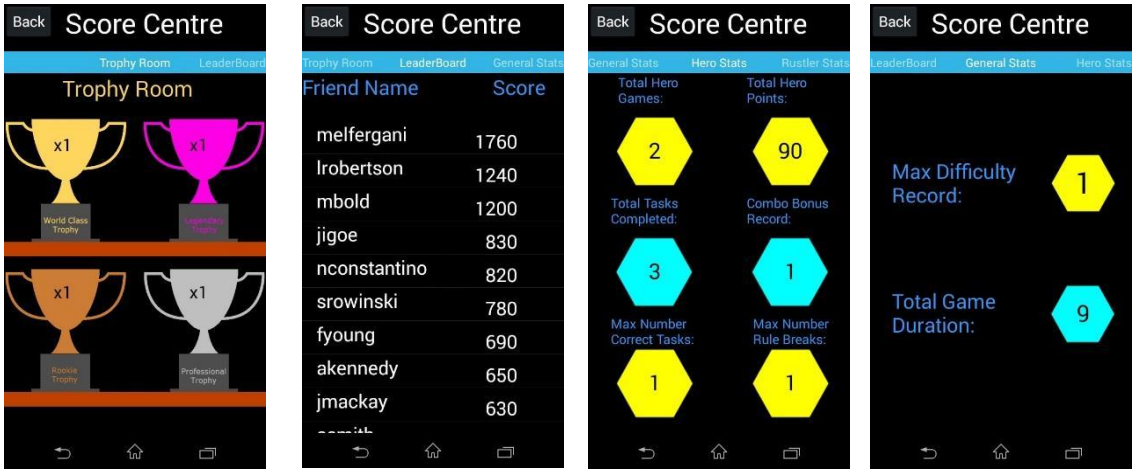


Figure 7. BrainQuest Trophies, Leaderboard, Historical Records (Gray, 2017)

Relatedness is an important aspect of the design which rarely features in existing CGTs, but is promoted in BrainQuest through the social dynamic of the heroes and rustlers. Children play together in groups of 3 and must interact face-to-face rather than indirectly through a digital medium. This requires the use of social skills and creates opportunities for undertaking a shared activity with friends or forming new relationships with others. Hero-rustler interactions may evoke emotion from enjoyment, comradery of engaging in a shared activity or feelings of competitiveness – there is a broad spectrum of possible emotional outcomes. There are opportunities for collaboration as well between rustlers, who may cooperate to challenge the hero. Between games, using the historical data, leader-boards, and trophies, there are opportunities for users to socialize by comparing achievements and sharing stories, which may spawn positive social interactions with others which encourage repeated use.

Autonomy is granted by allowing users freedom and control over their choices and actions (Ryan et al., 2006). Compared to other cognitive training games where gameplay is constrained within the confines of the underlying cognitive task upon a digital interface, BrainQuest allows the user physical control over a much larger proportion of the game environment – primarily the real-world arena in which the game is played. Users have the freedom of self-expression over how they wish to portray the different fantasy roles involved in the game, they can involve themselves in the leaderboard or trophy systems (or not), and decide whether they wish to cooperate or compete with other players. Hence, every game played can be unique.

Furthermore, despite the later integration of the 6E task ordering rules, users are not coerced into following the rules, and instead they receive a points bonus for doing so. Thus, it is hoped that the mixture of different activities and motivators could yield opportunities for users to define their own game goals – like Bekker et al. (2010). Despite this, autonomy in BrainQuest is an area to be further improved in future iterations.

Playground game mechanics and themes have been modelled to great effect in previous serious games as a vehicle for providing motivating and exerting gameplay experiences (Misund, 2009; Jegers, 2007; Ratel, 2004). Children's playground play is largely self-directed and can appears congruent with many intrinsically motivational elements. For example, games which are played by different social groups or between social groups may have positive implications for feelings of relatedness by providing regular opportunities to develop competencies in physical and social skills

(Van Delden et al., 2014). These games also frequently have a strong fantasy component, and involve chasing, catching, and seeking mechanics (Blatchford et al., 2003). Hence, during BrainQuest's user-centred design workshops, the scope of design ideas and evaluation was not limited to purely digital games, and the suggestions from many children reflected the mechanics of many popular playground games like 'Tig/Tag' and 'Cops and Robbers'. Based on the end-user suggestions, some mechanics and general themes of playground games adopted within the design of BrainQuest included: (1) Chase and catch – implemented in BrainQuest by hero-rustler catch tasks; (2) Stealing or rescuing items – implemented in BrainQuest by the hero setting captured animals free and by the rustlers stealing animals from hero pens; (3) The exchange of objects between opponents – implemented in BrainQuest by the rustlers giving up their bounty if captured by the hero; (4) Battle for control of an environment – implemented spatially in BrainQuest by the spread of the physical animals – i.e. lesser numbers of animals in rustler pen and more in hero pens indicate greater hero control and vice versa; and (5) Competition between good and evil forces – implemented by the 'Wild West' rustling vs hero fantasy within the game aesthetics and physical objects.

3.3.3 Integrating Cognitive Training Activities

After some early paper prototyping had been undertaken to implement initial designs based on the user-centred design workshop and the design principles identified from the motivational theory, the research team sought to establish how the serious content (the cognitive challenge component) could be best integrated. In this project, the serious content involved were (1) EF bolstering activities outlined by the literature, specifically physical activity (Diamond, 2012; Best, 2010; Hillman et al., 2008), and (2) the test of EFs present in a cognitive assessment, called the Modified Six Elements (6E) test from the BADS-C testing battery (Emslie, 2003).

The rationale for including physical activity was clear, given its relationship to EF outlined in the literature review and the children's desire for the game to incorporate playground games, found in previous research to be "fun" and "exhausting" (Van Delden et al., 2014). Yet not all physical activity is equal. Research suggests that physical activity involving a cognitive component (also known as 'cognitively engaging physical activity') like team or competitive sports may be of greatest benefit for EF (Diamond, 2015; Best, 2010) as individuals must work within game rules to coordinate movements and cooperate with teammates/opponents, anticipate others' behaviour, employ strategies, and adapt to changing task demands. If BrainQuest could mirror these qualities while providing the engaging qualities of video games and the ability to track performance over time, it could potentially be an even more useful means of training EF.

To achieve this, much like a sport, BrainQuest required rules of play within which cognitive skills could be challenged but there needed to be a rationale behind why such rules would require cognition, rather than creating an arbitrary and unstudied rule set. Hence, the rules of a cognitive assessment were deemed to be a feasible means of providing such a challenge (while it remained novel) which would allow the game to measure a known and studied subset of constructs. Nevertheless, given the problems outlined earlier in the paper with regards to prevalence of gamified tests which are decontextualized from real life and which unnaturally isolate specific cognitive skills, the test chosen had to hold excellent ecological validity (Lumsden et al., 2016), involve a diverse range of cognitive skills, and be translatable into BrainQuest's real world context.

3.3.4 BrainQuest and the Modified 6E Test

Modified 6E Overview

After reviewing and paper prototyping the integration of the rules of several different tests of executive function into BrainQuest, consultations with experts in developmental psychology resulted in the selection of the 'Modified 6E', due to its high ecological validity (Burgess et al., 2006) and diverse mixture of higher and lower-order cognitive skills (Emslie et al., 2004). It was hypothesized that the high ecological validity of the 6E, may improve the likelihood that performance in

BrainQuest would be representative of certain real-world EF abilities. The test benchmarks multi-tasking ability and involves a variety of EF skills, including planning, strategizing, regulation of attention, and use of working memory.

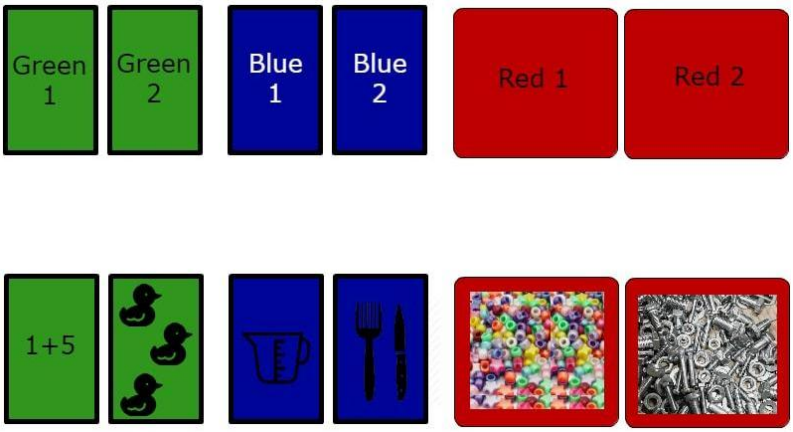


Figure 8. Modified 6 Elements Test (6E) (Gray, 2017)

The structure of the test is presented in Figure 8. In the test, participants are given three different colour-coded tasks to do: a green task (simple arithmetic), a blue task (picture naming), and a red task (sorting). Each of these tasks has two parts, part 1 and part 2, so there are two piles of cards for the green task and two piles for the blue task. Both parts of each task type are graded in difficulty to be suitable for children from age 8 years upwards. The third task, the red task, consists of two boxes of objects, containing objects to be sorted. Participants should schedule how they spend their five-minute time limit according to two task ordering rules, shown in Table 5.

6E Task Ordering Rule	**Example**
Rule 1: For each task choice, the individual being tested must change task type.	If the individual being tested completes a 'Green Part 1' subtask, they must not repeat another task of the 'Green Task' type for their next choice – i.e. not a Green Part 1, nor a Green Part 2. Instead, they must undertake a subtask of the type 'Blue Task' or 'Red Task'.
Rule 2: Within the 5-minute time limit, the individual being tested must make sure that they have attempted all 6 subtasks while following Rule 1.	The individual being tested must have completed at least one instance of Green Part 1, Green Part 2, Blue Part 1, Blue Part 2, Red Part 1, Red Part 2 within the time limit.

Table 5. 6E Task Ordering Rules

The test activities are explained in Table 6. Note, the correctness of the answers to the arithmetic questions (Green Task), picture naming (Blue Task), sorting (Red Task), are not important but what is important is how the individual being tested has managed their time according to the task ordering rules.

6E Task	**Subtask**	**Description**
1. Green Task	1. Green Part 1	Green Part 1 and Part 2 are a series of cards in their respective piles. For both parts of the Green Task, the individual being tested picks up the top card on the pile, turns it over and solves the simple arithmetic question on the other side. They write down their answer to the question before putting that card to the bottom. The arithmetic questions can be in form of a simple written addition or
	2. Green Part 2	

		subtraction or there may several illustrations they must count (e.g. 2 ducks, 4 dogs).
2. Blue Task	3. Blue Part 1	Blue Part 1 and Part 2 are a series of cards in their respective piles. For both parts of the Blue Task, the individual being tested picks up the top card on the pile, turns it over and solves the picture naming question on the other side. They write down their answer to the question before putting that card to the bottom. The picture naming questions are single drawings of objects.
	4. Blue Part 2	
3. Red Task	5. Red Part 1	Red Part 1 and Part 2 are two different boxes containing. For both parts of the Red Task, the individual being tested opens the chosen box and must sort the containing items into the lid according to the corresponding symbol. The boxes for each part contain different items to be sorted – one containing multi-coloured and multi-shaped beads, and the other a mixture of nuts, bolts, and washers
	6. Red Part 2	

Table 6. 6E Tasks

Integrating Modified 6E into BrainQuest

Earlier in this paper, we described why gamification of cognitive assessments has previously failed as a training activity, based upon two key factors: (1) the lack of motivational support facilitated by simply overlaid extrinsic motivators, and (2) the lack of transfer derived from training game contexts to the real-world. At this point, it is worth reiterating gamification paradigm shift BrainQuest represents. Previously, many cognitive training gamification models have started with a cognitive test of a single or small number of skills, before adding a layer of extrinsically motivational content. With BrainQuest, we have designed an engaging core gameplay experience involving opportunities for both intrinsic and extrinsic motivation, before integrating a multi-layered challenge of cognition and emotional regulation (hot and cool executive function) – physical activity and social interaction, coupled with the rules of a cognitive test requiring a diverse range of cognitive skills.

The integration of the 6E attempted not to change the fundamental game design requirements. Although BrainQuest involved activities of a totally different nature to the 6E – playground physical activity games as opposed to a paper and pencil laboratory test, the underlying EF processes involved in the 6E were distinct from their implementation – e.g. multitasking skills are generalizable between contexts. Both activities, the 6E and BrainQuest, would involve having to manipulate attentional resources, having to monitor time, having to remember previously completed tasks and their order, and having to develop a strategy to optimize performance – in other words, multitasking. Thus, rather than building the game upon the 6E test, BrainQuest's design was manipulated to involve similar abstracted EF processes. To apply these EF processes to BrainQuest, the structure of the 6E test; the task ordering rules; and the 5-minute activity duration, all which facilitated the multitasking demands, were integrated into the game design.

Despite this, the integration of the 6E task ordering rules in BrainQuest did inevitably affect some aspects of the game design, specifically the autonomy permitted by the game. For example, by asking the player to change task type each time (Rule 1) and, thereby, potentially disregarding a desirable task in favour of another which adhered to those the rules, it would provide an important test of inhibitory control. Yet, such a scenario could also impact the autonomy granted to the player to make choices by their own volition. Consequently, to lessen the chance that the player might feel constrained and to maintain the balance between maximum engagement value and cognitive challenge, the decision of whether to follow the task ordering rules was left up to the player. Instead

the rules were integrated to form a key part of BrainQuest's point scoring system. One could still play BrainQuest without following the task ordering rules but attempting to follow the rules resulted in scoring substantial bonus points.

Integrating the 6E test with the engagement design decisions of incremental and sustained challenge was also difficult. Cognitive training games often attempt to add challenge to the assessments they gamify, for example, the speed or number of stimuli encountered increases as the user becomes more efficient and the associated cognitive pathways become more fine-tuned with practice (Morra & Borella, 2015). In cognitive tests of single skills (like working memory), the lack of transfer witnessed would suggest this is an ill-advised approach (Simons, 2016; Redick, 2013). However, for tests of executive function (such as problem solving) which involve a novelty component, experts believe that only fundamental task demand changes which require the generation of new solutions will continue to present a challenge to executive skills (Anderson et al., 2010; Rabbit, 2004).

To solve this problem and maintain novelty, there are multiple factors at play in BrainQuest. As described, the variable difficulty level system incrementally removes supports and even adds additional challenges in later levels. This is designed to manipulate the level of cognitive load required to generate a solution to the problem while playing as the hero. For example, a strategy a player develops on Rookie level to follow the task ordering rules may no longer be applicable by Professional level. Meanwhile, there is an evolving challenge based upon the behaviour of other players, which may influence decision making.

Comparison of Modified 6E and BrainQuest

Table 7 shows the hypothesized comparison between how EF skills are challenged in the 6E test and BrainQuest.

EF Skill	**EF challenge in 6E**	**EF challenge in BrainQuest**
Motor Cognitive Coordination	Not challenged in the 6E test.	BrainQuest requires cognitively engaging physical activity, to follow the task ordering rules and emotional regulatory challenges while moving around the play space. Players must also coordinate on-screen activities (instructions, task choices, animations, feedback) with physical actions, as well as interactions with other players.
Working Memory	Working memory in the 6E is required to remember the previously completed task and whether the planned action is compliant with task ordering rules.	The same working memory demands as the 6E but with additional coordination demands: 1. Recall previously completed tasks in short-term memory and use working memory to check whether planned action is compliant with task ordering rules (also held in short-term memory). 2. Store and update visual, spatial, and auditory information of opponent's movements in working memory. 3. Review information from long-term memory regarding opponent characteristics and tactics, previously successful strategies, task procedures. Task support tools also help tailor working

		memory challenge. At World Class difficulty level, where Task Choice Support tool and Task History Stack are removed, BrainQuest becomes comparable to the 6E test. Then with the introduction of the Randomizer at Legendary level, the working memory demands increase. For each difficulty change, the goal of these tools is disruption of existing strategies. For example, if the user was using the task choice interface as a representation system and holding it in working memory, Legendary difficulty level sought to disrupt that visual image stored in working memory by randomizing the thumbnails in a different order using the Task Randomizer tool – requiring the user to manipulate the image in their mind.
Inhibitory Control	The 6E requires cool inhibitory control, such as sustained attention to complement working memory in staying focused on the goals of the task. Furthermore, there may be an element of selective attention required in keeping track of the time limit.	The test of cool inhibitory control skills involves switching attentional resources between multiple perceptual stimuli and the movement patterns of real life opponents. This potentially requires the hero to switch more regularly between sustained attention, selective attention and inhibition of action. There are hot EF demands required due to the social component of the game and the need to regulate emotions. Interactions may challenge inhibitory control. There is potentially added temptation for the hero to catch rustlers to impact on their opponent's score. This exploits the competitive element of the game to increase the level of self-control required during interactions. The nature of the interaction and the amount of self-control required may depend on the different mix of competitors involved in the game. Thus, teaching interactions with friends, acquaintances, and rivals – relevant to real-world contexts.
Planning / Strategizing	In the 6E planning / strategizing are required to optimally sequence tasks in terms of developing a pattern of task choice and designating equal chunks of time to each task.	Planning/strategizing skills are challenged by optimally sequencing tasks at each difficulty level. However, the incremental removal of supports and the later introduction of extra challenge may require changes in strategy and reformulation of plans – changing the task demands rather than training a specific strategy

		or process.
Cognitive Flexibility/Set Shifting	Cognitive Flexibility/Set Shifting is required to shift between different tasks in the 6E test often enough so that they undertake all 6 tasks but not so much that they waste time. Furthermore, some task changes include changes, such as the "how many" cards actively change an individual's predicted task demand - e.g. the user must count the number of different objects on a card after experiencing multiple cards with objectively written sums upon them.	Like the 6E, the player must time manage to complete all 6 tasks within the time limit. However, additional challenges exist in BrainQuest, as certain tasks hold a greater social weight – i.e. hero-rustler interactions. Cognitive flexibility may also be required to react to changes in the game environment or arising opportunities e.g. because of rustler behaviour or positioning. It may also be required when attempting new difficulty level for the first time and discovering a previous strategy has been rendered redundant.
Task Scheduling	Task scheduling is required when the user allocates time to the 6 different subtasks.	The same as the 6E test, the player must allocate time to each subtask to complete all 6 tasks.
Performance Monitoring	The user must monitor one's own thoughts and actions, as well as to self-correct those thoughts and actions to follow the task ordering rules completely.	Like the 6E test with regards to monitoring performance in following the task ordering rules, though Task History Stack, point scores, graphics and sounds provide additional feedback on performance

Table 7. EF Challenge: BrainQuest vs 6E

4. A school-based field study

The purpose of this study was to gather qualitative evidence to describe user enjoyment, cognitive activity, user motivation (pride, self-efficacy and confidence) and social relationships during BrainQuest sessions. We explored the following research questions:

1. To what extent does the use of motivational game design theories affect the engagement value of a serious game for executive function?
2. What evidence is there to suggest an engagement-focused training game can challenge and improve executive function?

4.1 Materials and Method

4.1.1 Participants

The pilot study was a 5-week longitudinal evaluation, involving 31 children (aged 11-12) from one of the partner primary school's P7 classes, however, data is only reported on a consenting subset of 28 children (16 boys and 12 girls). 9 case study participants (4 boys and 5 girls) were purposefully selected from the consenting 28 participants. Considering absences, all 28 participants at least 3 BrainQuest sessions.

4.1.2 Partner School Profile

The partner school selected for the user-centred design process and study reported in this paper, is a state-run primary school in Edinburgh, residing in a postcode in the second most deprived quintile of the Scottish Index of Multiple Deprivation (The Scottish Government, 2016). However, the catchment area also includes postcodes in the most deprived, and third most deprived quintiles.

4.2 Data Gathering

This paper focuses on qualitative semi-structured interview and observational data, and measures of in-game activity and performance from automated log files.

4.2.1 Observation notes

General: notes on the general activities during the sessions including technical issues, questions, and feedback. These were initially taken by 1 or 2 observers (depending on the prevalence of technical issues and misunderstandings) who split their time between the group.

Case study: notes on the activities of the case study subset of participants relating to engagement motivation and social interaction. During all sessions, 1 dedicated observer took notes on the activities and behaviours of each case study child within each of their roles.
Session review: following each session the observers compared opinions and highlights before the main researcher recorded a brief session review which included consensus and any details which had evaded the general observations.

4.2.2 Semi-structured interviews

At post-test, the researchers conducted 20-30-minute semi-structured interviews comprising questions relating to engagement, motivation and social interaction as well as specific aspects of the game's design, and general opinions. The interviews included the 9 case study children involved in the study and the classroom and PE teachers. Interviewing the teachers who spend a great deal of time with the children daily, allowed the capture of subjective perspective regarding the game's general reception as well as the occurrence of behavioural changes beyond the scope of the study. The interviews were audio recorded but later transcribed.

4.2.3 Log file data

Database and local phone log files were generated during BrainQuest login and logged different facets of performance: a) Ability to follow task ordering rules b) Task selections c) Where successes/mistakes were made d) Trophies won e) Hero and rustler points achieved f) Hero support tool usage g) Number of hero tasks attempted h) Number of rustler Shuttle Runs i) Game bugs and crashes.

4.2.4 Other measures

Additional quantitative data was collected to assess feasibility for a fully powered study in the future, including pre-and post-test EF Assessments (BADS-C battery) and background physical activity measures (historical mile time and beep test data) – see Gray (2017) for further details.

4.3 Ethics

Written child and parental consent was gathered. Prior to the study starting, the procedure was explained to every child individually to ensure they were comfortable. They were also told that they could withdraw from any part of the study at any time.

All data collection sessions were conducted within public areas of the school and always in sight and earshot of the class teacher. All observers present at each session had undergone police background checks and had active Disclosure Scotland approval to work with children. Also, with respect to storage and publication, all data reported was anonymized to protect the privacy of the participants,

with data stored on protected University servers. This study was given ethical approval by the Moray House School of Education ethics committee at the University of Edinburgh.

4.4 Procedure

4.4.1 Overview

The study took place over the course of 7 weeks between the months of February and March 2015, consisting of a pre-test week, a game tutorial week, 5 weeks (8 sessions) playing BrainQuest, and a post-test week – Figure 9.

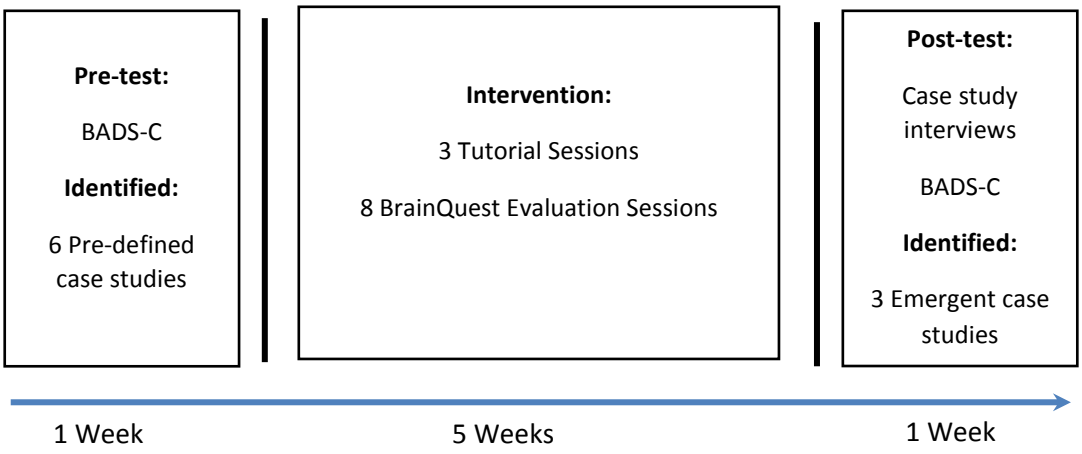


Figure 9. Study Structure

4.4.2 Case Study Selection

During the pre-test week, the study was explained to each child before their EF was benchmarked using the BADS-C test, taking 30-40 minutes per child to administer. After the pre-test marking, the researchers identified case study participants to generate a series of individualized experiences with BrainQuest which would enable us to understand a range of user experiences. These six case study children (referred to hereafter as *pre-defined* case studies) were identified by dividing the class into 3 equal numbered segments according to their pre-test performance score – high, medium, and low performing segments. 2 children from each segment were selected as case studies (4 girls, 2 boys) following discussion with the teachers and consideration of teacher assessment of physical activity. The goal was to create groups of mixed ability primarily with regards to EF but also groups of mixed gender and physical ability. As there are 3 players in each BrainQuest game, the 6 case studies were split up into 2 groups of 3 children which remained the same throughout the sessions.

Following the intervention an additional 3 emergent case studies (2 boys, 1 girl) were identified. This was necessary to mitigate any planned case study effects (i.e. Hawthorne effects) caused by the supervised nature of their gameplay in comparison to non-case study peers. The emergent case studies were chosen according to EF ability (low, medium, and high) and the frequency of data collected on them to form an understanding of their user experience.

4.4.3 Tutorial

Following this, two researchers conducted a tutorial week including 3x60 minute sessions with the children. The goals of these sessions were to teach the children the game rules and troubleshoot any unforeseen issues.

During each session, the class was split into 4 groups – A, B, C, D – each comprising up to 7 children. For the first 30 minutes of each session, one researcher taught the tutorial activity to Group A, while

the other researcher did the same for Group B. Meanwhile, Groups C and D undertook their regular PE activity before swapping with Groups A and B for the second 30-minute period of the session.

Tutorial Sessions 1 and 2 – Tutorial sessions 1 and 2 began with a game walk through where the children shadowed the researcher and undertook example game tasks. Following this, the children undertook practice games which were supervised and assisted by the researchers. The children took turns in playing the game in groups of 3, while the observing children critiqued the performance of their peers. Following the end of each game, the children communicated and discussed the feedback with their peers while the researchers provided additional advice.

Test Game – The final tutorial session (referred to as the 'Test Game'), enabled the children to undertake a full simulation of the BrainQuest sessions planned for the training period, including timing, pre-defined game grouping, and play space setup. The children played the game on Professional level (without support tools) to provide the researchers with a benchmark of the class BrainQuest ability level.

4.4.4 BrainQuest Training Period

Procedure – There were 2 × 60-minute BrainQuest sessions per week for 5 weeks in which each child got to use BrainQuest for 30 minutes: 3 x 5-minute games in each of the game's roles (hero, cow rustler, and sheep rustler; 3 x 5-minute undirected breaks between games allowing an opportunity to view feedback screens, point scores, the leader-board, trophies, and reset the play space.

The equipment setup allowed for a maximum of 5 concurrent BrainQuest games to be played at one time and a maximum of 15 children. Hence, as in the tutorial sessions, while half of the class played BrainQuest for 30 minutes, the other half took part in an alternative activity before swapping for the remainder of the session. During one session per week the alternative activity was their regular PE lesson and in the other session they undertook an outdoor classwork lesson.

During the game sessions, the two case study groups were always observed by a dedicated case study observer, meanwhile, the other observer(s) divided their time between all the groups – Figure 10. Before the start of each session, play spaces were set up by one researcher while the other researcher undertook a pre-game briefing in the classroom: detailing the difficulty levels each child would be playing, the groups for the session, repeating the task ordering rules, and answering questions. The children started at Rookie level, with the full range of support tools available but with each successfully completed level, they could increase the difficulty.

Equipment – The games occupied one-half of the school's AstroTurf pitch, providing game environments of approximately 15 square metres in size. There were 5 play spaces and each consisted of: 4 plastic hula hoop 'pens' (one at each corner of each game) containing 3 bean bag sheep or cow toys; each hoop contained a sign denoting the purpose of the hoop – rustler sheep pen, rustler cow pen, hero cow pen, hero sheep pen; 3 sheep and 3 cow toys in the middle of the 'play space'. Each toy and sign had an NFC (near field communication) tag (sticker) which could be scanned using an NFC-enabled Sony Xperia M2 smartphone, so children could interact with it in the game. The phones were loaned to the school by the University for the duration of the study. All associated costs were met by the University.

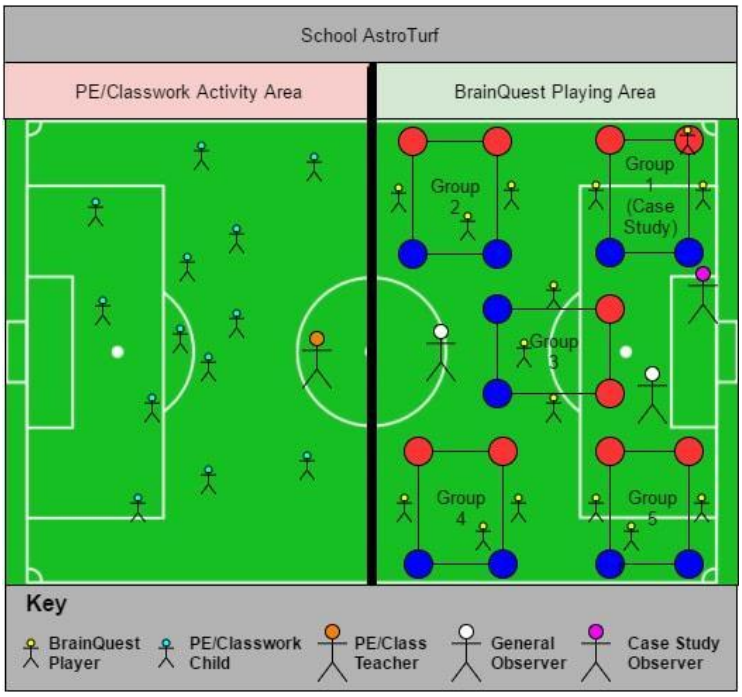


Figure 10. BrainQuest Study Game Space Setup

4.4.5 Post-test

Following the training, a post-test week was undertaken using the same BADS-C testing battery as well as case study interviews. The interviews were undertaken in the same open plan area as the pre-and post-testing, took approximately 30 minutes, and were audio-recorded for later transcription.

4.5 Analysis Methods

4.5.1 Qualitative data

All qualitative data from researchers' observation notes and interviews with children and teachers were typed and entered into NVivo 10 (Nvivo, 2012). Based on Diamond's indirect pathways to EF development (Diamond, 2012), a coding scheme was developed for use in thematic analysis (Guest et al., 2011; Braun & Clarke, 2006, Hayes, 2000) (Table 8).

The coding scheme sought to identify data relating aspects of the motivational game design and executive function literature within BrainQuest. The *'BrainQuest Design'* code related to player's opinions of specific game design decisions. Within this code, there were sub-codes concerning intrinsic supports – the fantasy, the playground activities, difficulty levels, sound, and animations, tangible objects; extrinsic motivators – leaderboards, and trophies; and general views of the design – positive, negative, and easy of understanding. *'Emotional Behaviour'* and *'Social Behaviour'* codes attempted to identify data relating to the wider implications of the game for competence, autonomy and relatedness. *Emotional Behaviour* also attempted to identify any evidence of emotional regulatory challenges, while *Social Behaviour* looked to understand the different types of social interaction observed – Competition, Cooperation, and Communication. Hence, the *BrainQuest Design* code contributes exclusively to the first research question concerning engagement, while *Emotional Behaviour* and *Social Behaviour* categories contribute to both the first and second research questions. These codes often co-occurred in the dataset as they are highly related concepts.

Source Balance – The code-able data set consisted of 31 source files – 16 sources were case study exclusive (case study observations, interviews) and 15 sources concerned all participants including both case study and non-case study individuals (general observations, session reviews).

Inter-rater Reliability – After defining the coding scheme, the main researcher coded the data set in its entirety – all 31 source files – using Nvivo 10 software. Following this, the second and third authors then coded a subset of the data set using the same coding scheme – 20% of the 10 category labels or 2 random case study children (Leonard and Angelina). In total, this amounted to a review of 24 data source files. Cohen's Kappa coefficient was generated for each parent node of the coding scheme. Cohen's Kappa = 0.7 was agreed by all coders at the outset as the minimum threshold for data to be included as part of the results without the need for further triangulation with additional sources.

Emotional behaviour and *BrainQuest Design* parent codes were above the threshold for acceptable agreement. However, aspects of '*Social Behaviour'* failed to meet the threshold as parent codes of agreement (Table 8). Thus, these failed codes required an additional stage of analysis to address the ambiguities identified by the inter-rating process which led to differences of opinion. The data sources involved in the qualitative analysis were triangulated with game logs, cognitive assessment data, and physical ability data to address the ambiguities of the observations and interviews. It enabled qualitative observations to be compared with specific time-stamped events and task choices, the opinions of additional observers, or interview self-reports of behaviour. Ambiguous incidences coded from one data source now required corroboration or further information from at least one additional source. The results of the additional triangulation were validated by the second author.

Code	Description	Kappa Agreement Value
BrainQuest Design	Data related to observed appraisal of specific BrainQuest design decisions – (1) Playground Game Activities; (2) Fantasy Story, Sounds, Animations, Tangible Objects; (3) Game Difficulty; (4) Support Tools; (5) Rewards; (6) Trophies; (7) General Likes and Dislikes; (8) Ease of Understanding	0.72
Emotional Behaviour	Data related to the observed emotional behaviour during BrainQuest sessions – (1) Challenge of Emotional Regulation; (2) Enjoyment; (3) Competence; (4) Autonomy; (5) Negative Emotions	0.70
Social Behaviour – *Competition*	Data related to the observed emotional behaviour during BrainQuest sessions – (1) Social interaction; (2) The nature of interaction; (3) Relatedness	0.49
Social Behaviour – *Conversation*		0.63
Social Behaviour - *Cooperation, and Encouragement*		0.72

Table 8. Coding scheme used in thematic analysis

4.5.2 Quantitative data

Analysis was conducted using Microsoft Excel and to create graphs of performance evolution and draw descriptive statistics. The statistics described are purely correlational and consider the relationship between pre- and post-test BADS-C scores and measures of hypothesized EF challenge in BrainQuest. Only exploratory correlational statistics were produced because of the lack of study

power and the lack of control group in this initial evaluation. This was deemed appropriate rather than producing inferential statistics on a small dataset, a prevailing problem within the cognitive training game literature base (Simons, 2016).

4.5.3 Log file analysis

Log files were collated and imported from the database and local phone files into Excel, where totals, means, and frequencies could be applied to a range of quantitative variables, regarding both hero and rustler performance, how often task support tools were utilized, leader-board, and trophy performance. Database and local phone data were checked for consistency on overlapping variables. Task choices were also recorded for every session, with strategies and trends identified by hand for case study participants. The strategies were initially informed by strategy heuristics defined in the 6E test marking scheme but emerging patterns of task choices were also noted – they are described in Table 9.

Complexity Level	**Strategy Description**	**Strategy Explanation**
None	Uninterpretable or no strategy	The user makes no attempt to follow either task ordering rule.
None	Grouping tasks of the same type together	The user groups tasks of the same type together breaking task ordering rule 1.
Low	Simple task type change each time	The user changes task type each time but task selections may be random and they may not complete rule 2.
Low	Task type = n-2 throughout * n = current task number	The user maintains the same task type on every second selection throughout and they may not complete rule 2.
Moderate	Task type = n-2 until all subtypes complete * n = current task number	The user maintains the same task type on every second selection throughout and attempts a previously unimplemented task of the 6 subtypes in between times.
High	2 or more consecutive cycles comprising 3 different types	The user completes 2 or more cycles, each comprising 3 different task types to complete rule 2 without breaking rule 1.
Very High	Grouping animals together for 2 or more consecutive cycles of 3 tasks	This strategy builds upon F but for each cycle of 3 the user is consistent in their choice of animal.
Very High	Undertaking task types in a repeatable order for 2 or more consecutive cycles	This strategy builds upon F but for each cycle of 3 the user is consistent in the order in which they pick tasks e.g. return, save, stop.
Very High	Selecting tasks top to bottom for 2 or more consecutive cycles	This strategy builds upon F, G and H but the user uses the interface to guide choices e.g. return cow, stop cow rustler, save cow, return sheep, stop sheep rustler, save sheep.
Maintenance + High	Changing to a more simplistic strategy after completing all 6 task types - in other words, making rule 1 a priority	After completing rule 2 using a moderate or high-level strategy, the user may change to a low-level strategy which allows them to concentrate on attending to rule 1. This is an efficient strategy as it relinquishes having to

		hold both rules in working memory.
Maintenance + Moderate	Stopping additional tasks to preserve trophy	After completing rule 2 using, the user may stop undertaking any further tasks to leave no chance of breaking rule 1. This strategy is likely to end in success but drastically limits the number of hero points available.

Table 9. BrainQuest Strategies

5. Results

5.1 RQ1: To what extent does the use of motivational game design theories affect the engagement value of a serious game for executive function?

5.1.1 Enjoyment

From the data triangulated from data logs with *BrainQuest Design* and *Emotional Behaviour* codes, in general, the children appeared to enjoy their experience with BrainQuest. The children's general opinions of the game were very positive, particularly towards the end of the study, as this comment from a participant illustrates:

"Come play this game, it's epic" – Jax*, General Observations.*

This was echoed by the class teacher's comments:

"I think it has been very enjoyable. There's been a lot of motivation, there's been a lot of buzz about it and they've been enthusiastic about the leader-board and who's got what trophy and they've looked forward to each session" – Class Teacher, Interview

In the qualitative data set, there were 439 references to children expressing positive emotions towards or during the game, and there were 175 references to negative emotions. Aspects of the game that involved social interactions seemed to be particularly enjoyable, particularly the playground game style chases. The children were also positive about achieving self-set goals within the reward system. The children enjoyed the fantasy-enhancing sound and graphics in BrainQuest:

"I found some of the animations really funny, like the sheep on the ladder" – Leonard, Interview

5 of the case study children reported enjoying the sounds and animations that appeared at various points throughout the game, and for 2 of these children, they were their favourite aspect of the phone app.

The negative emotions were largely related to frustration with game bugs which were an intermittent issue, particularly in early sessions but only some had observably detrimental effects on user engagement. The most common grievance concerned errors affecting point scores or trophies performances, and logging bugs requiring games to be restarted. Once these bugs were fixed, there was a large reduction in negative comments from the children.

The balance (or lack thereof) between the hero and rustler roles also appeared to hinder user engagement. There were 4 observed occurrences of children expressing their frustration while playing as the rustler when the hero pens were empty and there was nothing for them to steal and they were not being chased by the hero. Furthermore, during the interviews, 2 children stated the desire for future games to include larger groups of players, suggesting there were not enough opportunities for social interaction.

"*Patrick is complaining that there are a lot of sheep in his pen so she's not returning sheep back to her pen*" – Observer, Case Study Observations

Interest in the game appeared to be maintained throughout the study. When asked at interview how their interest levels changed throughout the project, 6 of the case study children said that it was higher at the end of the project and 3 said it remained the same throughout. Observation notes indicate that in general the children still appeared to be enjoying the game in the later sessions, and they continued to request extra turns of the game. However, the class and PE teachers felt engagement followed a pattern of peaks and troughs:

"I think in weeks 2 or 3, their enthusiasm dipped a wee bit … but on the last week the enthusiasm went right up again, and I don't know if that is to do with the challenge of the game?" – PE Teacher, Interview

This observation may be valid as there was a dip in the level of challenge during weeks 2 and 3 when many children encountered World Class difficulty. This dip occurred because some children had been playing the Professional difficulty without using the available support tool – the Task History Stack tool. In such circumstances, when the user either ignored or was unaware of the tool, it made Professional difficulty equivalent to World Class. Thus, upon completing Professional and attempting World Class, these children would not be met with any incremental increase in challenge which may, in turn, have affected motivation. Hence, perhaps this contributed to the fluctuation of motivation between individuals.

Similarly, player goal differences may have been an additional factor on motivation, with children who had invested in the extrinsic motivators, leader-board or trophy rewards, encountering obstacles towards completing their goals. For example, by weeks 2 and 3, the individual who eventually topped the leader-board by the end of the study had already assumed a seemingly unassailable lead. Meanwhile, another common goal was to attempt to collect all trophies but this was only achieved by 9 of the 28 children, suggesting that this may have proved unachievable and subsequently demotivating for others, though the inbuilt supports for competence may have helped soften the blow:

"Kids tend to react badly when they don't win trophies. They are initially disappointed and complain but soften after reading the task history screen" – Observer, Session Review

There was some evidence of goal re-formulation observed, for example, one emergent case study child, Stevie, had originally targeted topping the leader-board but after several sessions changed his goal to collecting all trophies.

"Stevie was disappointed to have lost his top spot on the leader-board after being absent" – Observer, Session Review

5.1.2 Motivation: Competence and Autonomy

From the data triangulated from data logs with *BrainQuest Design* and *Emotional Behaviour* codes, BrainQuest appeared to be notably accessible to children of different ability levels and children across the spectrum of both physical and EF abilities exhibited pride and enjoyment throughout game play. For example, some of the children who scored least well on the BADS-C (e.g. case study children Natalia, Leonard) and some of the children that scored least well on the PE teacher's fitness measurement (e.g. case study children Leonard, Patrick), asked to play the game for additional periods of time in later sessions of the study.

Often children's pride and confidence appeared to be derived from progress towards their goals – in every session there were observations of children verbally telling others of their achievements.

Participants appeared to derive pride from winning trophies and performing well on the leader-board. In sessions 3, 4, and 5 there were 28 occurrences of children approaching observers to relay their achievements, coinciding with many children winning their first trophies according to the data logs. However, in the remaining sessions emphasis changed from communicating pride to the observers, to communicating pride to their peers:

"*Before, during, and after each of the game sessions, there was a lot of social interaction between the kids while looking at each other's phones - at the leader-board and trophy cabinets."* – Observer, General Observations

7 of the case study children reported feeling proud of their achievements. Most case study children indicated confidence and self-efficacy towards physical ability, strategizing ability, and general mastery of the game,

"Because in the first week I didn't really get it at all, but now I get it…I've got better" – Participant, Leonard

"So how does it make you feel, that you've got better at the game?" – Researcher

"Hmm…really good about myself, like proud I guess" – Participant, Leonard

Hence, it appears in-game achievements supported feelings of competence and may have been the catalyst for social interaction.

The trophies and leader-board also seemed to be used as methods of goal setting. At interview, 4 of the case study children reported goals relating to collecting trophies, while 3 had goals about their performance on the leader-board. 2 of the case study children who completed trophy goals before the final session decided on new motivational goals.

"*Ellen and Melvin had run out of trophies to earn. Melvin's focus shifted to beating a personal point's target that he had set himself, of ten thousand points which he achieved and then celebrated wildly with joy – jumping up and down! Ellen was happy just to keep winning Legendary trophies, letting me know of how many were now in her trophy cabinet."* – Observer, General Observations

Yet there were instances where failing to attain a goal led to feelings of diminished confidence. The observation notes report one child, who failed to achieve a trophy because he broke the task ordering rules on his final task, subsequently going on strike and refusing to play for the session remainder.

"John is in a bit of a huff [sulk] after not winning a trophy. John is lying on the ground complaining that he should have won a trophy…he is still moody and tells me that he doesn't want to play again" – Observer, General Observations

BrainQuest does provide alternative targets to some extent. Some children, who initially expressed a desire to achieve one goal, later claimed it to be of little interest and instead favoured another goal. E.g., several children initially communicated an interest in the leader-board before changing to trophy goals as their initial goal became increasingly unachievable.

Physical activity was also a source of pride, confidence, and self-efficacy (e.g. Alexa felt the game had "helped her with her running"), while mastery of game rules also created feelings of self-efficacy. Finally, some children derived pride from their actions and ways in which they expressed themselves, e.g. Jax, who became known for his rustling abilities (rustler points were recorded in the 'score centre' menu of the game). Jax scored the most rustler points of any other child and opted to play more rustler games than anybody else in his pursuit of being the best. The prevalence of self-expression suggests BrainQuest facilitated user autonomy but may also highlight the need to officially reward rustler activities as well as individual playing styles.

5.1.3 Social Relationships

From the data triangulated from data logs with *BrainQuest Design*, *Emotional Behaviour,* and *Social Behaviour* codes, the observation notes and interviews indicate the prominence of social interaction in the BrainQuest interactions. There were 1029 references to social behaviour across 32 data sources. BrainQuest enabled children of different physical and cognitive ability levels to play together for many sessions without any negative consequences.

Motivation to play for some was simply the opportunity to interact with other people.

"Patrick seems to only be running when he thinks he's going to be chased, that is when he enjoys it the most" – Observer, Case Study Observations

Social community appeared to be fostered by the leader-board and trophy systems, creating opportunities for children to communicate with each other. During the interviews, 7 of the case study children mentioned conversing with other players regarding their achievements, and it was common to observe the children gathered together between games to compare their scores.

Cooperation was fostered by learning game rules and exchanging strategic advice – interactions appeared to transcend friendship groups. All the case study groups were observed helping each other with learning the game rules and sharing tips. In case study observations, Rachel and Angelina appeared to cooperate with each other in hero and rustler roles to maximise each other's scores, while Patrick and Alex were observed verbally encouraging their peers during games. Melvin thought it was fun to play and interact with class mates he wouldn't normally play with. However, 2 of the case study children much preferred to play with their friends rather than the teacher-specified groups.

The hero-rustler chase interactions had interesting effects on game performance and enjoyment. Leonard and Patrick were children with poor physical ability but enjoyed hero-rustler chases more than any other activity and this encouraged them to persist in shuttle runs. By the end of the project, Leonard's teachers had noticed an improvement in his physical ability – he was now able to run a mile in his PE class. However, in BrainQuest, Leonard would still object to running if there was not the prospect of returning any cattle for points, suggesting that his motivation was extrinsic. As noted by Stevie, the level of physical activity promoted during hero-rustler interactions depended on the matching of abilities of the children in these roles – vigorous PA was most likely to be promoted when the hero and rustler were of similar speed.

5.2 RQ2: What evidence is there to suggest an engagement-focused training game can challenge and improve executive function?

5.2.1 Cognitive Activity During Gameplay

Based on the triangulation of the coded qualitative data and logs, there is good evidence that the children engaged with the game through cognitive (and physical) activity throughout the sessions, as indicated by the progression through difficulty levels and points collected in the hero role.

Table 10 shows how the children progressed through the levels of the game at each session. Session 1 (the 'Test Game') is not included because it was a practice session. Table 10 shows the percentage of children who finished each session on each difficulty level. Note that the totals do not sum to 100% because children who were absent at a session are not included in the total for that session. By the end of the project, there was a wide variance in performance: 10.7% of the children were unable to progress past the first level, while 32.1% had managed to get to the most difficult level. This suggests that BrainQuest is playable by users with a wide range of ability levels but those at the lower end of the ability spectrum may benefit from extra support.

The change in game scores over time are shown in Figure 11. The graph shows the average number of points per session played by users in the role of hero over sessions 1 to 7. It illustrates that the children were sufficiently cognitively engaged with the game to put in the effort to earn points even in the later sessions. The graph demonstrates that scores improved over time but not linearly and that there was some variance in performance between players. There was a dip in performance between sessions 3 and 4, and there is a marked improvement between sessions 6 and 7. The performance drop can be explained by the withdrawal of game scaffolding between Rookie level and Professional level – as shown in Table 10, around one-third of the children had reached Professional level by the end of session 3. Observations suggest that the increase in points in session 7 is possibly due to users performing at higher levels who were now competent enough to take advantage of the combo bonuses which reward the user with multipliers of points for streaks of tasks performed without breaking the rules. This suggests the need for additional difficulty levels to cater to higher ability levels.

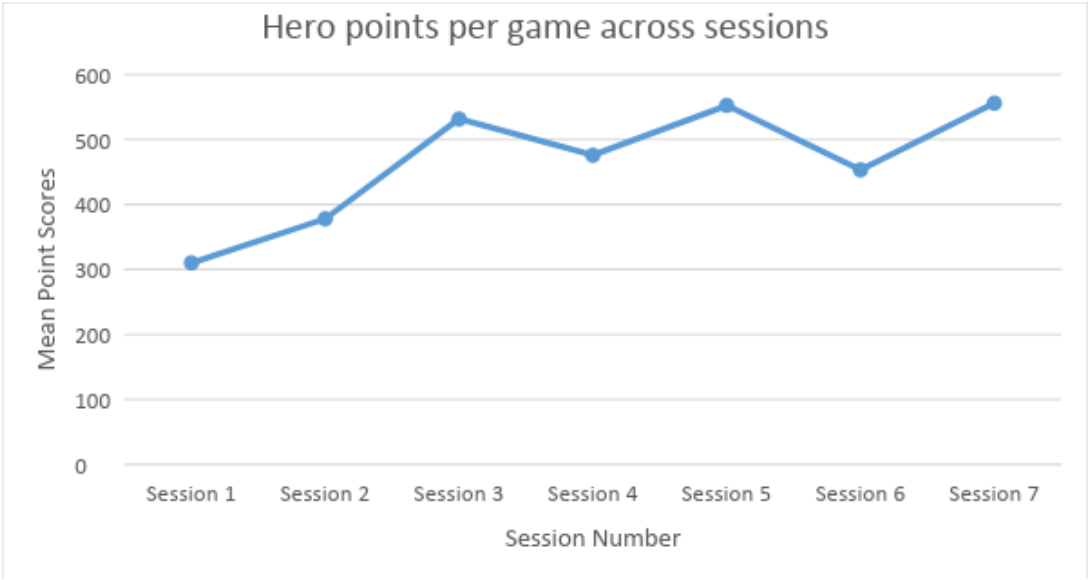


Figure 11. Hero points per game across sessions

	Session 2 end	Session 3 end	Session 4 end	Session 5 end	Session 6 end	Session 7 end
Rookie	92.9%	67.9%	39.3%	21.4%	7.1%	10.7%
Professional	0%	14.3%	35.7%	42.9%	35.7%	14.3%
World Class	0%	0%	10.7%	10.7%	17.9%	21.4%
Legendary	0%	0%	0%	10.7%	21.4%	21.4%
Completed All Levels	0%	0%	0%	0%	0%	32.1%

Table 10. Difficulty Level Progression by Session

In depth log-file analysis of the order in which games tasks were executed by the case study children and can be found in more detail in Gray, 2017. The following results summarise the case study evidence for cognitive and emotional regulatory challenge during BrainQuest gameplay:

Working Memory – BrainQuest was designed to challenge working memory by users having to store, manipulate and update task ordering rules, previously completed tasks, potential task choices, spatial and visual information about the game environment, previously successful strategies, and opponent information. For case study children, challenge seemed to manifest itself in a difficulty of remembering previously chosen tasks while choosing a new one, suggesting the efficacy of the designed challenge. There were 5 examples from the interviews of case study children reporting memory difficulties during particular difficulty levels and these could be triangulated with decreases in performance in data logs – when required to select a new task they struggled to "remember" which task they should pick next. In such games, these children posted lower point scores and number of attempted tasks suggesting an increase in the amount of time spent while make decisions, and in other cases even mistakes. On the other hand, however, all case study children felt that, in general, BrainQuest became easier over time.

Inhibitory Control – The data analysis was unable to draw any conclusions regarding inhibitory control of attention because it was impossible to triangulate user direction of attention from observations alone. Consequently, only inhibitory control of actions and emotions could be reported following triangulation of data logs, observations, and interviews.

The case studies suggested the hero-rustler role as a challenge of hot EF inhibitory skills and there were 7 instances of case study children failing to regulate their emotions and becoming embroiled in arguments requiring observer arbitration. There were 2 direct accusations of cheating with players seeking arbitration from observers. 7 case study children were involved in arguments because of hero-rustler chases, and 4 were involved in violations of game boundaries during hero-rustler chases. There was also a social influence on task choices and some children failed to follow the rules when presented with the temptation of chasing opponents – failure to inhibit their actions and not gaining optimal points. One case study child repeatedly broke the task ordering rules to catch another (rival) player. Another case study child was observed changing her strategy and even breaking the task ordering rules to cooperate with other players (with whom she was friendly). 2 children adopted or modified a strategy to enable for more frequent catching of rustlers, and one child adjusted her task choices to time catching the rustlers efficiently. For one case study child, adopting a 'stealth' style of play (sneaking up on rustlers) coincided with a decrease in overall strategic complexity.

Notwithstanding, the teachers described improvements in emotional regulation beyond the classroom. One example was, Victoria, a case study child whose teachers had described her difficulty in socially interacting with others during lessons but who had made noticeable improvements towards the end of the BrainQuest intervention. Another was Melvin, who stated that his relationships with some class mates had improved over the course of the study. Though these are the opinions of two teachers and a self-report of one child, it justifies the need for future exploration into any potential real-world benefits of BrainQuest.

Planning/Strategizing – Though there may have been some challenges to working memory and inhibitory control in isolation, they were mostly challenged within the context of planning/strategizing to follow the task ordering rules. Some key findings were: (1) Most case study participants could generate a range of strategies which varied in complexity; (2) BrainQuest forced the generation new strategies rather than allowing the repeated implementation of the same strategy in all games by changing the interface demands – 4.3 was the mean number of unique strategies generated by the case studies; (3) Social factors were an influence on strategies deployed and affected task choice – 5 case study instances; (4) Improvements in strategizing scores were seen on the BADS-C post-test following BrainQuest for 3 case studies, with one child deploying the same strategy which he had developed in BrainQuest but 3 other case studies failed to improve.

As stated, there is a novelty problem associated with many challenges of executive function as well as the problems with many cognitive training games. However, BrainQuest appears to require the user to repeatedly invent novel strategies, rather than just refine or increasing speed of specific processing or increase the span of items to remember.

Social factors seemed to influence strategizing task choice for 6 case study children. For example, the desire to stop the rustlers appeared to lead to rule breaks, changes in strategy, and the adoption of more flexible and less structured strategies. However, it also facilitated the generation of additional strategies to govern playing style. For example, Patrick developed a "stealth" style of play which involved deception of rustlers by "pretending to do another task". Furthermore, Leonard timed his runs to coincide with certain opponents and hid animals from opponents to make them think his pen was empty. These results may be indicative of an emotionally-affective hot EF factor on strategizing during BrainQuest gameplay.

Further suggesting the impact of hot EF on strategizing was the prevalence of cheating during gameplay, particularly during rustler roles. There were 3 games noted in the observations where rustlers continually ran through the middle of play spaces rather than around the perimeter (after having previously been corrected by observers) to trick the hero. Other ways of cheating included: rustlers collecting animals from the middle, rustlers running into other game spaces to escape, rustlers trying to hack buttons on the interface to allow them to earn extra points without having collected any animals. Fortunately, cheaters were held to account by other members of the group and reported to observers, yet scheming to achieve competitive advantage may suggest the rustler role to be more cognitively engaging than first anticipated.

Taken together, the progression through levels, continued accumulation of points, and the adaptive strategy development of the case study children indicates cognitive engagement with the game throughout the study. Most of the children managed to achieve some competence at the game, which was one of the three design principals intended to promote engagement.

5.2.2 Correlation Between BrainQuest and 6E Performance

Based on data generated by BADS-C testing and data logs, the correlation between BrainQuest performance measures and 6E performance was also calculated, introducing the following analysis measures:

1. Trophies per game (Trophies/Game) – the number of trophies represents the number of times the hero successfully followed the task ordering rules correctly per game
2. Hero points per game (Hero Points/Game) – as there were absences some children played the game more than others so hero points per game (rather than session) is an even more accurate representation of performance
3. Rustler points per game (Rustler Points/Game) – as there were absences some children played the game more than others so rustler points per game (rather than session) is an even more accurate representation of performance
4. Rustler shuttle runs per game (Shuttle Runs/Game) – as rustler points do not purely correspond to physical activity (e.g. you earn 20 points for completing a shuttle run with an animal but only 10 without an animal), rustler runs was an alternative measure used to measure the number of shuttle runs completed alone

Correlations were run between these performance measures and the pre-test results of every BADS-C subtest – the only correlation was with the 6E test. There were moderate correlations between the 6E pre-test and Trophies/Game performance measure (r=0.55) and the 6E pre-test and Hero Points/Game performance measure (r=0.50) – those with higher test scores earning more trophies and points in the hero role. Hero points and trophies per game also moderately correlated with each other (r=0.60). There were low correlations between 6E pre-test and rustler points (r= 0.36) and the

6E pre-test and rustler runs (r=0.40). Finally, there were relationships between all hero and rustler performance measures.

These results suggest that, as designed, the EF skills required by the 6E may also have been a factor upon BrainQuest performance. Moreover, a less than perfect correlation is to be expected given the contextual differences between the two (i.e. the use of indirect pathways, variable difficulty, technology etc.) and increased range of EF skills used in BrainQuest. The lack of correlation between BrainQuest performance and the other BADS-C subtests may also be the consequence of task impurity – the inclusion of some EF skills in BrainQuest but beyond the scope of EF subtests. Furthermore, it also appeared that the rustler role may have included a greater cognitive component than expected.

6. Discussion

There are many shared qualities between motivational game design theories and models for EF training interventions. The concepts of competence, autonomy, and relatedness so fundamental to PENS model (Rigby and Ryan, 2011) overlap lap with the supports for pride, confidence, and self-efficacy; community; and enjoyment of EF training described in Diamond (2012). Hence, ensuring a motivational player experience should be a prerequisite of any game designed to approach cognition or emotional regulation, for the benefit of both player engagement and quality of training. We first consider BrainQuest's engagement value before contemplating the EF impact, and then provide recommendations for future design. Throughout the section, recommendations are highlighted in situ with a design recommendation code (DR).

6.1 Establishing BrainQuest's Engagement Value

The results of the 5-week study suggested that users continued to enjoy playing the game throughout and, therefore, it appeared BrainQuest had (at least to some extent) successfully integrated *competence*, *relatedness* and *autonomy* for the benefit of engagement. For example, the absence of observed engagement novelty effects, which can often be so problematic in serious games (Macvean & Robertson, 2013; 2012), and the particularly positive sentiments towards the end of the 5-week period were positive indicators. Yet, the number of 30-minute sessions played by children was still relatively short at an average of 8 sessions and in time it is likely this engagement would start to diminish unless motivation can be maintained. What was the extent, then, of motivational efficacy in BrainQuest?

6.1.1 Social Interaction, Competition and Cooperation

Building BrainQuest around the mechanics of playground games seemed to be justified given the number of references to positive emotions during gameplay social interactions and especially the game chases, and suggested a positive impact on the game's ability to provide relatedness (DR1). The competitive chase and catch dynamics of the game may have been one of the most powerful sources of BrainQuest's appeal and sustained engagement but despite this, it is unclear what the effects of this type of activity might have been without the presence of the researchers observing the experience.

The formal rules of BrainQuest, governing what the hero or rustler player can do during each task may have been, for the most part, feasible in the presence of authoritative figures (observing researchers) who were there to give 'help' but were also approached to provide arbitration in disputes. However, without the researchers present the prevalence of cheating or negative implications of competition may have dramatically increased. This is one challenge of BrainQuest's mixed reality design. With a digital interface alone, it can be made much more difficult to circumvent formal rules but this is made harder by the real-world aspect of BrainQuest and the associated freedoms of the player's choice and action. Earlier in this paper BrainQuest was described as being

similar to a sport, and perhaps like a competitive sport the game requires a referee to ensure fairness and equality which cannot be facilitated by the digital interface alone. On the other hand, arbitration of disputes and the emotional regulation involved in doing so is a viable challenge and opportunities to test these skills may be a valid means of skills training. Maybe this is part of the value of self-governed playground games. Nevertheless, when emotional regulatory challenges obstruct gameplay, the cognitive demands involved in playing the activity correctly may also be suspended. Moreover, at what point does this begin to negatively affect engagement?

With regards to fostering feelings of relatedness beyond simply taking part in a shared activity, encouraging cooperation is deemed key to creating social belonging and community. The intended supports for cooperation, the multiple rustler roles which would allow them to work together, only featured in a couple of isolated examples. There are several possible theories for why this was observed. Perhaps it was because such behaviour was not made obvious by the game's digital interface and there were not enough provisions for shared objectives, as it was assumed it might occur organically. Perhaps the inclusion of the leaderboard and personal rewards pushed the impetus towards an individualistic mentality or perhaps cooperation was predicated on whether or not a potential team mate was regarded as a friend. On the other hand, a great deal of cooperation observed regarding the explanation of the task ordering rules as well as the general rules and procedures governing the game. Children took it upon themselves to help other and teach less able peers, often beyond immediate friendship groups. It was unclear whether this desire to help was completely altruistic or whether it was to some extent self-serving, to ensure at least some sort of opponent challenge existed. Hence, ensuring a closeness of challenge may have been a common goal for all players and future versions of BrainQuest should learn from the potentially positive social consequences of providing shared goals during gameplay to encourage greater cooperation (DR2).

The chase and catch activities between heroes and rustlers appeared to be hugely engaging but these interactions may not have happened with enough regularity. For example, children wanted future versions of BrainQuest to allow for games of a greater number of children rather than just the 3 participants in each game. Such a dynamic would potentially increase the diversity of the social interactions available, require an additional cognitive component to orient oneself with a greater number of opponents or team mates, and satisfy the desire of children to interact with their friends. In any case, given the prevalence of social interaction as a motivator, future BrainQuest versions should seek not only to create additional opportunities for this but must also evaluate any new or changes to relationships between players both within and beyond the confines of gameplay to measure the feelings of relatedness which are so important to both game design and EF training methods (DR3).

6.1.2 Autonomy of Player Roles

Attempts to not constrain the player coupled with the Wild West fantasy had limited but seemingly positive implications for autonomy. For example, different children interpreted the roles differently, especially the rustler role and created not only their own versions of the fantasy but their own goals as a result (DR4). Some players adopted unique playing styles which future versions could identify and issue a tailored reward, i.e. for Patrick, who attempted to play in a 'stealthy manner' by sneaking up on opponents, the post-game feedback could describe him as a 'BrainQuest Ninja'. Similarly, another child who specialised in rustler points could be presented with a reward for being 'the fastest rustler in the West'. Despite this, it was clear that additional choice was required within the rustler role of the game, as well as more freedoms to make the most of the interaction between hero and rustlers, e.g. when children complained about not having any reason to run when there were no hero animals to steal. Also, there were no extrinsic rewards for any of these self-determined goals, which could have enhanced the fantasy.

The lesson here for game design might be that players may enjoy the ambiguity of a character or role when it allows them to express their own characteristics or explore their own version of the

fantasy provided. With that in mind, future versions of the game may benefit from a homogenization of roles, which does not assign players to a rigid role i.e. hero or rustler. Instead, the player should decide for themselves the characteristics they wish to explore and how they wish to play the game (e.g. exhibiting malevolence or becoming a force for good). With the introduction of more props, all players could play in a single role, and the different task types could be tweaked to make provisions for players who wish to play competitively or cooperatively. Meanwhile algorithms could be introduced which attempt to characterize and evaluate different playing styles, supporting players with tailored rewards to enhance the experience and acknowledge the character attempting to be portrayed (DR5).

6.1.3 Competence and Support for Cognitive and Physical Ability

One of BrainQuest's most important successes was being able to mitigate the negative effects of disparity in ability levels. Children at opposite ends of the leaderboard or on different difficulty levels could enjoyably play together and have their actions directly impact the other person (i.e. for rustlers to make the hero's job as hard as possible). By enabling games of mixed ability, it enabled the less skilled players to learn from their better able peers, both indirectly (through watching their actions) and directly (by giving advice and teaching strategies). The question of learning is intriguing, cognitive skills may be trainable but are they teachable? For example, by understanding the actions undertaken by a more skilled peer, is the child simply copying a learned pattern rather than thinking in a different way for themselves? If the former theory is true, then the underlying EF abilities reflected by in-game performance may be a fallacy. Future studies should seek to understand this.

Similar issues exist for the BrainQuest support tools to find the right balance between reducing cognitive load and letting children keep cognitive challenge at the cusp of ability, rather than simply teaching children strategies to copy. Given the incremental progression and the fact that most children did not complete all the difficulty levels, it appeared that challenge did remain throughout. However, some difficulty levels appeared to be more challenging than others which may have reflected the need for certain support tools to support competence to a greater extent. For example, the post-game task history tool allowed the user to reflect upon their correct and incorrect task choices but the game did not go far enough in terms of detailed feedback and encouragement. This inequality in challenge between difficulty levels can have both positive and negative implications. If the perfect balance between more difficult and easier levels of challenge can be achieved, there is the opportunity to induce powerful engagement like the state of 'flow' described by Csikszentmihalyi (1990). On the contrary, to incrementally make EF improvements, challenge should always be at the cusp of ability (Mishra, Anguera, Gazzaley, 2016). Thus, in future versions of BrainQuest one solution may be to create personalized challenge for individuals within the game based on data derived from their gameplay which identifies abilities and levels of engagement (DR6).

An analogy made throughout this paper has compared BrainQuest to a physically intense sport or to playground games, however, the difference with BrainQuest may be in the balance be between physicality and mental ability, as far more points can be accumulated by making correct decisions (as the hero) or clever timing (as the rustler) rather than doing as many tasks as possible. The benefit of this appeared to be the enjoyment and accessibility of BrainQuest to the entire class, even the least physically able, but the cost may be the associated benefits from undertaking less physical activity. On the other hand, the efficient and thoughtful approach did not appear to be undertaken by every child and the intensities during hero-rustler chases were vigorous. The reports of real-world transfer of physical ability competence in some of the least able children is also a positive outcome but requires additional study.

6.1.4 Impact of Extrinsic Motivators

As stated, the impact of extrinsic motivators alone as a gamification approach is problematic, yet this does not diminish their potential to harness player's motivation in the short term, nor the possibility that with the right outlets they can produce more intrinsically motivated behaviour over time. In BrainQuest, the leaderboard and trophy systems (extrinsic motivators) played a useful role in facilitating feelings of competence and relatedness.

Winning all the trophies and scoring highly on the leaderboard became an early goal which children tried to achieve and a notable marker of competence with players avidly publicising their progress and achievements. Data suggests that not all children had completed their goals within the 5-weeks and, given their extrinsic nature, it is unclear how fulfilment (or lack thereof) of these goals would have impacted motivation in the longer term. Without additional appealing extrinsic goals, children's interest in BrainQuest may have drastically diminished. Furthermore, it is important to recognize that in some instances where a child failed to achieve their goal and earn their extrinsic reward, it sometimes had a negative effect upon their perceived competence. In hindsight, with more detailed and encouraging feedback that negativity may have been somewhat mitigated (DR7).

For those who invested in the extrinsic motivators, it also seems that the appeal of these extrinsic goals was so powerful because of the social value of the achievements given. Children were frequently seen telling others of their achievements and many discussions were observed between groups of children comparing trophy cabinets and leaderboards. Initially this may have been an easy outlet for the high performing children to feel pride but over time the discussions involved children from all spectrums of ability, transcending the boundaries of friendship groups and gender, and conversations did not seem to be constrained to BrainQuest achievements, suggesting a greater sense of community may have been forming. Further research is required to categorize the nature of the conversations invoked to better understand this phenomenon and its relationship to individual performances.

The implication for serious game designers is, therefore, that extrinsic motivators can have intrinsic consequences but it may depend upon the nature of the game design and the environment of play (DR8). In this example, without the outlet of real-world face-to-face communication between peers, they may not have held the same value and would have been unable to facilitate the same sort of social interaction.

6.2 Efficacy of BrainQuest's Cognitive Challenge

Although the primary focus of this paper considers the appropriateness of gamification influenced by motivational design theory, an engaging serious game is only of limited use if it fails in what it is trying to teach. The study presented suggests that BrainQuest presents a viable challenge to cognitive and emotional regulatory skills based on both the qualitative and quantitative data. However, the extent of this challenge, its accessibility players of different ability levels, its sustainability over time, and its impact upon real world functioning all require additional study. This section explores the current findings and considers these factors.

6.2.1 Interpretation of Quantitative Results

As stated, there was moderate correlation between 6E pre-test performance and BrainQuest hero role performance measures yet the interpretation of this is unclear. On one hand, it may validate BrainQuest's challenge of a similar subset of EF skills given the relationship between the structure and task ordering rules of BrainQuest and the 6E. Moreover, the rustler role also exhibited a low correlation with the 6E test, suggesting EF was also a factor in multiple roles.

Equally, however, the hero correlation was only moderate with the 6E and there were no correlations with any other pre-test subtest. There may be several plausible reasons for this. The hot EF component of the game which involves emotional regulation may have been far more prevalent

than expected, for example directly during hero-rustler interactions and indirectly through the social implications of motivational phenomena (i.e. the leaderboard, trophies, or self-constructed social goals). Hence, this may have influenced the decision making and behaviour of children during BrainQuest but not during the 6E and the other BADS-C subtests which are of a more cool and cognitive nature.

Similarly, the diverse and unique nature of the EFs challenged throughout during a game of BrainQuest may have also made it less likely for association with one single subtest. For example, each BADS-C subtest challenges a specific combination of cognitive skills which together produce an end result – the sum of its parts. However, though these tasks share certain cognitive skills (e.g. working memory, inhibitory control, strategizing – like the 6E and BrainQuest), performance is usually compared with respect to the complete results and not the results of isolated skills. This mirrors real-world functioning because we usually use multiple combinations of skills during a particular task but also explains why tasks presumed to involve similar skills can have different results – sometimes regarded as the task impurity problem. Further illustrating this is the lack of relationship between the BADS-C subtests themselves. The BADS-C subtests themselves mostly fail to correlate with each other – in our dataset at pre-test, only the Playing Cards test significantly and moderately correlated with Zoo Map 2. There were no correlations at post-test.

There are also user interface differences between the 6E and BrainQuest – the way task choice is presented to player which may affect a player's approach. For example, in BrainQuest, following the completion of an instance of one task, the user is returned to the task choice screen and only then presented with 6 possible task choice thumbnails. In the 6E, different task choices remain visible throughout as all tasks are placed horizontally on the desk and they may do as many instances as they like of one task in succession before changing task type. This difference in task demands may also change the way they approach the 6E test in comparison to BrainQuest and can even allow for additional strategies e.g. doing an equal number of instances of each task type.

Furthermore, BrainQuest has a greater number of rules than the 6E test. In BrainQuest there are several procedures within one instance of a task with associated rules. I.e. to return a cow, the hero must (1) pick up a cow from the play space and scan the tag, (2) return to the hero cow pen and scan the pen to open it, (3) place the cow in the pen. Additional rules are also involved in the rustler role, e.g. the user interface (i.e. a range of alternative buttons to press depending upon whether the hero pen is full or empty, and a button to press if caught by the hero) and rules of movement and interaction. Players must work with additional long-term memory items like previously successful strategies and opponent characteristics. Consequently, understanding BrainQuest may be a more demanding challenge to EF.

In summary, in making an executive training task which takes an eclectic and wide-ranging approach to challenging cognitive and emotional regulatory skills, it makes the evaluation of outcomes of EF hard to measure. Hence, producing an exact correlation between EF and a specific assessment, despite shared qualities, may be impossible. Further, changing the training task so that it would hold greater congruency (e.g. removing hot EF or physical activity challenge) may increase the correlation but also likely hampers the training value of the task. Hence, further quantitative evidence of EF training will need to consider many tests which provide a diverse an ecologically valid picture of ability of both cognitive and emotional regulatory skills, while ensuring study samples have the required power.

6.2.2 Interpretation of Qualitative Results

The correlation between multiple BrainQuest performance measures and BADS-C pre-test performance supports the premise of the game's EF challenge. However, it appeared that challenge evolved throughout the evaluation. For example, only 9 children completed all difficulty levels so it appears there was some success in sustaining challenge over time. The game also seemed to

distinguish between different ability levels because the participants' final difficulty level achieved was spread across the game levels at the end of the project rather than all participants reaching the highest level or all unable to progress beyond the first level. However, with regards to maintaining the task novelty required to preserve maximum EF challenge and, thereby, make continual EF improvements, BrainQuest's ability is unclear. Self-reporting of the difficulty levels suggested that BrainQuest became generally easier over time. On one hand, this could imply that the variable level of 'cognitive challenge' (i.e. following the task ordering rules), yet it may also refer to initial game rule understanding and learning to use the technology.

If indeed the cognitive challenge of following the task ordering rules is becoming primarily easier over time, the evidence of task ordering rule proficiency does not necessarily support this. For example, the users who reported the game becoming easier over time deployed more complex strategies at more advanced levels of difficulty. Further, though Rookie and Professional difficulty levels had high rates of failure (failures/games played), before these rates dropped during World Class level, failure rates substantially increased at Legendary level. Hence, this may imply the successful disruption of pre-learned user plans for following the task ordering rules at the final difficulty levels. Consequently, the self-reports may suggest that the early novelty of understanding the game rules and using the technology was a significant and unforeseen challenge but one which did not remain over time. From a usability perspective, this would imply users need additional support in initial game explanations, as well as a more of an incremental and evenly spaced level of challenge between difficulty levels.

Returning to the cognitive challenge facilitated by the difficulty level system, the qualitative analysis of the case studies also supports the idea of an evolving challenge. This was demonstrated by the generation of novel, variable, and even multiple strategies by players following the task ordering rules as well as handling the social component of the game. Strategies varied in complexity and suitability depending on the difficulty level and the children were required to re-plan and develop new strategies to overcome new difficulty levels, thereby, suggesting the maintenance of a novel challenge (DR9). This is critical to sustaining improvements in EF and is an aspect missing from many CTGs which seek to manipulate difficulty through decontextualized cognitive challenges, like list lengths and speed of processing as described by Melby-Lervåg et al. (2016).

The game also presents a third challenge, necessitating emotional and regulatory skills and the interplay between these skills and the strategic cognitive demands of following the task ordering rules highlight the important relationship between cognition and emotion (DR10). Despite this, whether increases in game performance relate to any benefits in the real world demands further scrutiny. Both teachers and some specific children suggested improvements in relationships with peers and emotional regulation. Future research must corroborate individual accounts with detailed qualitative data from parents and other sources, real-world assessment questionnaires, and objective measures of real-world benefits (e.g. test scores).

6.3 Recommendations for designers of cognitive training games

The answers to the research questions discussed in the previous subsections provide some important lessons for the future of cognitive training game design and more general design lessons which are relevant to serious game designers who are contemplating gamification of serious content.

Greater reflection on understanding human motivation and the reflecting on the continuum that exists between extrinsic and intrinsic motivation and the pathways which can encourage greater internalization of motivation over time is critical. For cognitive training, individuals need encouragement to repeatedly use and practice skills and while extrinsic motivators (like leader-board and reward systems) are useful for capturing early user motivation, they should not exist alone.

When coupled with sources of intrinsic motivation (like competence, relatedness and autonomy), extrinsic motivators can play a useful supporting role and may even assume intrinsically motivating properties over time. For example, the (intrinsic) social interactions and goal setting precipitated by the (extrinsic) trophies and leaderboard, and the (intrinsic) feelings of competence gained from achieving the (extrinsic) reward. Nevertheless, it is important to recognize that extrinsic motivators may not hold universal appeal and can still have undesirable consequences if not executed correctly (i.e. feelings of competence when being rewarded may have the opposite effect when a reward is not received – consistent with Kaczmarczyk and Markopoulos, 2017). Hence, less predictability in the timing of rewards, offering positive and detailed support to explain what they did wrong and how to improve, as well as providing a range of alternative goals for the user to refocus their energies upon if needed.

Although it may be because of its prominence within BrainQuest's design, relatedness revealed its importance for engaging children of this age. The children were motivated by playing in the same physical space as their peers and enjoyed sharing their achievements face-to-face, as well as helping each other to understand the game. For any serious game, harnessing the power of this endogenous (i.e. where one's actions directly affect their opponent) social play may pay dividends for engagement. Future cognitive training game designers must realize that the social nature of the game may also directly contribute to the efficacy of training because cognition is not isolated from affect; performance in the real world is moderated by one's emotion and capacity for behavioural regulation. Games which aim to prepare children to solve problems in the real world is more likely to be successful if social and emotional interactions are integral to the task. They also provide a more varied range of cognitive and emotional challenges which may be more relevant to the real world. Despite this power, however, games with an endogenous social component require a means to maintain order and help the players involved (if children) to be self-governing rather than requiring a referee.

In summary, it appears that competence, relatedness, and autonomy share a reciprocal relationship where they promote each other. Furthermore, designing CTGs which support social interaction and the scaffolding of challenge may produce viable and ecological tests of cognitive skills beyond gamified cognitive activities. As such, it is fundamental these pillars are incorporated into serious game design more widely, much less cognitive training games, and designers should design for engagement from the outset rather than as an afterthought.

Based on the lessons we have learned from our work on BrainQuest, we have curated the following recommendations for the designers of future cognitive training games:

> **DR1:** Endogenous face-to-face social play (typified by playground games) is an immensely powerful tool to promote engagement and as a viable hot EF challenge but children may require support to ensure fair and equal gameplay
>
> **DR2**: To encourage cooperative game play, shared goals and objectives should be considered, and opportunities for social interaction should be plentiful
>
> **DR3:** Consider the real-world changes to relationships between players both within and beyond the game environment to assess the extent of relatedness achieved
>
> **DR4:** Allowing users to impose their own ideals and versions of the defined fantasy may encourage wider engagement
>
> **DR5:** Greater analysis of individual playing styles and rewarding self-expression may enhance feelings of autonomy

DR6: Individualized game difficulty challenge should be included to maximise training efficiency and to sustain engagement

DR7: Extrinsic motivators can be a useful way to reflect activity competence but care should be taken to ensure they don't become a double-edged sword, and that equal feedback supports are there to soften the blow of failing to achieve a goal

DR7: Extrinsic motivators can have intrinsic consequences when executed correctly and with the correct outlets

DR8: To replenish the novelty of cognitive challenge required by higher-order executive skills, cognitive training games should present obstacles to previously successful strategies

DR10: The relationship between cognition and emotion should be appreciated by game designers due to its reflection of real-life challenges

6.4 Appropriate research methods for future gamification studies

As we have argued that relatedness is key to engaging children, social interactions during the task should be encouraged to develop real word problem solving skills. Researchers should develop appropriate methods for evaluating the social aspects of cognitive training games. Qualitative observational data is time consuming to gather and analyse but it may be possible to find evidence of social interactions between players through social network analysis of log file analysis and proximity of devices.

Video data would be especially useful for studies of multiplayer games like BrainQuest, where a lot of activities and interactions are occurring concurrently. This would allow a greater depth reflection upon observations and the chance to better understand environments (e.g. social interactions and strategies) from different points of view. It would also aid with the reliability of the analysis, as multiple researchers would be able to individually interpret the same sequences of events. However, such in depth analysis would greatly increase analysis time.

In the BrainQuest study reported in this paper, strategies had to be discerned by hand from the data logs which was a very time-consuming process and, consequently, could only be completed for the case study participants. An automated pattern recognition system for known and emerging strategizing could be very useful in understanding how children attempt to solve problems and how this changes over time.

There is also potential to take advantage of emerging multimodal measures of engagement. Recent technical advances have made it possible to gain measures such as eye gaze, electroencephalogram (EEG) or skin conductivity from mobile interaction. Such data can be triangulated with observational data such as that reported in this paper. Furthermore, as suggested by Kaczmarczyk and Markopoulos (2017), creating such an understanding of individual players may allow the game to be tailored to individual user experience requirements and contribute to greater engagement.

Finally, this study has illustrated the importance of the longitudinal evaluation of games where motivational factors exist because it is important to capture how the motivational pathways for the user change as they become more familiar with the game.

6.5 Current Limitations

The work presented in this paper represents an initial evaluation with the goal of appraising the engagement value and gaining early insights into the viability of BrainQuest's cognitive challenge. Through the design of BrainQuest, our research addresses many limitations present in cognitive

training games and serious games more widely, such as the practice of gamification using extrinsic motivators and the creation of varied cognitive and emotional regulatory challenges with a strong training efficacy rationale, yet some methodological shortcomings must be addressed in future studies. For example, if BrainQuest appears present a cognitive challenge while encouraging engagement, it would be pertinent to compare it to other engaging games associated with positive cognitive and emotional regulatory training (including any viable cognitive training games, sports, and playground games) as active controls.

The 5-week study described was designed to appraise BrainQuest's efficacy and, hence, the goal was to concentrate on gathering qualitative insights from a limited number of children to make further refinements to the game's design before attempting to ascertain its effectiveness quantitatively by comparing means using a range of appropriate cognitive tests. This first step of establishing efficacy seems to be overlooked by many cognitive training game researchers, and their impatience to publish inferential statistics to prove game effectiveness may be one of the reasons why game designs have suffered and critics have preyed upon methodological research weaknesses. Hence, while the lack of inferential statistics may be viewed as a limitation, in our view it is a logical next step but would have not been appropriate at this stage of our research.

6.6 Future directions for BrainQuest

These results are from a study of a relatively small number of users. A further study is required in future to conduct a quantitative evaluation of changes in EF outcomes. An appropriately powered cluster randomised trial should be conducted to document changes in EF because of playing the game. Care should be taken when choosing the tools for measuring EF changes: in common with other EF tests, BADS-C suffers from low re-test reliability, partly because an inherent aspect of successful EF is to adapt to novel situations. Furthermore, our eventual aim is that BrainQuest should help children to develop EF skills which help them to cope with real world problems. Therefore, establishing changes in a cognitive test score would be only partially successful. Evidence of changes in the real-world use of EF skills would be more compelling, perhaps as measured by a behavioural inventory of EF as carried out by a teacher, such as BRIEF 2 which has a high retest reliability (Dodzik, 2017).

Another direction for future research would be to establish the relationship between the points system with the game and the 6E test in BADS-C – (or other measures of EF). It would be beneficial to psychologists if a game like BrainQuest could be used to reliably and dynamically measure fine grained changes in EF over time with low participant burden. This is in stark contrast to traditional 'paper and pencil' measure of EF in which the measures and tests are static. Similarly, the development of automated strategy detection from log files (which would enable scaling up of the hand analysis of case study children's log files in this study) would give insight into how multitasking and cognitive flexibility develop in individuals.

7. Conclusion

The paper presented an initial evaluation of a novel active smart phone game for developing children's executive function, which coupled cognitive training demands with motivational game design theory. The game sought to encourage repeated play by creating an intrinsically motivating user experience which fostered social abilities and self-confidence, while creating a layered challenge for both hot and cool EF skills. A mixed methods evaluation during a 5-week study with twenty-eight 11-12-year-old school children provided exploratory qualitative and quantitative evidence on the potential benefits of the game. From an executive function perspective, the game appears to demand strategy generation of variable complexity, as well as emotional regulatory

challenges – hence, representative of real world EF challenge. From a user experience perspective, the intrinsically motivating game design decisions produced sustainable user engagement which did not appear to suffer from novelty effects. The game's multiplayer design encouraged a range of positive social interactions and a sense of community, most often characterized by help for one another which crossed friendship group borders. The extrinsic motivators, trophies and leader-boards, also contributed to feelings of pride and positive social interactions for many children.

In reference to previous gamification research, the evidence gathered from this study suggests that in serious games, reward-based systems can be a useful technique when they are used in a supporting role within an intrinsically motivating game environment, rather than as the focal point of gameplay. With respect to cognitive training games, designers should focus on creating gameplay which can remain engaging over time in addition to gamifying cognitive challenges, as repeated practice is the key to the development of any skill. Designing games to be social experiences can help to achieve this but also present an emotional regulatory challenge which is a key influence on real-world tests of cognition. Doing so may help to bridge the current gaps in transfer from training game abilities to real-world competencies.

Initial evidence supports the efficacy of BrainQuest's ability to engage users over time but additional development is required enhance successful aspects of the current design and to include further user autonomy. Although further study is required to ascertain if the game can provide any real-world executive function improvements, early indications suggest an enduring challenge to certain hot and cold EF skills is present during game play.

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Appendix

Children's Post-Testing Interview Questions

- What did you think of BrainQuest? Did your opinion change about BrainQuest over the 4 weeks? In what way? [Assessing EF Indirect Route: Fun]
- Did you find BrainQuest fun? What did you find fun about it? [Assessing EF Indirect Route: Fun]
- What parts of BrainQuest motivated you (if any)?
- Do you feel if your BrainQuest skills have changed over the 4 weeks? [Assessing EF Indirect Route: Pride/Self Efficacy]
- Did you find any parts of BrainQuest tiring? On a scale of 1 to 10, where 1 is not tiring and 10 is exhausting, how tiring was it? [Assessing EF Indirect Route: Physical Activity]
- How did you feel about playing BrainQuest in groups with your classmates? Did they ever help you in any way? [Assessing EF Indirect Route: Social Support/Belonging]
- Has anything made you feel proud while playing BrainQuest? [Assessing EF Indirect Route: Pride/Self Efficacy]
- Every time you moved up a difficulty level, how much harder was it than the level before? [Assessing EF Support + EF Direct Route: Challenge/Ability]

- Can you remember the task ordering rules? What were they? [Assessing Understanding]
- Did you ever find it hard to remember what tasks you had to do in order to win a trophy? [Follow up: If so, what difficulty level were you playing? [Assessing EF Direct Route: Challenge/Ability]
- When playing as the hero, did you have a strategy when trying to follow the task ordering rule? [Assessing EF Direct Route: Challenge/Ability]
- Were there any times where you had to change your strategy? [Assessing EF Direct Route: Challenge/Ability]
- What did you think of the Task Choice Support Tool tool? How did you use it? [Assessing EF Support]
- What did you think of the Task History Stack tool? How did you use it? [Assessing EF Support]
- Did you use the feedback after completing each game? How did you use it? [Assessing EF Support]
- What was your favourite thing about the BrainQuest app?
- If you could improve BrainQuest, what would you do?

Teacher Post-testing Interview Questions

- How enjoyable do you feel that BrainQuest has been for the children?
- How do you think the children's motivation towards BrainQuest has changed over the course of the 4 weeks? In what way?
- Has there been any discussion about BrainQuest during class time between children? If so, can you give me some examples of what you have observed? [Assessing EF Indirect Route: Pride/Self Efficacy + Social Support/Belonging]
- Have you noticed any social changes in the classroom in general or between certain individuals? Such as new friendships or changes in communication between children. [Assessing EF Indirect Route: Social Support/Belonging]
- Have any children reported BrainQuest achievements to you directly? [Assessing EF Indirect Route: Pride/Self Efficacy]
- How tired have the children been following BrainQuest sessions in comparison to with their regular PE lessons? [Assessing EF Indirect Route: Physical Activity]

We're going to focus on the case study children now (Relating to case study children):

- Have you noticed any changes in how active any of these children are over the course of the study? Do you think this is related to BQ? [Assessing EF Indirect Route: Physical Activity]
- Have you noticed any changes in any of the case study children's behaviour which you connect to BQ? In what way? Assessing EF Direct Route]
- Has there been any change in academic performance of any of the case study children which you connect to BQ? In what way? [Assessing EF Direct Route]

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Table File

Hero Task	Subtask	Description
1. Return Animal Task	1. Return Sheep	Collect animals and return them to designated 'hero' animal pens. There are two different types of return task: one for returning sheep, one for returning cows.
	2. Return Cow	
2. Stop Rustler Task	3. Stop Sheep Rustler	Chase and catch the rustlers as they attempt to steal the hero's animals and take them to their 'rustler' pens. There are two different types of chase and catch task: one for sheep rustlers, one for cow rustlers.
	4. Stop Cow Rustler	
3. Save Animal Task	5. Save Sheep	Save animals who have been captured inside rustler pens. There are two different types of save task: one for saving sheep, one for saving cows.
	6. Save Cow	

Table 1. BrainQuest Hero Tasks

Play Space Element	Description
Hero Sheep Pen	One blue hula hoop is the 'hero sheep pen'. The hero returns sheep bean bags from the middle of the play space to this pen one at a time. The hero may also capture sheep from rustlers and return it to this pen. Meanwhile, rustlers visit the pen to steal hero owned sheep bean bags.
Hero Cow Pen	The other blue hula hoop is the 'hero cow pen'. The hero returns cow bean bags from the middle of the play space to this pen one at a time. The hero may also capture cow bean bags from rustlers and return it to this pen.
Rustler Sheep Pen	One red hula hoop is the 'rustler sheep pen'. The rustlers use this pen to store sheep bean bags stolen from the hero sheep pen. The hero may visit the rustler sheep pen to rescue sheep bean bags.
Rustler Cow Pen	The other red hula hoop is the 'rustler sheep pen'. The rustlers use this pen to store sheep bean bags stolen from the hero sheep pen. The hero may visit the rustler sheep pen to rescue sheep bean bags.
Sheep Bean Bag	Multiple (6+ sheep) sheep bean bags are scattered around the play space. Each sheep has an NFC sticker on it which can be scanned by a player's smartphone.
Cow Bean Bag	Multiple (6+ cows) cow bean bags are scattered around the play space. Each sheep has an NFC sticker on it which can be scanned by a player's

	smartphone.
Hero Owned Bean Bag	Hero owned sheep and cow bean bags reside in the hero pens, having been previously collected from the play space or rescued from a rustler pen.
Rustler Owned Bean Bag	Rustler owned sheep and cow bean bags reside in the rustler pens, having been previously stolen from hero pens.
Pen Signs	Every hero and rustler pen has a sign on the outside which corresponds to visual stimuli presented on the BrainQuest interface, to guide the player to the corresponding physical location. To access the contents of a pen (to 'unlock') the pen, the player must scan the pen NFC tag using their smartphone.

Table 2. BrainQuest Play Space Setup

Hero Task Ordering Rule	**Example**
Rule 1: For each task choice, the hero must change task type.	If a hero player completes a 'Save Sheep' subtask, they must not repeat another task of the 'Save Animal' type for their next choice – i.e. not a Save Sheep, nor a Save Cow. Instead, they must undertake a subtask of the type 'Stop Rustler' or 'Return Animal'.
Rule 2: Within the 5-minute time limit, the hero must make sure that they have attempted all 6 subtasks while following Rule 1.	The hero player must have completed at least one instance of Return Sheep, Return Cow, Stop Sheep Rustler, Stop Cow Rustler, Save Sheep, and Save Cow within the time limit.

Table 3. BrainQuest Hero Task Ordering Rules

Rookie Difficulty (Level 1) Tools:	**Professional Difficulty (Level 2) Tools:**	**World Class Difficulty (Level 3) Tools:**	**Legendary Difficulty (Level 4) Tools:**
Task Choice Support Tool (EF Support)	Task History Stack (EF Support)	Task History Feedback	Task Randomizer (EF Aggravator)
Task History Stack (EF Support)	Task History Feedback	Written Instruction	Task History Feedback
Task History Feedback	Written Instruction	Audio Commentary	Written Instruction
Written Instruction	Audio Commentary		Audio Commentary
Audio Commentary			

Table 4. BrainQuest Difficulty Levels & Support Tools

6E Task Ordering Rule	Example
Rule 1: For each task choice, the individual being tested must change task type.	If the individual being tested completes a 'Green Part 1' subtask, they must not repeat another task of the 'Green Task' type for their next choice – i.e. not a Green Part 1, nor a Green Part 2. Instead, they must undertake a subtask of the type 'Blue Task' or 'Red Task'.
Rule 2: Within the 5-minute time limit, the individual being tested must make sure that they have attempted all 6 subtasks while following Rule 1.	The individual being tested must have completed at least one instance of Green Part 1, Green Part 2, Blue Part 1, Blue Part 2, Red Part 1, Red Part 2 within the time limit.

Table 4. 6E Task Ordering Rules

6E Task	Subtask	Description
1. Green Task	1. Green Part 1	Green Part 1 and Part 2 are a series of cards in their respective piles. For both parts of the Green Task, the individual being tested picks up the top card on the pile, turns it over and solves the simple arithmetic question on the other side. They write down their answer to the question before putting that card to the bottom. The arithmetic questions can be in form of a simple written addition or subtraction or there may several illustrations they must count (e.g. 2 ducks, 4 dogs).
	2. Green Part 2	
2. Blue Task	3. Blue Part 1	Blue Part 1 and Part 2 are a series of cards in their respective piles. For both parts of the Blue Task, the individual being tested picks up the top card on the pile, turns it over and solves the picture naming question on the other side. They write down their answer to the question before putting that card to the bottom. The picture naming questions are single drawings of objects.
	4. Blue Part 2	
3. Red Task	5. Red Part 1	Red Part 1 and Part 2 are two different boxes containing. For both parts of the Red Task, the individual being tested opens the chosen box and must sort the containing items into the lid according to the corresponding symbol. The boxes for each part contain different items to be sorted – one containing multi-coloured and multi-shaped beads, and the other a mixture of nuts, bolts, and washers
	6. Red Part 2	

Table 5. 6E Tasks

EF Skill	EF challenge in 6E	EF challenge in BrainQuest
Motor Cognitive Coordination	Not challenged in the 6E test.	BrainQuest requires cognitively engaging physical activity, to follow the task ordering rules and emotional regulatory challenges while moving around the play space. Players must also coordinate on-screen activities (instructions, task choices, animations, feedback) with physical actions, as well as interactions with other players.
Working Memory	Working memory in the 6E is required to remember the previously completed task and whether the planned action is compliant with task ordering rules.	The same working memory demands as the 6E but with additional coordination demands: 1. Recall previously completed tasks in short-term memory and use working memory to check whether planned action is compliant with task ordering rules (also held in short-term memory). 2. Store and update visual, spatial, and auditory information of opponent's movements in working memory. 3. Review information from long-term memory regarding opponent characteristics and tactics, previously successful strategies, task procedures. Task support tools also help tailor working memory challenge. At World Class difficulty level, where Task Choice Support tool and Task History Stack are removed, BrainQuest becomes comparable to the 6E test. Then with the introduction of the Randomizer at Legendary level, the working memory demands increase. For each difficulty change, the goal of these tools is disruption of existing strategies. For example, if the user was using the task choice interface as a representation system and holding it in working memory, Legendary difficulty level sought to disrupt that visual image stored in working memory by randomizing the thumbnails in a different order using the Task Randomizer tool – requiring the user to manipulate the image in their mind.
Inhibitory Control	The 6E requires cool inhibitory control, such as sustained attention to complement working memory in staying focused on the goals of the	The test of cool inhibitory control skills involves switching attentional resources between multiple perceptual stimuli and the movement patterns of real life opponents. This potentially requires the hero to switch more regularly

	task. Furthermore, there may be an element of selective attention required in keeping track of the time limit.	between sustained attention, selective attention and inhibition of action. There are hot EF demands required due to the social component of the game and the need to regulate emotions. Interactions may challenge inhibitory control. There is potentially added temptation for the hero to catch rustlers to impact on their opponent's score. This exploits the competitive element of the game to increase the level of self-control required during interactions. The nature of the interaction and the amount of self-control required may depend on the different mix of competitors involved in the game. Thus, teaching interactions with friends, acquaintances, and rivals – relevant to real-world contexts.
Planning / Strategizing	In the 6E planning / strategizing are required to optimally sequence tasks in terms of developing a pattern of task choice and designating equal chunks of time to each task.	Planning/strategizing skills are challenged by optimally sequencing tasks at each difficulty level. However, the incremental removal of supports and the later introduction of extra challenge may require changes in strategy and reformulation of plans – changing the task demands rather than training a specific strategy or process.
Cognitive Flexibility/Set Shifting	Cognitive Flexibility/Set Shifting is required to shift between different tasks in the 6E test often enough so that they undertake all 6 tasks but not so much that they waste time. Furthermore, some task changes include changes, such as the "how many" cards actively change an individual's predicted task demand - e.g. the user must count the number of different objects on a card after experiencing multiple cards with objectively written sums upon them.	Like the 6E, the player must time manage to complete all 6 tasks within the time limit. However, additional challenges exist in BrainQuest, as certain tasks hold a greater social weight – i.e. hero-rustler interactions. Cognitive flexibility may also be required to react to changes in the game environment or arising opportunities e.g. because of rustler behaviour or positioning. It may also be required when attempting new difficulty level for the first time and discovering a previous strategy has been rendered redundant.
Task Scheduling	Task scheduling is required when the user allocates time to the 6 different subtasks.	The same as the 6E test, the player must allocate time to each subtask to complete all 6 tasks.
Performance	The user must monitor one's own thoughts and actions, as	Like the 6E test with regards to monitoring

Monitoring	well as to self-correct those thoughts and actions to follow the task ordering rules completely.	performance in following the task ordering rules, though Task History Stack, point scores, graphics and sounds provide additional feedback on performance

Table 6. EF Challenge: BrainQuest vs 6E

Code	**Description**	**Kappa Agreement Value**
BrainQuest Design	Data related to observed appraisal of specific BrainQuest design decisions – (1) Playground Game Activities; (2) Fantasy Story, Sounds, Animations, Tangible Objects; (3) Game Difficulty; (4) Support Tools; (5) Rewards; (6) Trophies; (7) General Likes and Dislikes; (8) Ease of Understanding	0.72
Emotional Behaviour	Data related to the observed emotional behaviour during BrainQuest sessions – (1) Challenge of Emotional Regulation; (2) Enjoyment; (3) Competence; (4) Autonomy; (5) Negative Emotions	0.70
Social Behaviour – *Competition*	Data related to the observed emotional behaviour during BrainQuest sessions – (1) Social interaction; (2) The nature of interaction; (3) Relatedness	0.49
Social Behaviour – *Conversation*		0.63
Social Behaviour - *Cooperation, and Encouragement*		0.72

Table 7. Coding scheme used in thematic analysis

Complexity Level	Strategy Description	Strategy Explanation
None	Uninterpretable or no strategy	The user makes no attempt to follow either task ordering rule.
None	Grouping tasks of the same type together	The user groups tasks of the same type together breaking task ordering rule 1.
Low	Simple task type change each time	The user changes task type each time but task selections may be random and they may not complete rule 2.
Low	Task type = n-2 throughout	The user maintains the same task type on every second selection throughout and they may not complete rule 2.

	* n = current task number	
Moderate	Task type = n-2 until all subtypes complete * n = current task number	The user maintains the same task type on every second selection throughout and attempts a previously unimplemented task of the 6 subtypes in between times.
High	2 or more consecutive cycles comprising 3 different types	The user completes 2 or more cycles, each comprising 3 different task types to complete rule 2 without breaking rule 1.
Very High	Grouping animals together for 2 or more consecutive cycles of 3 tasks	This strategy builds upon F but for each cycle of 3 the user is consistent in their choice of animal.
Very High	Undertaking task types in a repeatable order for 2 or more consecutive cycles	This strategy builds upon F but for each cycle of 3 the user is consistent in the order in which they pick tasks e.g. return, save, stop.
Very High	Selecting tasks top to bottom for 2 or more consecutive cycles	This strategy builds upon F, G and H but the user uses the interface to guide choices e.g. return cow, stop cow rustler, save cow, return sheep, stop sheep rustler, save sheep.
Maintenance + High	Changing to a more simplistic strategy after completing all 6 task types - in other words, making rule 1 a priority	After completing rule 2 using a moderate or high-level strategy, the user may change to a low-level strategy which allows them to concentrate on attending to rule 1. This is an efficient strategy as it relinquishes having to hold both rules in working memory.
Maintenance + Moderate	Stopping additional tasks to preserve trophy	After completing rule 2 using, the user may stop undertaking any further tasks to leave no chance of breaking rule 1. This strategy is likely to end in success but drastically limits the number of hero points available.

Table 8. BrainQuest Strategies

	Session 2 end	Session 3 end	Session 4 end	Session 5 end	Session 6 end	Session 7 end
Rookie	92.9%	67.9%	39.3%	21.4%	7.1%	10.7%
Professional	0%	14.3%	35.7%	42.9%	35.7%	14.3%
World Class	0%	0%	10.7%	10.7%	17.9%	21.4%
Legendary	0%	0%	0%	10.7%	21.4%	21.4%
Completed All Levels	0%	0%	0%	0%	0%	32.1%

Table 9. Difficulty Level Progression by Session

Figure File



Figure 1. BrainQuest NFC Interface (Gray, 2017)

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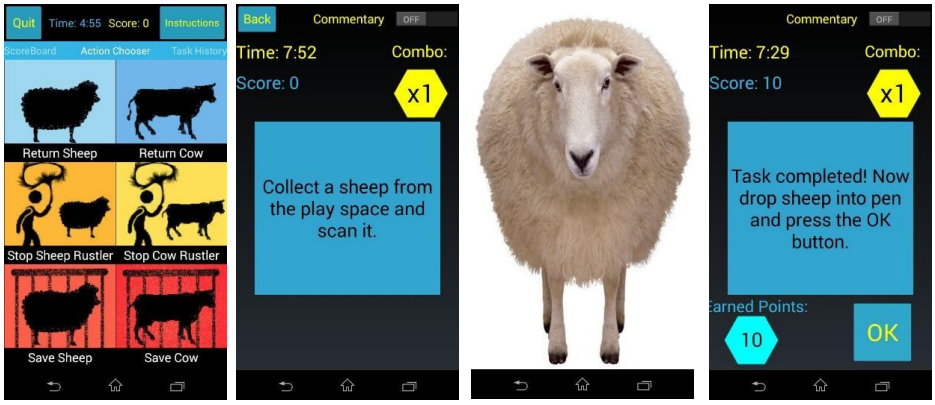
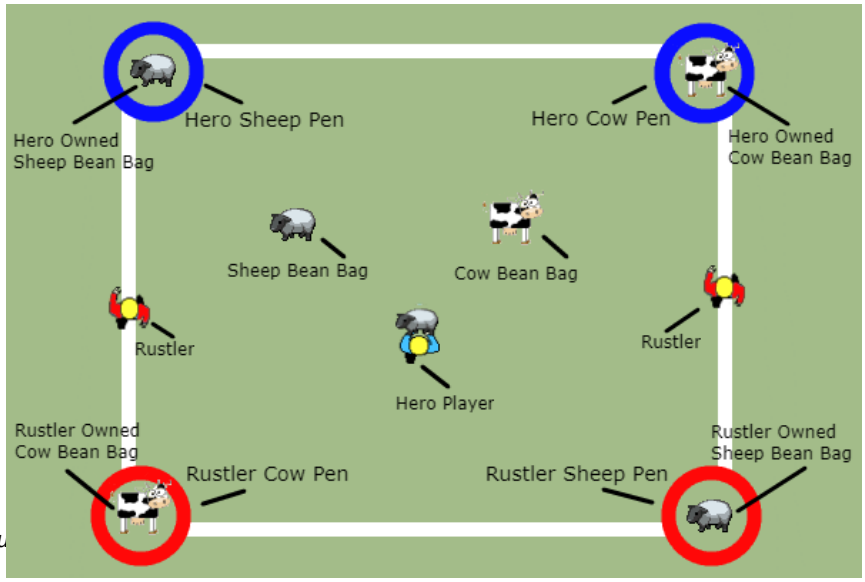


Figure 2. BrainQuest Hero User Interface (Gray, 2017)



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Figure 4. BrainQuest Play Space – Mock-up Diagram (Gray, 2017)



Figure 5. BrainQuest Fantasy Enhance Examples (Gray, 2017)

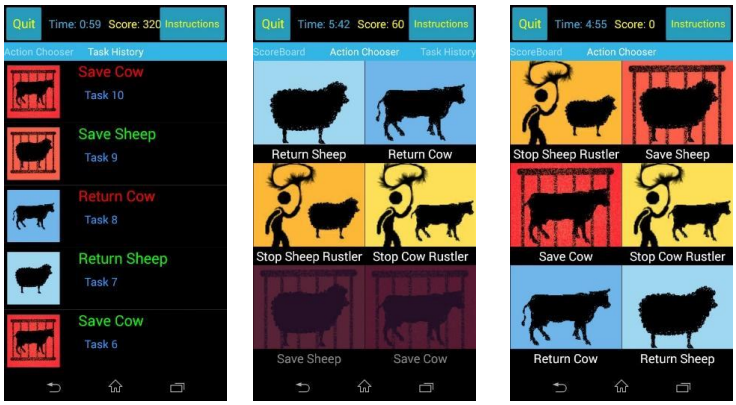


Figure 6. *Task History, Task Shader, Task Randomizer Tools (Gray, 2017)*

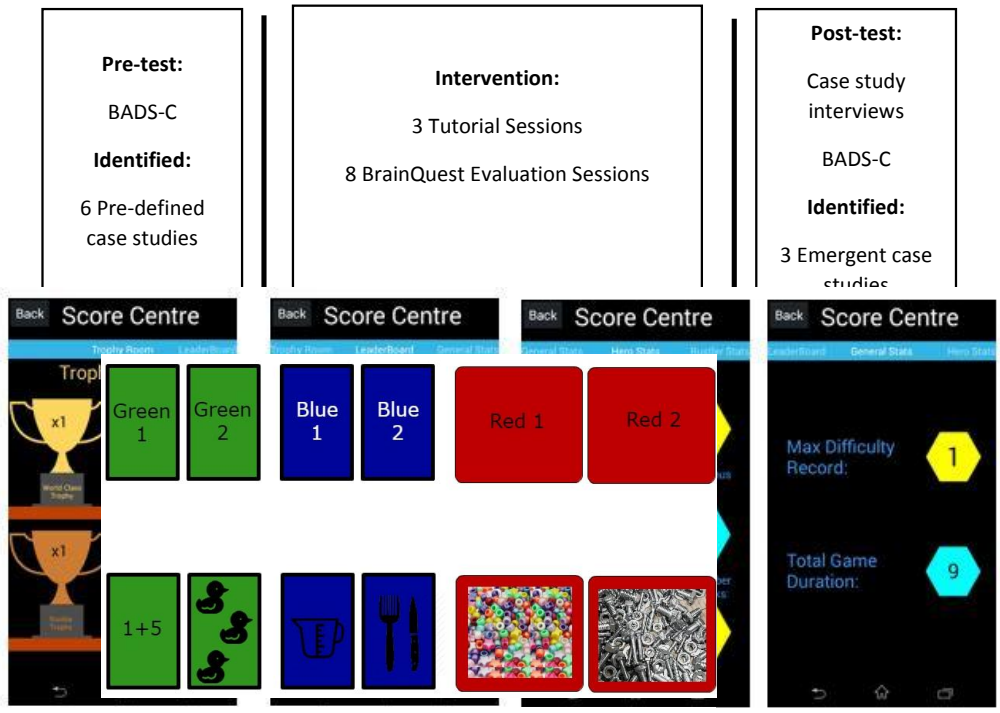


Figure 8. Modified 6 Elements Test (6E) (Gray, 2017)

Figure 7

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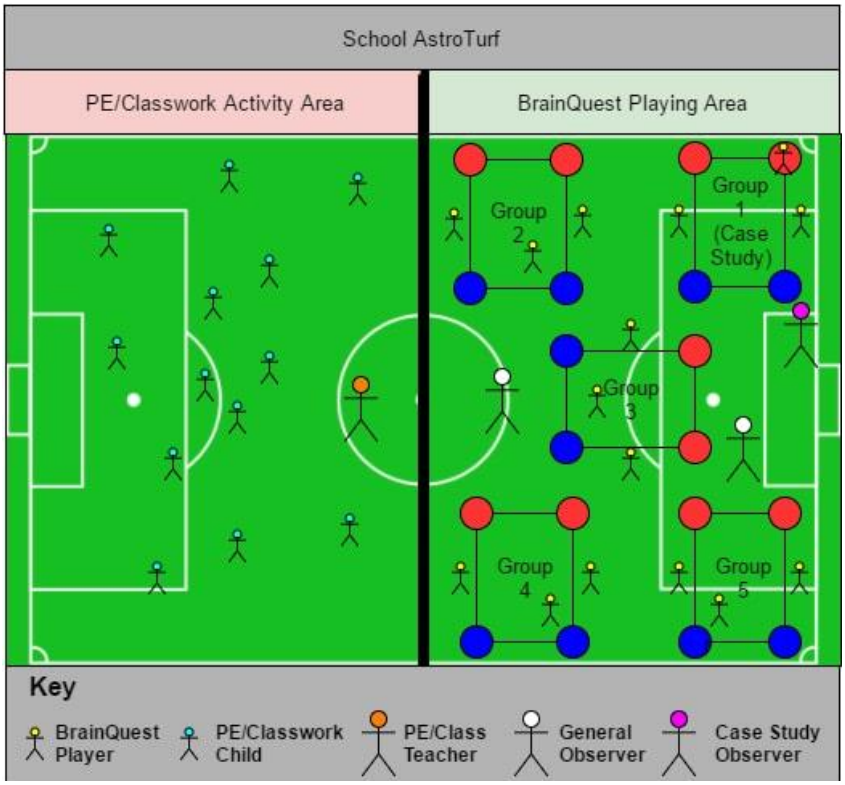


Figure 10. BrainQuest Study Game Space Setup

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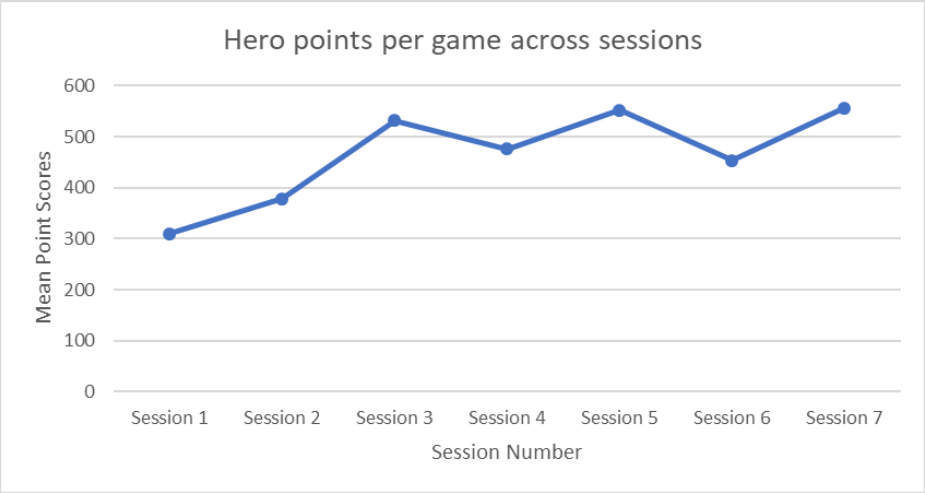


Figure 11. Hero points per game across sessions

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