Guidelines to Assist Building Effective Educational Applications And E-Games for Children With ADHD

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Declaration

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Abstract

Many researchers and psychology specialists aim to develop educational applications and e-games, which target cognitive abilities, behavioural and social skills for children with Attention deficit and hyperactivity disorder (ADHD). These applications apply certain learning strategies that might improve certain abilities and skills. They could be found easily in online stores, yet hard to judge the efficiency and desirability of each one unless they are evaluated and tested. For this reason, there was a need for the existence of a list of guidelines that could be used to assist building learning systems with effective e-strategies for children with ADHD. The main objective of this work was to form a foundation that guide software developers in implementing effective educational applications to develop these children's abilities and skills. In addition, it may help educators and parents to distinguish between available applications. As our first stage of investigation, a meta-analytical review of multiple empirical studies was conducted, that outlined the effective game features on the development of abilities and skills for children with ADHD. Five units of analysis were done separately, targeting: attention, working memory, processing speed, behaviour, and social skills. The most significant and effective methods/features from the included studies were highlighted and used to draw out our list of guidelines. As the second stage, we investigated an existing e-game with certain game features to check if our guidelines apply, and evaluated its effectiveness toward improving cognition, behaviour and social skills. Seventeen female students with ADHD, from two primary schools in Saudi Arabia, participated in the evaluation. they played with the game three sessions a week, for four months. Significant improvements found on their cognition, behaviour, social skills and academic performance. As for our intervention, we validated 'e-socialization' component;

by developing and evaluating a social online tool for children with ADHD. Seven Saudi students with ADHD, aged between 6 and 8 years, participated in the evaluation. The intervention involved playing ACTIVATE mini games, and a chatting session after each game. Children showed fairly significant improvements in games scores. The online socialization tool, found to be positively influencing children's knowledge and experience exchange, motivation, and social skills. As a conclusion, we could say that our produced list of guidelines might assist in building effective applications and games for children with ADHD. Therefore, aiding the process of improving their academic achievements, improving their cognition and behaviour, and supporting socialisation.

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List of abbreviations

AACAP	American Academy of Child and Adolescent Psychiatry
ACTeRS	ADD-H: Comprehensive Teacher Rating Scale
ADD	Attention Deficit Disorder
ADHD	Attention Deficit Hyperactivity Disorder
AES	Attention Enhancement System
APA	The American Psychiatric Association
CASTT	The Child Activity Sensing and Training Tool
CI	Confidence Interval
CWMT	Cogmed Working Memory Training
DSM III	The third edition of the Diagnostic and Statistical Manual of Mental Disorders
DSM III-R	A revision of the DSM-III
DSM-5	The Fifth Edition of the DSM
DSM-IV	The fourth edition of the DSM
DTI	Diffusion Tensor Imaging
EEG	Electroencephalography
EF	Executive Function
ERIC	Education Resources Information Center
fMRI	Functional Magnetic Resonance Imaging

HCI	Human-Computer Interaction
HSQ	Barkley Home Situations Questionnaire
ICF	International Classification of Functioning
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
iOS	iPhone operating system
KSA	The Kingdom of Saudi Arabia
LD	Learning disability
MEG	Magnetoencephalography
ms	Milliseconds
NIH	The National Institute of Health
RIGO	The Research Integrity and Governance Office
RT	Reaction Time
SEN	Special Educational Needs
SSQ	Barkley School Situations Questionnaire
TRF	Teacher Report Form of the Child Behaviour Checklist
VR	Virtual Reality

Chapter 1

Introduction

The first thing that parents think about when their child reach the age of understanding is searching for an educational institute that develops his/her knowledge and cognition, so he/she can enjoy a bright and a successful future. They start their search by looking for a school that have a good reputation, with qualified teachers who have excellent educational experience in delivering information and skills development. Highly qualified teachers can identify the different levels of their students and classify them based on their understanding of the curriculum, through observation and assessment. In fact, some of the students have learning issues that might affect their overall academic progresses and achievements.

Some of the issues that students could suffer from are caused by a behavioral condition called Attention Deficit Hyperactivity Disorder (ADHD). In simple words, the child with ADHD is hyperactive and sometimes impulsive; additionally, he/she has attention problems, disorganized, and faces difficulties in finishing tasks. These symptoms could be reflected at school as difficulty in managing impulsive manners, not paying attention to teachers in classroom, poor skills in mathematics, and may struggle in reading (Vicini, 2011). ADHD was discovered a long time ago, but now it becomes easier to recognize on individual cases because of the awareness of some teachers and parents about it. We can say that it is widely spread among students especially from pre-school until 12th grade; this is supported by the findings of a meta-analysis of more than 170 studies, done globally, on the occurrence of ADHD in children in school age, which stated a percentage of 7.2% (Thomas et al., 2015).

In school environment, the teacher has a significant role in recognizing the students with ADHD symptoms. On the other hand, teachers must be equipped with the knowledge for dealing with this learning need using best ways and strategies; to ensure providing those students with equal learning chances. It is recommended for teachers to improve their teaching methods as well as using different kinds of strategies to deliver better learning for children with ADHD. Some teachers stimulate and attract their attention by utilizing sounds, bright colours, movements, or images during lessons. Others tend to use more effective strategies such as: stimulate teamwork, theatrical presentations, choice making, peer tutoring, and create competition among students through contests and other creative methods (Loe, Feldman, 2007).

In the beginning of this millennium, technology have been engaged in all aspects of our daily lives. Schools and educational institutions introduced the latest technology in their educational systems as effective tools to assist in the academic development of their students. Classrooms have been modernized to include technical tools and devices to assist delivering information in an interesting way. Students use different applications to understand mathematical problems, to produce creative short movies, to organize agenda and much more (Lewandowski et al., 2016; Storksdieck, Hunter,2017). More teachers and researchers now are encouraging the admission of handheld devices and mobile phones into classrooms as assistive technological tools, which have proved their effectiveness in improving children skills (Storksdieck, Hunter,2017). Now, the teacher is no more the central source inside the classroom, instead he/she became the supervisor and the assistant in this open-source technical context (Goodwin, 2012).

For this reason, many researchers and psychology specialists were encouraged to develop applications and games, which target cognitive abilities, behavioral and social skills for children with ADHD (Bul et al., 2015). These applications apply certain developing strategies that might improve attention and working memory, organization and time awareness, hyperactivity control and behavioral skills, social skills and problem solving, etc. They could be found easily in online stores, yet hard to judge the efficiency and desirability of each one unless they are evaluated and tested. In the presence of technological treatments and interventions, there is a need for the existence of developing guidelines or recommendations that could assist building systems with effective e-strategies for children with ADHD.

1.1. Aims and Objectives

The Key Research aim is to come up with a list of guidelines, which propose automated strategies (features). It could help, assumingly, interface designers and developers create effective learning systems for children with ADHD to improve their abilities and skills. Utilizing this model might results in better academic achievements; improvement in cognition and behavior; and reinforcing socializations.

Therefore, to achieve our ultimate aim, we proposed Three-fold objectives.

First of all, we drew out our list of developing guidelines; a meta-analysis was constructed, from multiple empirical studies, to outline the effective game features on the abilities and skills of children with ADHD. To fulfill this goal, we investigate the following research questions:

(1) What are the studies that investigated the effect of game features and technological methods on the cognition, behaviour and social skills of children with ADHD?

(2) What are the most effective and highly significant game features that target attention, working memory, processing speed, behaviour and social skills in children with ADHD?

Secondly, after choosing an existing e-game with certain game features, we inspected its effectiveness toward improving cognition, behavior and social skills for children with ADHD; as an initial investigation to check if our guidelines apply. To fulfill this goal, an experiment was performed in Saudi Arabia to investigate the following research questions:

(1) What are the effects of using an e-game to develop abilities and skills for Saudi children with ADHD?

(2) What is the user experience upon interacting with the e-game interface in terms of usability and desirability?

(3) What are the recommended amendments, that could be done, to improve the investigated e-game?

Finally, our first intention was to explore e-collaboration, which is one of the recommended components in our list. Therefore, we developed a chatting tool, for user engagement. But due to time limitations we did not have the chance to evaluate a collaborative work. Instead, we evaluated the chatting act and investigated the impact of its support for socialization on children's skills. To fulfill this goal, an experiment was performed in Saudi Arabia to investigate the following research questions:

(1) How does the use of a chatting tool by children with ADHD in school settings affect their motivation toward e-learning activities?

(2) How does the use of a chatting tool by children with ADHD in school settings affect their Knowledge and experience toward e-learning activities?

(3) How does the use of chatting tool by children with ADHD in school settings affect their Social behaviour toward their teachers and peers?

(4) Does the presence of a teacher as a contributor in the online activity affect the behaviour of children with ADHD? Is the teacher a supportive or inhibitive element?

(5) Is the developed chatting tool interface usable and subjectively pleasing for children with ADHD?

Thus, we will present and summarize, the three objectives of this research as:

- To **draw out** a list of guidelines by constricting a meta-analysis from multiple empirical studies, to outline the most effective and highly significant game features on the development of abilities and skills for children with ADHD.
- To **select** an existing e-game, with game features that fit with our list, and **evaluate** its effectiveness toward improving cognition, behaviour and social skills for Saudi children with ADHD.
- To **investigate** one of the guidelines components, by developing and evaluating a socialisation online tool for children with ADHD.

1.2.Contributions:

The contributions of the thesis are as follows:

1. Presenting a meta-analytical review of multiple empirical studies, that outline the effective game features on the development of abilities and skills for children with ADHD.

2. Investigating an existing e-game with certain game features that could fit into our list of guidelines, and inspecting its effectiveness toward improving cognition, behaviour and social skills for children with ADHD.
3. Developing and evaluating an online socialisation tool for children with ADHD

1.3. Thesis Overview:

This thesis is divided to 6 chapters, the remaining chapters is organized as follows:

Chapter 2 defines the ADHD disorder, presenting its symptoms and signs, as well as its causes and methods of diagnose. Then, it describes the criteria of choosing an e-game, with games features that met some of the effective learning strategies, that would be investigated more in the study. Additionally, the research focused, on studying the effectiveness of the selected e-game, on the abilities and skills for children with ADHD, then gives an overview about the selected e-game.

Chapter 3 presents a meta-analytical review of multiple empirical studies, that outlined the effective game features on the development of abilities and skills for children with ADHD. Then, proposes a list of recommended guidelines that could be used to build effective educational systems for children with ADHD.

Chapter 4 investigates an experimental study on the effect of using an e-game to develop abilities and skills for Saudi children with ADHD. It provides findings of three months evaluation within school settings. Also, it delivers the user experience upon interacting with the e-game interface in terms of usability and desirability. Finally, it suggests recommended amendments, that could be done, to enhance the investigated e-game.

Chapter 5 overviews the developing process of a chatting online tool to support socialization amongst children with ADHD. Then it presents the findings of evaluating the chatting tool by establishing an experiment for Saudi children with ADHD.

Chapter 6 summarizes the findings achieved throughout this work and suggests future work.

Chapter 2

Literature Review

Since the last decade, there have been many approaches and strategies suggested and applied by teachers and educators to reduce the weaknesses of students with ADHD and aimed to strengthen their learning. With the digital era, new computerised programs and technological interventions replaced traditional strategies and treatments, especially in the educational environment. There are various available applications and tools that exercise attention, memory operations, movement self-control, and time awareness and time management. As reviewed from the literature, we explained the ADHD disorder and its symptoms, signs, causes, and diagnosis. Then, we explored some of the e-games and applications available online which are designed for children with ADHD. We highlighted their supposed effects on skills and abilities and whether they are effective or not.

2.1. What is ADHD?

In the past few decades, the term ADHD has proliferated among teachers and parents who are concerned about the hyperactivity of their children. The term stands for attention deficit hyperactivity disorder (APA, 1994). Teachers at school may predict that a child could have ADHD depending on the behaviour in class and overall academic level. Furthermore, ADHD affects children and adolescents and may carry on to adulthood. It is recognised by a form of inattention and/or hyperactivity/impulsivity that could take place at school, home, or social settings.

Historically, the third edition of the *Diagnostic and Statistical Manual of Mental Disorders* (*DSM III*) altered the concept of the disorder for the first time and assigned 'attention' as the main characteristic in 1980 to become 'attention deficit disorder (ADD)' (APA, 1980). In 1988, Douglas and other researchers found some cognitive impairments in children who seem to have ADD, while Lahey, Schaughency, and Hynd found that there is a fundamental contrast between inattentive children with a hyperactive or impulsive behaviour and inattentive children with no behavioural issues (Brown, 2006). As a result, (*DSM III-R*) revised the notion to include the 'hyperactivity' characteristic in the disorder to become 'attention deficit and hyperactivity disorder (ADHD)' (APA, 1987). In 1994, the *Diagnostic and Statistical Manual of Mental Disorders* (*DSM-IV*) defined subtypes of the disorder depending on whether there is hyperactivity/impulsivity characteristics associated with the disorder or not, but it seemed that the notion 'hyperactive' has been linked to the disorder whether it is diagnosed as a symptom in a particular case or not (APA, 1994).

Moreover, ADHD is associated with inattentive and/or hyperactivity/impulsivity problems. Some of the children with this disorder are inattentive, for example becoming easily distracted, having difficulty staying in focus, being unorganised, making careless moves or decisions, and failing in completing tasks and assignments. Some of them could have hyperactivity problems, such as excessive movements, excessive talking even when inappropriate, restlessness, continually running and hopping, and the inability to sit still. Impulsivity could be noticed as intolerance, being more emotional, and doing things without thinking of the consequences (USDE, 2006). Children with

ADHD could have one type or a mix of both types. We will introduce the three different types of ADHD in this chapter, but we will refer to general ADHD later.

In school, students with ADHD suffer academically. They cannot sustain attention for a long time and as a result have low grades, low reading and/or mathematical skills, difficulty completing tests on time, and sometimes grade retention. Students who show inattention and/or hyperactivity/impulsivity signs with or without proper diagnosis of ADHD also seem to suffer academically (Loe & Feldman, 2007). Some schools provide special services to help these students and others who have any learning difficulties. In addition, they provide special educational classes with appropriate settings. Depending on the severity level of ADHD, teachers use different kinds of interventions that could help the students improve academically; otherwise, medical treatments could be used (Loe & Feldman, 2007).

Unfortunately, various studies (Hechtman & Weiss,1984; Klein & Mannuzza, 1991; Hill & Schoener, 1996; Faraone et al., 2006) showed that the main characteristics and impairments of ADHD could severely evolve over time if no action or treatment is taken (NCCMH, 2009). The disorder could slow the development of cognitive skills of children with ADHD compared to their normal peers. Same studies also confirmed that children with ADHD aged between 4 and 14 years, when compared to normal children at the same age, will maintain the same level of inattention and hyperactivity, disruptive behaviour, and low academic achievements (NCCMH, 2009).

Regardless of the attempts to revise terminology for this disorder and the focus on obvious symptoms only, another group of researchers explored cognitive deficiencies associated with ADHD by studying different measuring approaches to define the main problem. These studies used cognitive tests designed by neuropsychologists, which were initially used for patients with stroke, schizophrenia, or traumatic brain injury to assess the brain and measure the degree of impairment. Many executive function (EF) tests, such as the Wisconsin Card Sort, Rey–Osterreith, tower of Hanoi/London, and others, were used with ADHD by neuropsychologists (Brown, 2006; USED, 2006). These studies discovered that the ADHD disorder could be defined as the impairment of some EFs that could be measured, then treated. Brown (2006) described EF as the management system of the brain and designed a model to explain the EF that could be impaired in ADHD, which was illustrated in Figure 2.1.

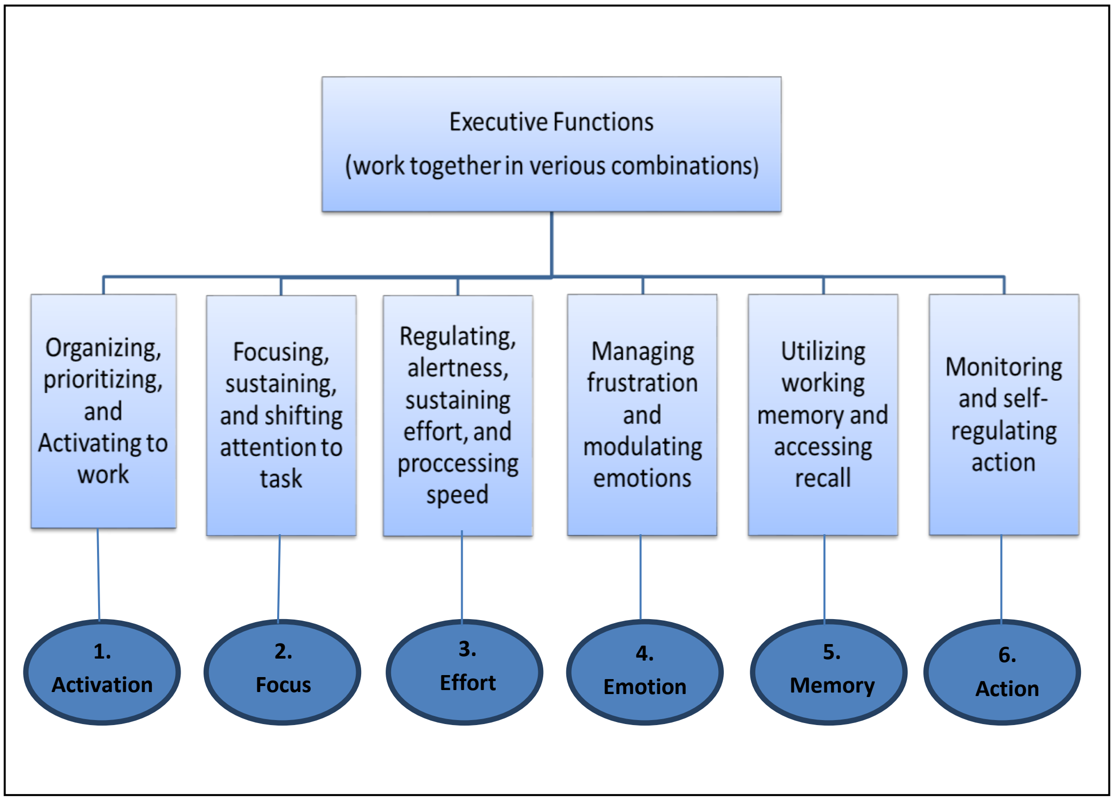

Figure 2.1. Executive functions impaired in ADHD Syndrome (Brown, 2006).

Brown (2006) found that individuals diagnosed with ADHD have impairment in one or more of these EFs mentioned in his model, which leads to a significant problem with the related cognitive function. Identifying the exact type of impairment leads to an effective and specific treatment. The improvement in one impairment of EF will affect and improve the rest.

The University of Maryland Medical Center (UMMC, 2013) has published an electronic article that summarised the problems caused by impairment in EFs, which are the following:

- Short-term memory impairment: cannot store information.
- Skill impairment: no organising or planning talent.
- Behavioural impairment: struggle to use plans to monitor and control behaviour.
- Emotional impairment: incapable of controlling emotions.
- Cognitive impairment: difficulty moving between subjects, thoughts, cognition, and tasks mentally.

It is worth mentioning that, in 2005, Schuck and Crienela proposed that there is no link between EF and general intelligence. Some people do not differentiate between them, and some relate them to each other (i.e., a child with ADHD has impairments in EF, so his or her intelligence is low, which is false. The researchers proved by clinical evidence that some individuals with ADHD with significant impairment in EF scored high on IQ tests (Brown, 2006). In the last few years, Professor Bruce Wexler, who is a senior research scientist at Yale School of Medicine, identified the EFs (Wexler, 2013), which are divided into eight core cognitive capacities: sustained attention, working memory, speed of information processing, response inhibition, cognitive flexibility, category formation, pattern formation, and multiple simultaneous attention. These cognitive capacities were the main abilities that have been measured in this study.

There is a global interest in determining the size of the problem and applying different solutions for this dilemma. Regarding the statistics, current studies have estimated the occurrence of ADHD in the UK for children between the ages 4 and 14 to be about 3.62% in males and 0.85% in females (NCCMH, 2009). In the US, the diagnosis of ADHD is wider among children and young children with an estimation of 13.2% in males and 5.6% in females, which is the highest prevalence among countries ever (APA, 2013). A recent study in Saudi Arabia revealed that the percentage of female children diagnosed with ADHD is approximately 3.5% (Jenahi, Khalil, & Bellac, 2012).

2.1.1. Symptoms and Signs

Normal children run everywhere, are easily distracted with more interesting things, forget their homework, act chaotically, and become emotional sometimes. However, parents and educators must realise that hyperactivity, impulsivity, and inattention are also signs of the ADHD disorder. Ignoring these signs may lead to difficulties in the academic and social life of a child. Table 2.1 lists some of the problems associated with children with ADHD. Thus, to solve the problem, the symptoms and signs must be recognised. As mentioned earlier, there are three types of ADHD disorder (UMMC, 2013):

- Type A: *Mainly Hyperactive-Impulsive Type* (with no inattention symptoms).
- Type B: *Mainly Inattentive Type* (with no hyperactivity or impulsivity symptoms).
- Type C: *Combination of Type A and B.* This is the most common type of ADHD.

Table 2.1. Common problems associated with ADHD in children (NCCMH, 2009).

Non-compliant behaviour	**Motor tics**
Sleep disturbance	Mood swings
Aggression	Unpopularity with peers
Temper tantrums	Clumsiness
Literacy and other learning problems	Immature language

The American Psychiatric Association (APA) had developed a diagnostic scheme for ADHD, *DSM-5*, which describes criteria to help a skilled clinician diagnose individuals who may have ADHD (Table 2.2). This manual should be supported by information from family and surrounding people about that individual, including his or her relationships, daily life functioning, and overall behaviour over time (APA, 2013).

Table 2.2. *DSM-5* criteria for ADHD diagnosis (APA, 2013).

A persistent pattern of inattention and/or hyperactivity-impulsivity that interferes with functioning or development, as characterised by (1) and/or (2):
Inattention: Six (or more) of the following symptoms have persisted for at least 6 months to a degree that is inconsistent with the developmental level and that directly negatively affect social and academic/occupational activities:
Often fails to give close attention to details or makes careless mistakes in schoolwork, at work, or during other activities (e.g., overlooks or misses details or work is inaccurate).
Often has difficulty sustaining attention in tasks or play activities (e.g., has difficulty remaining focused during lectures, conversations, or lengthy reading).
Often does not seem to listen when spoken to directly (e.g., mind seems elsewhere even in the absence of any obvious distraction).
Often does not follow through on instructions and fails to finish schoolwork, chores, or duties in the workplace (e.g., starts tasks but quickly loses focus and is easily sidetracked).
Often has difficulty organising tasks and activities (e.g., difficulty managing sequential tasks; difficulty keeping materials and belongings in order; messy, disorganised work; has poor time management; fails to meet deadlines).

Often avoids, dislikes, or is reluctant to engage in tasks that require sustained mental effort (e.g., schoolwork or homework; for older adolescents and adults, preparing reports, completing forms, or reviewing lengthy papers).
Often loses things necessary for tasks or activities (e.g., school materials, pencils, books, tools, wallets, keys, paperwork, eyeglasses, and mobile phones).
Is often easily distracted by extraneous stimuli (for older adolescents and adults, may include unrelated thoughts).
Is often forgetful in daily activities (e.g., doing chores, running errands; for older adolescents and adults, returning calls, paying bills, keeping appointments).
Hyperactivity and impulsivity: Six (or more) of the following symptoms have persisted for at least 6 months to a degree that is inconsistent with the developmental level and that directly negatively affects social and academic/occupational activities:
Often fidgets with or taps hands or feet or squirms in seat.
Often leaves seat in situations when remaining seated is expected (e.g., leaves his or her place in the classroom, in the office or other workplace, or in other situations that require remaining in place).
Often runs about or climbs in situations where it is inappropriate. (Note: In adolescents or adults, may be limited to feeling restless.)
Often unable to play or engage in leisure activities quietly.
Is often 'on the go', acting as if 'driven by a motor' (e.g., is unable to be or uncomfortable being still for extended time, as in restaurants and meetings; may be experienced by others as being restless or difficult to keep up with).
Often talks excessively.
Often blurts out an answer before a question has been completed (e.g., completes people's sentences or cannot wait for turn in conversation).
Often has difficulty waiting his or her turn (e.g., while waiting in line).
Often interrupts or intrudes on others (e.g., butts into conversations, games, or activities or may start using other people's things without asking or receiving permission; for adolescents and adults, may intrude into or take over what others are doing).
Several inattentive or hyperactive-impulsive symptoms were present prior to age of 12 years.
Several inattentive or hyperactive-impulsive symptoms are present in two or more settings (e.g., at home, school, or work; with friends or relatives; or in other activities).
There is clear evidence that the symptoms interfere with or reduce the quality of social, academic, or occupational functioning.
The symptoms do not occur exclusively during the course of schizophrenia or another psychotic disorder and are not better explained by another mental disorder (e.g., mood disorder, anxiety disorder, dissociative disorder, personality disorder, or substance intoxication or withdrawal).

Signs and symptoms of children with ADHD change relatively during their growth. For instance, children with ADHD under seven years old tend to be extremely active; they are continually on the go, jumping and running, and are often unstable in one place. Older children from 7 to 12 years old have less movement although they are active, for example, always bored and fidgeting, playing with nearby objects, or moving their seats forward and backward in class. They normally fail to finish tasks on time or shift to another without finishing the first. Teenagers with ADHD, on the other hand, are less social and tend to be solitary; they are usually impulsive, reckless, and react with no planning (USDE, 2006).

The World Health Organization designed the International Classification of Functioning (ICF), Disability, and Health model to introduce an organised and universal framework for defining and evaluating implications of different health problems, whether a disorder or disease (Figure 2.2). Loe and Feldman (2007) used the ICF framework to produce a conceptual model that labels and outlines the functional complications associated with children with ADHD in school using the exact terms of the classification system (Figure 2.3). The model is useful to assist in the process of comparing different health conditions across circumstances, treatments, interventions, community, and countries. The essential idea of the ICF framework is that health disorders or diseases effect function at three interactive analytical stages: body functions and structures, activities of daily living, and social participation. The first stage is dealing with impairments, which is clearly defined in the conceptual model better than in *DSM-5*. In addition, limitations and restrictions are short and clear terms for the second and third stages, which could also affect functioning. Other factors, such as environmental and personal, could affect function, as they occur normally in life (Loe & Feldman, 2007).

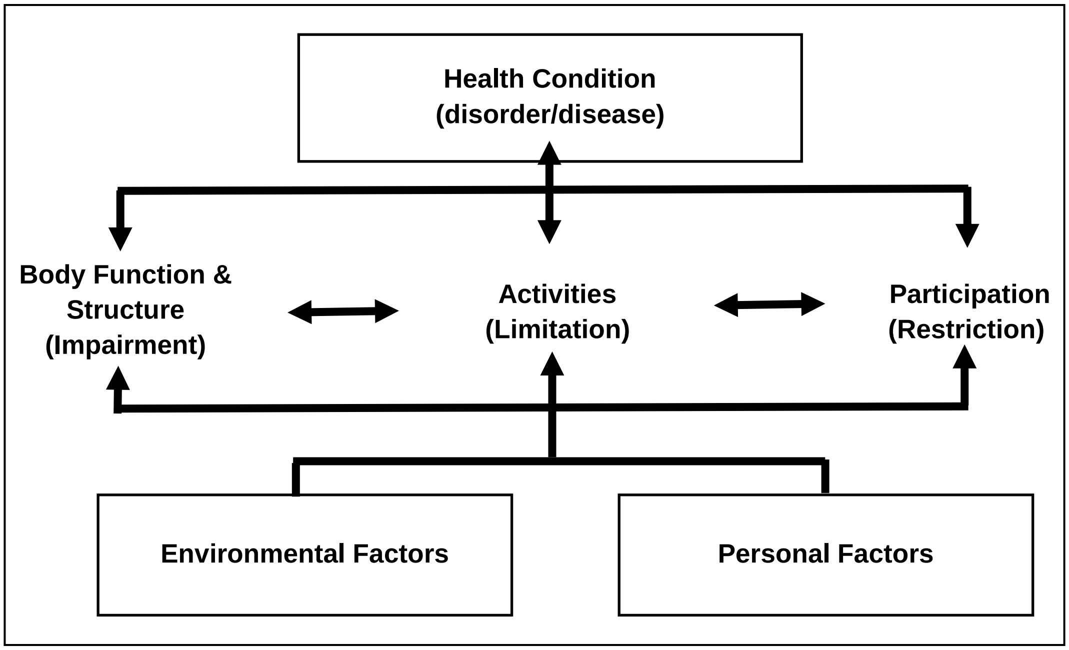

Figure 2.2. Conceptional model of International Classification of Functioning, Disability, and Health (Loe & Feldman, 2007).

2.1.2. ADHD aetiology (causes of disorder)

Some clinicians and researchers have indicated that ADHD is caused by brain damage or a brain birth defect (Lange et al.,2010), while others concluded that there is no specific reason other than different environmental or cultural effects (Brown, 2006). The National Collaborating Centre for Mental Health (NCCMH, 2009) reported some of the probable causes of this disorder. The University of Maryland Medical Centre (UMMC, 2013) suggested some aetiologies; we list them as follows:

- Genetic influences.
- Environmental influences.
- Biological factors.
- Dietary factors.

- Psychosocial factors.
- Brain structure or chemicals.
- Risk factors.

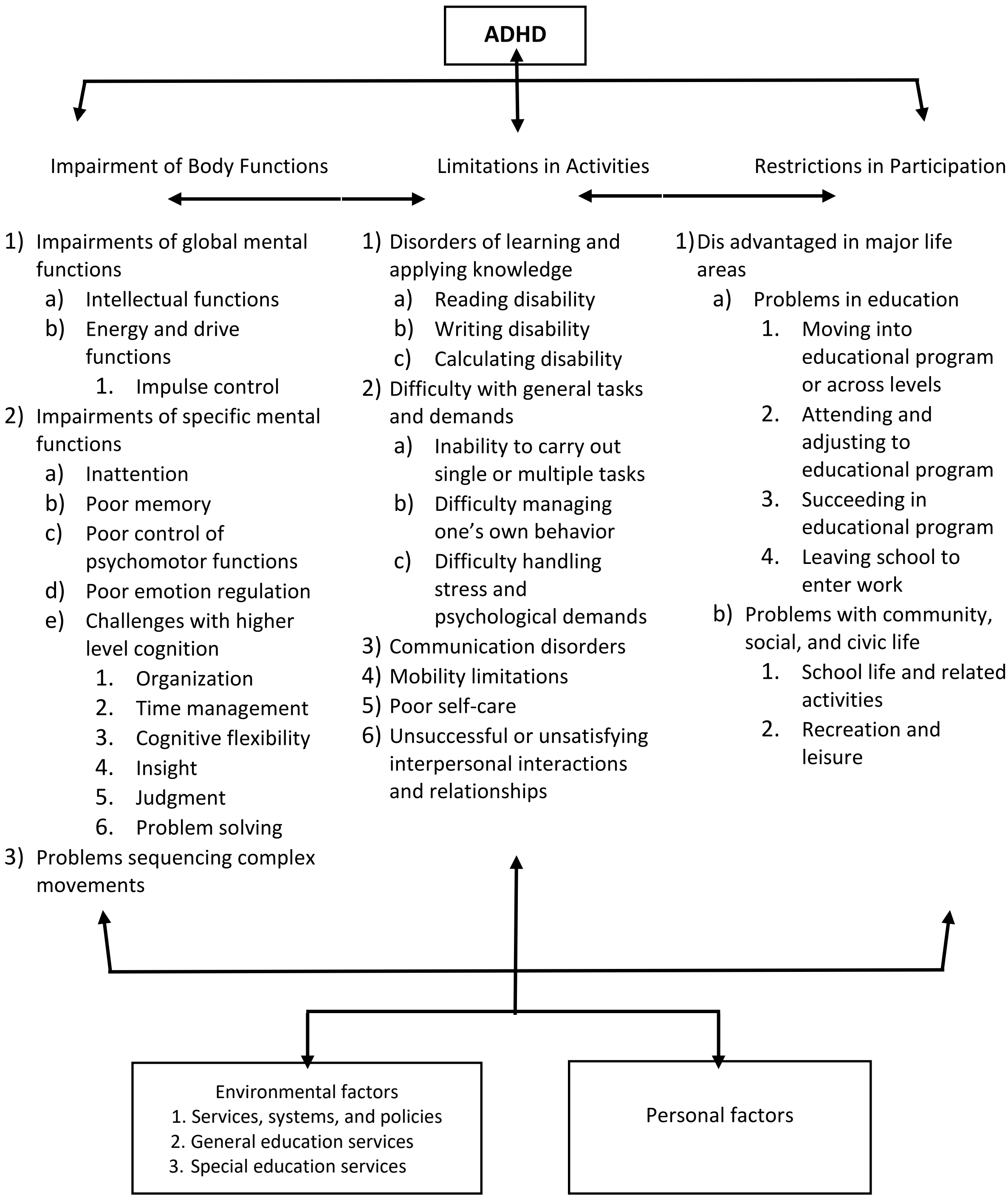

Figure 2.3. Functional problems associated with ADHD using the International Classification of Functioning, Disability, and Health conceptual model (Loe, Feldman, 2007)

2.1.3. ADHD diagnosis

In the last few years, many medical researchers have highlighted the diagnosis of ADHD in children using medical imaging and signal processing techniques. Techniques such as electroencephalography (EEG), functional Magnetic resonance imaging (fMRI), diffusion tensor imaging (DTI), magnetoencephalography (MEG) have been used by clinicians for early diagnosis of ADHD (Sridhar et al., 2017). Although some of these techniques have 95% accuracy, some doubtful parents still ask for traditional methods for diagnosis.

There is no particular physical test for detecting ADHD, unlike other illnesses (Simon & Zieve, 2013). In addition, signs and symptoms of this disorder could be easily confused with other common problems, such as learning difficulties and emotional problems. Hence, a specialist in mental health must be involved, a set of tests and medical exams could be done, and certain criteria may be applied to accurately diagnose ADHD (Lundholm-Brown & Dildy, 2001). The specialists may need to collect more information from parents and educators about the child’s behaviours in different settings, such as at school, home, or work. The diagnosis depends on detecting the level of impairment in an individual with ADHD by monitoring such actions as completing tasks and chores, organising ideas, understanding requests, dealing with situations, making the correct decisions, and relating socially in and out of school (NCCMH, 2009).

In school, educators can recognise key symptoms related to ADHD in students through behaviours. The clinical practice guidelines in America encourage the involvement of educators in the procedure of diagnosing the disorder by recording any signs and symptoms they notice or even using rating scales to help in evaluating the condition. Rating scales and checklists are used to gather information about functioning and actions in various settings. According to the American Academy of Child and Adolescent Psychiatry, the most common scales for ADHD are (Brown, 2005; NCCMH, 2009):

- Parent-completed Child Behaviour Checklist,
- Teacher Report Form (TRF) of the Child Behaviour Checklist,
- Conner's Parent and Teacher Rating Scales,
- ADD-H: Comprehensive Teacher Rating Scale (ACTeRS),
- Barkley Home Situations Questionnaire (HSQ), and
- Barkley School Situations Questionnaire (SSQ).

Conner's rating scale was selected due to its simplicity and commonly used for screening ADHD among children. It was used in the first part of the study by the researcher to measure the behaviour and habits of children as a preliminary screening for ADHD. 'Not only does this help to diagnose children who otherwise may have been overlooked, but it also offers a point of comparison for those who do suffer from ADHD' (Kessler et al., 2006). The Conner's test facilitated the following:

- Measure hyperactivity and attention in youngsters;
- Offer a viewpoint on children's behaviour from those who interact regularly with the children;
- Create a preliminary base before starting treatment or training to help monitor progress over time; and
- Provide standardised data to support any conclusions, diagnoses, and treatment decisions.

In our final evaluation, recruited participants were only those who were clinically diagnosed with ADHD.

2.1.4. ADHD versus Learning Disabilities

Learning disabilities (LDs) and ADHD are the most prevalent among other disorders in children. Many parents and educators mix up the correct terms regarding whether a child has ADHD or LD problems. Moreover, sometimes unprofessional clinicians misdiagnose these due to the significant similarities between the two. Some older students assume that having symptoms of ADHD or LD will give them the chance to have special classroom settings with special testing measures and circumstances (DuPaul & Volpe, 2009). According to the *DSM-5*, ADHD is not the same as a LD, as each have its own problems, severity levels, and treatments. However, that does not prevent the fact that a child could have a LD associated with ADHD (APA, 2013).

An LD is a disorder of one or more mental processes, which affects the ability to understand, think, express thoughts, process information, read and write, or solve mathematical problems (Mayes, Calhoun, & Crowell, 2000). An LD child is not ‘stupid’ or ‘lazy’, but mental processing is done in a different way than normal. Research findings indicate that around 20% to 30% of students have both ADHD and LD (Mayes, Calhoun, & Crowell, 2000). Another resource estimated that one-quarter to one-third of all children with ADHD have LDs (USDE, 2006).

More studies were conducted to clarify the ambiguous relation between the two disorders; they claimed that (DuPaul & Volpe, 2009):

- The relation between ADHD and performance problems is caused by inattention rather than hyperactivity or impulsivity.
- ADHD and LD both have problems and insufficiencies with working memory and processing speed.
- ADHD and LD both have problems with reading skills, and multiple genes may be responsible.

- The ADHD and LD relation is not fully understood by cognitive theories or behaviour ones.

2.2. Assistive Technologies

In today's lifestyle, children are used to being continually enthused and interested. Multimedia technology, such as TV, movies, cartoons, video recordings, Internet, and games, has a major influence on the learning and behaviour of children. Therefore, a quiet environment may be unbearable for children who are used to a fast and active life. In fact, children with ADHD find it hard to sit motionless for a period of time in the classroom and to be involved in activities that demand listening and thinking (Lundholm-Brown & Dildy, 2001). Because of that, it is essential to incorporate technology in the learning process to grasp children's attention; thus, this will be reflected in their achievements. A few years ago, many researchers directed their attention to activating the use of tools, programs, and technological interventions in the classes of special educational needs.

. In this section, we mentioned the reasons the iPad was chosen as a research tool in our study. In addition, we reviewed examples of educational applications and the techniques used to target cognition, behaviour, and social relationships.

2.2.1. Tablets

Touch screen devices, or tablets, are powerful portable technologies that have been used recently in many fields, especially in learning. In the last few years, tablets were and still are considered productive learning tools used inside and outside of the school setting to assist education. They provide innovative use and direct access to a wealth of many resources. Many educational applications were developed with the help of teachers and educators for transforming learning (Goodwin, 2012).

One of the main benefits of tablets is that they support learning anywhere, anytime. That changes the traditional concept where the classroom is the essential learning place controlled by the teacher instructions during a typical school day (Goodwin, 2012). These devices offer users access to a wider and more variable source of learning resources and knowledge than what is offered in ordinary classrooms.

Many studies have proven the benefit of using tablets, such as the iPad, in enhancing the learning procedure inside and outside of school. In fact, these studies suggest considering this technology not just a ‘tool’ but a ‘cognitive tool’ (Goodwin, 2012). They also have provided evidence that using iPads in the classroom by students improves engagement and enthusiasm, enhances collaboration and one-to-one tutoring, and improves learning outcomes. For instance, Wrońska, Garcia-Zapirain, and Mendez-Zorrilla (2015) verified that using an iPad-based tool helped students with ADHD through reading comprehension. In our study, the iPad was selected to be used as the ‘tool’ of the experiments to test the validity of the claimed objectives owing to its ‘significant and very positive impact on learning’ (Heinrich, 2012, p. 54).

2.2.2. Applications for ADHD

Most adults and even children find it very easy to download any application from any online application store on their tablets or mobile devices with a single touch on the screen. Applications such as games, health tracking, news, social media, education and other categories are now considered essential needs of daily life. Approximately 3 million applications for iOS (iPhone operating system) and android systems are available for download in leading application stores, such as the Apple Store and Google Play, according to the Statistics

Portal in March 2017 (Statista, 2017). Many applications have been adopted in schools and institutions that provide educational tools and skill development, and most of these apps are classified as ‘education’ in the iTunes App Store (Shuler, 2012). Some developing companies have claimed to design usable and effective educational applications with certain design features that support the needs of diverse learners, such as students who experience different LDs or disorders (O’Connell, Freed, & Rothberg, 2010). Few applications have been evaluated within schools by researchers to help students of all capabilities overcome learning obstacles, especially students with ADHD. Some of the applications have been found useful in facilitating the student’s school day and organising daily life (O’Connell, Freed, & Rothberg, 2010). Students with ADHD constantly need to be reminded, notified, and instructed; thus, using alarm applications, for instance, would be helpful. Other applications were found to enhance the students’ academic level and develop some of their skills. However, not all ‘educational’ or ‘brain-train’ applications/games that are available were proved effective by research. After reviewing the literature, Table 2.3 lists some of the most popular applications and games used by children diagnosed with ADHD (Cooper-Kahn & Dietzel, 2015; Kumaragama & Dasanayake, 2015; Bul et al., 2015; iTunes, 2015).

Table 2.3. Applications/games for children with ADHD.

Name of App	Type	Description
HomeRoutines Alarmed-reminder timers inClass My Homework	Time management apps	Create checklists Set alarm Reminders Notifications
Audio-notes recorder Event Countdown Dragon Dictation Speak It To Me	Audio apps	Record notes Voice recognition

Name of App	Type	Description
Talkulator Voice Dream Reader		Talking calculator Reading lists
Evernote Notability Quiver Notebook Write	Note taking apps	Take notes and photos, generate to-do lists Record vocal reminders Support handwriting Word processing
iEarnedThat-lite iReward	Behavioural apps	Reinforce positive behaviours using visual rewards Develop desirable behaviours by working towards tangible goals
TooLoud Too Noisy Kibits Collaboration Show Me	Classroom apps	Monitor classroom noise level Graphical presentations of the background noise level in a room in an exciting and engaging way Create collaboration to engage with real-world group Turn your iPad into an interactive whiteboard
Mathtopia+ iWriteWords LetterForms	Math and handwriting apps	Math game Handwriting exercises
Play Attention SmartBrain Technologies ADHD Kids Trainer Lumosity ACTIVE Plan it commander	Cognitive, executive functions apps	Training concentration Neurofeedback technology that allow one to control the computer by mind/attention alone using tools, such as helmets Improves brain capacities: Attention, working, memory, processing speed

E-Games such as Play Attention, KAPEAN, Lumosity, TARLAN, and ACTIVATE have been found effective by researchers (Wexler, 2013; Olounabadi, 2014; Cooper-Kahn & Dietzel, 2015; Kumaragama & Dasanayake, 2015; Martínez et al., 2016). They provide mini games with attractive animations and sounds, which train different parts of the brain. By experiment, researchers found significant improvements in one or more EFs, such as attention, behavioural skills, and social skills. In addition, these improvements had a great effect on the academic levels of these children (Wexler, 2013; Olounabadi, 2014; Cooper-Kahn & Dietzel, 2015; Kumaragama & Dasanayake, 2015; Martínez et al., 2016).

After clustering the available technologies that target the development of the abilities and skills of children with ADHD, we found five main categorises, each aimed at a certain deficiency. Some of these systems focus on treating one deficiency, while others focus on treating two or more by utilising specified strategies for each one. A detailed systematic review with the methods used and the outcome of effective technological interventions to reduce ADHD weaknesses in children is presented in Chapter 3. The five main categories of technology-based treatments targeted attention, working memory, processing speed, behaviour, and social skills.

Attention-targeted interventions: There were many strategies to grasp and enhance children’s attention. Most of these interventions offered attention-training exercises. Augmented reality was used as motivational tool to facilitate the children’s concentration (Richard et al., 2007). Another study showed a positive correlation between working memory and attention. By targeting and training working memory, the attention ability will improve (Klingberg et al., 2005). In addition, Kilngberg emphasised displaying progress scores to all participants to motivate them to be focused on tasks. Fernández-Molina (2015) found that using a reward/punishment strategy as a motivational stimulus will help children concentrate on completing their tasks. The researcher encouraged using colourful pictures and drawings as well as sound alerts instead of long explanatory text to indicate right or wrong answers as feedback.

Working memory-targeted interventions: Many studies offered working memory exercises, such as visuospatial working memory tasks; verbal tasks; categorising objects upon certain characteristics or features; remembering the sequence order of numbers, letters, or objects; and reordering in reverse. Furthermore, it was found that automatically adjusting the difficulty level of tasks to match the cognitive load of the child will help improve working memory (Klingberg et al., 2005). In addition, using an effective academic approach and high-quality content along with adjusting the difficulty level will assist mastering certain skills and abilities (Kourakli et al., 2016). The author also emphasised the importance of appropriate feedback in enhancing memory operations. Reproducing or recalling information from memory is considered an effective working memory training (Carpenter et al., 2016).

Processing speed-targeted interventions: One of the effective strategies was adjusting the time needed to finish a particular task, depending on the child's pace (Chacko et al., 2014). After enough practice, the time will decrease gradually once the child enhances performance and increases speed. Another effective strategy investigated by Mahmoudi (2015) was binding time with a scoring system, where more time needed means less score gained. Without a high enough score, users cannot proceed to further levels. This strategy improves thinking skills and processing speed.

Behaviour-targeted interventions: Some interventions use sensory strategies, such as stimulating senses by encouraging children to smell or touch objects (Richard et al., 2007). This strategy motivates children while performing tasks including tangible activities for matching and arranging objects. The researcher reported positive improvements in behaviour. Another study encouraged the inclusion of physical activities and movement-based tasks (Kourakli et al., 2016). The researcher discussed the effect of using a joystick to repeat a given pattern in the right order. These games train behavioural management and enhance behavioural control in children.

Social skills-targeted interventions: Olounabadi (2014) focused on improving solving real-life social problems. One of the main goals of his intervention was to improve inhibition; thus, children with ADHD will be able to inhibit early responses. Animated scenarios were developed wherein children can practice solving social problems step by step to gain social competency. The author included other effective strategies, such as the use of avatars to represent the child, audio instructions, immediate feedback, and displaying an agent that expresses facial emotions upon answers. There have been noticeable a lack of technological interventions targeting social skills especially for children with ADHD. There were studies targeting a different age group that investigated the effect of social media and online peer-communication on social skills for adults with ADHD (Mazer et al., 2007; Fovet, 2009). More investigation needs to be done regarding the effect of e-collaboration and e-communication among peers on the social skills for children with ADHD, considering all the security measures and behaviour monitoring procedures.

2.3. Conclusion

Throughout the ages, education and the development of teaching methods and strategies have been important goals endeavoured by specialists and researchers in the field of education. As technology evolved, many technical tools and software have emerged to facilitate the learning process and the development of students' skills and abilities. Some of these programs and applications have claimed to develop cognition, behaviour, and social skills of students with ADHD. In this chapter, we aimed to explore some of the well-known educational applications and e-games. Then, we clustered them into groups targeting certain executive functions based on game elements they offer. More detailed meta-analysis of studies investigated existing technology to improve abilities and skills for children with ADHD was presented in Chapter 3. After exploring available online games and applications for ADHD, we chose an e-game for further evaluation to examine its effectiveness and usability. The e-game was evaluated regarding its effects on improving cognition, behaviour, and social skills for children with ADHD. Details about the experiment and findings were presented in Chapter 4. In Chapter 5 we developed and evaluated an online chatting tool to enhance social skills for children with ADHD.

Chapter 3

Meta-Analysis of the Effects of E-games on Cognitive, Behavioural, and Social Skills for Children with ADHD

During the last decade, many studies have evaluated several technological interventions intended to aid ability and skill development of young children with attention deficit and hyperactivity disorder (ADHD; Wilkes-Gillan, 2017). These include technologies such as virtual reality, hyperactivity control tools, video games, metronome beats, and distance learning. Many were found to be positively effective in improving the children's executive functioning, although with different rates (Richard et al., 2007; Sonne et al., 2015; Fernández-Molina et al., 2015).

Another important outcome that has been observed is the enhancement of their social skills. Thus, evidence shows that applying some of these interventions in learning environments could provide the best and most efficient e-learning experience for children with ADHD. We define 'learning' as the process of developing knowledge, abilities, and skills (Kraiger et al., 1993). Thus, we can achieve an effective learning experience by developing the following: 1) knowledge through introducing effective e-educational strategies, 2) abilities via training and stimulating cognition, and 3) skills through controlling behaviour and helping the children to be more socialised. Based on the reviewed studies, specific methods and gaming features applied within the interventions are found to reinforce certain abilities and skills.

Regarding executive function development, many proposed methods and game features were explored in the literature. For example, to improve the attention/focusing ability, some studies suggested graphical interactive designs, feedback, and eye tracking features (Klingberg et al., 2005; Fernández-Molina et al., 2015; Sullivan-Carr, 2016). To enhance working memory functioning, effective academic approaches were used as well as adjusting task difficulties based upon student abilities (Fovet, 2009; Richard et al., 2007; Carpenter et al., 2016). Others used interactive metronome and timer features to improve processing speed ability (Chacko et al., 2014; Langereis et al., 2012). Most of the reviewed studies focused on behavioural control methods as the second important weakness in the ADHD disorder after attention along with working memory development. They evaluated methods such as the inclusion of physical activities within video games, motivation and rewards, and movement sensors and control devices (Sonne et al., 2015; Kourakli et al., 2016). Less research has been found related to social-skill enhancement. Although subject to some restraints, a number of methods have been found effective, such as peer collaboration, interactive communication, and social media (Fovet, 2007; Haydon et al., 2012; Olounabadi, 2014).

No systematic review or meta-analysis was found that covers studies about the effect of technological game features on children's cognition, behaviour, and social skills. Therefore, our objective in this contribution was to construct a meta-analytical review to examine the effects of different technological tools and methods with game features on the development of children with ADHD. We outlined the most effective and highly significant features. Then, we generalized these features/methods into recommendations. By the end of this work, with supporting evidence from empirical studies, we were able to come up with a list of design guidelines that could help designers and developers to build effective applications and games for children with ADHD.

3.1. Methods

We conducted a meta-analysis to synthesise the methods and findings of quantitative inquiries of technology-based programmes that been used as an intervention or treatment to enhance young students with ADHD cognitively, behaviourally, and socially.

Studies included in this review examined the outcomes of young participants with ADHD who are exposed to any type of technology that affects their executive functions, behaviours, or social skills.

We excluded studies from the meta-analysis that only examined symptoms, evaluation or diagnostic methods, assessments of children with ADHD, or studies without published outcomes. The dataset comprised studies published between 2006 and 2016, targeting young school-age children. All studies were research articles written in English with the full text available. Studies using theoretical, pharmacological, or traditional methods (no technology used) were excluded. References and case studies from other meta-analysis studies were explored and included as well.

The search methods for the identification of studies are summarised below. The following inclusion terms were used:

- Names of the condition: attention deficit hyperactivity disorder, ADHD, inattentive, learning disorders, working memory, and impairments.
- Technology-related outcomes: technology, applications, games, tabs, tablets, tools, electronic devices, mobiles, iPads, computer, web, media, and ICT.
- Main objectives and outcomes: development, enhancement, intervention, training, improved, affected, cognition, executive function, academic level, social skills, behaviours, learning, education, class, school, reading,

language, math, processing, collaboration, reward system, time management, error analysis, and reaction time.

- Publication types: reprint, review, conference papers, and electronic articles.

3.2. Data Collection

To identify as many published studies as possible, six scholarly search engines were used: Base-Search, Education Resources Information Center (ERIC), Google Scholar, Institute of Electrical and Electronics Engineers (IEEE), ScienceResearch.com, and ScienceDirect Elsevier. Results of the search were considered until the tenth page only because duplicates occurred after that. References from each study were also explored. Duplicates were eliminated electronically and manually, yielding 131 potentially relevant studies based primarily on title, abstract, and conclusion. After deep exploration and screening, the exclusion criteria were applied (Figure 3.1). These studies were reviewed manually, resulting in 49 relevant studies that were included in the analysis.

Data from each study were manually extracted from the full text of the study to a database, including 1) study location, 2) study sample size, 3) participant age range, 4) executive functions targeted or (academic level or skills), 5) technology used, 6) human-computer interaction (HCI) measures, 7) treatment method, 8) treatment duration, and 9) outcome results.

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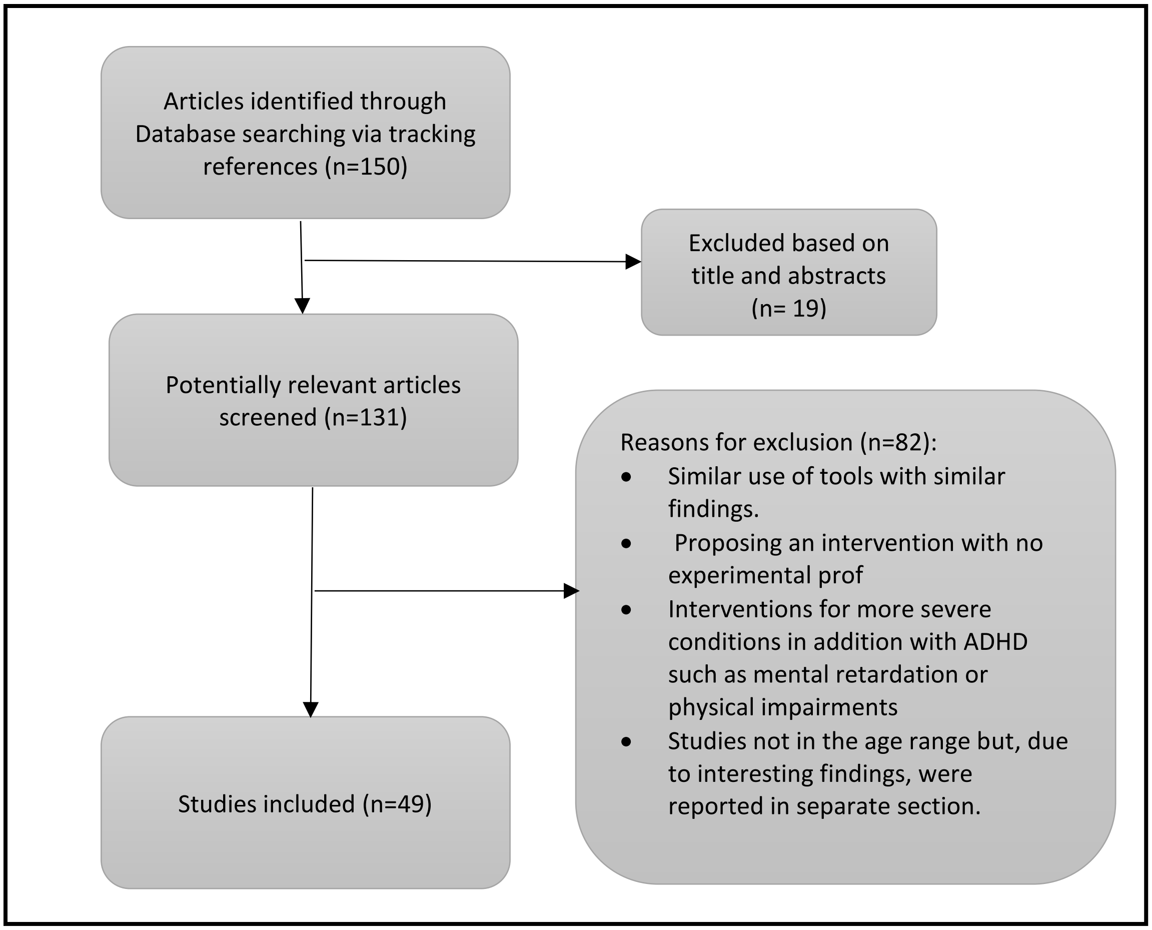

Figure 3.1. Search strategy and flow chart for the analysis.

3.3. Coding Procedure

During the coding procedure, the following were used as moderator variables: types of groups (treatment/experimental group, waitlist, placebo, active control group, developmental control group); types of interventions (Plan-It Commander, ADHD Trainer, CASTT, KAPEAN, Fast ForWord, Braintrain, CogMed, RoboMemo, AR Alphabet Book, and other tools/applications); treatment duration; targeted abilities/skills; and outcome measures (three levels: cognitive [attention, processing speed, working memory], behavioural, and social).

Two strategies were used to make it easier to distinguish between the interventions used. First, different types of game measures were defined: instant error analysis and evaluation, motivation and feedback, dynamic time-span scheme, match between task difficulties with student abilities, and physical activity integration. Second, these were then used to classify the gamification parts for each study.

The 49 studies included in this review explored different tools and features to improve attributes, such as cognitive abilities, behaviour, and social skills for children with ADHD. To make the analysis more subjective, studies were examined as separate units of analysis. They were categorised to five main groups, depending on their targeted outcomes. These were studies presenting methods or tools to improve attention, working memory, processing speed, behaviour, and social skills.

Table 3.1. Systematic review of studies included in the analysis.

Study	Location	Sample size	Age range (years)	Targeted attribute (Domain)	Technology used	Treatment duration
(Bul et al., 2015)	The Netherlands	42	8-12	Behavioural learning objectives, attention, and concentration	Computer workstation with Internet and sound facilities	8 weeks
(Ruiz-Manrique et al., 2014)	Spain, at home	1	10	Attention, memory, and perceptual reasoning	Mobile/tablet software	6 months
(Sonne et al., 2015)	School settings	20	8-10	Behaviour and attention	Accelerometers, smartphone, heart rate monitor, and electro-encephalogram (EEG) headset	35 minutes
(Martínez et al., 2016)	Mexico	15	8-12	Reinforce attention, cognition, memory, and visuospatial skills	Computer, recorded camera, webcam, Microsoft Kinect, and EEG headset	10 minutes per session
(Irvine, 2013)	USA	15	18	Cognitive and behaviour	Smartphone applications	3 weeks
(Given et al., 2008)	USA	65	11-13	Auditory temporal processing combined with language exercises	Computer-based application, headphones, and mouse to respond	12 weeks
(Rabiner et al., 2010)	USA	77	6-7	Attention and memory	Computer-based programs	14 weeks
(Lee & Vail, 2004)	USA	4	6-7	Reading, word recognition, and comprehension	Computer-based program and mouse	1 year
(Wegrzyn et al., 2012)	USA, school lab	10	10-16	One or more executive functions and attention	EEG, video segments, Nintendo DS, and Brain Age software	5 weeks
(Klingberg et al., 2005)	Sweden, at home	53	7-12	Attention, response inhibition and reasoning, and behaviour	Computer, Internet access, mouse, and Program CD	25 days
(Thomas et al., 2013)	Singapore	5	8-12	Attention and working memory	Computer and EEG	18 sessions
(Koceski & Koceska, 2015)	Republic of Macedonia	10	6-12	Attention, working memory, processing speed, and behaviour	Microsoft Kinect, sensor, RGB camera, depth sensor, and microphone array	4 weeks
(Dovis et al., 2015)	At home, Netherlands	89	8-12	Visuospatial working memory, inhibition, and cognitive flexibility	Computer game	5 weeks
(Rambli et al., 2013)	Malaysia	15	5-6	Attention	Camera, computer, ARToolkit software, and pattern markers	1 session
(Fesakis et al., 2011)	Classroom settings	4	5-6	Comprehension	Computer with Internet, email, website, software that supports both vector graphics and audio recording	2 sessions
(Foster & Anthony, 2016)	USA	247	3-5	Effective academic strategies	Software	21 weeks

Study	Location	Sample size	Age range (years)	Targeted attribute (Domain)	Technology used	Treatment duration
(Fovet, 2009)	USA	12	12-18	Behaviour, social skills, academic learning, attention, and processing speed	Social media programme: Facebook	1 year
(Andreou et al., 2016)	School, Greece	66	13-14	Attention, behaviour, and academic level improvement	Interactive board, word editor, concept mapping software, videos, and multimedia	2 teaching hours
(Fernández-López et al., 2013)	Elementary schools, Spain	39	6-15	Working memory, attention, cognitive skills, academic level, and behaviour	iPod touch, iPhone, and iPad	6 months
(Sack, 2016)	Canada	4	6-13 Y	Attention and behaviour	Application and eye tracking system	30 hours
(Simsek, 2016)	USA, school	4	12-14	Attention, cognitive skills, and behaviour	Application on mobile phones or tablets	2 weeks
(Ali & Puthusserypady, 2015)	Denmark	11	18	Attention and processing speed	Head electrodes, computer screen, Adobe Photoshop, 3D modelling software, Autodesk, and 3DS Max	9 tests
(Cho et al., 2002)	Korea	50	14-18	Attention, hyperactivity, and impulsiveness	EEG signal device and two computers	8 sessions
(Fovet, 2007)	USA	2	16	Behaviour	Distance learning tools, online access, interactive PowerPoint, videos, electronic documents, websites, and blogs	21 months
(Jiang & Johnston, 2015)	China	5	8-11	Attention, hyperactivity, and working memory	Computer game with EEG input via wireless, single-channel, dry-sensor, portable measurement device	25 sessions
(Wrońska et al., 2015)	Spain	6	8-12	Cognitive skills	iPad	1 day
(Shih et al., 2014)	Taiwan	2	12-14	Hyperactivity	Nintendo Wii, remote control, computer, and Bluetooth wireless system	4 weeks
(Kim et al., 2014)	South Korea	17	7-12	Executive functions: working memory and attention	EEG technology	16 weeks
(Sullivan-Carr, 2016)	Boston	3	14-15	Attention and cognitive	iPad and online access application	3 weeks
(Glass et al., 2013)	USA	72	19-20	Cognition	Video game, software, and laptop	40 hours
(Olounabadi, 2014)	New Zealand, Iran	40	8-12	Attention and behavioural skills	Computer and TARLAN software	8 sessions
(Lee et al., 2010)	USA	31	18	Attention and behavioural skills	Computer	During exam
(Mautone et al., 2005)	USA	3	8-9	Cognitive and behaviour	Computer application and software package	6 weeks

Study	Location	Sample size	Age range (years)	Targeted attribute (Domain)	Technology used	Treatment duration
(Fernández-Molina et al., 2015)	Spain	52	4-5	Attention, processing speed, and working memory	Computer	5 weeks
(Oei & Patterson, 2014)	Singapore	52	18	Attention and response inhabitation	Personal computer in lab, iPhone, or iPod	20 hours
(Haydon et al., 2012)	USA	3	17-18	Attention, cognitive, and behaviour	iPad	15 sessions
(Chacko et al., 2014)	USA	85	7-11	Working memory and cognition	Internet access, computer, and program	5 weeks
(Shute et al., 2015)	USA	77	18	Cognitive skills	Internet access, Lumosity web portal	10 hours
(Nouchi et al., 2013)	Japan	32	18	Cognition and attention	Portable console, Nintendo, and timer	4 weeks
(Fassbender et al., 2012)	Australia	48	18	Working memory	Video game, projector, display system, and Sennheiser HD 280 stereo headphones	12 minutes
(Kourakli et al., 2016)	Greek, classroom	20	6-11	Cognitive abilities, working memory, behaviour skills, and attention	Kinems learning games	8 weeks
(Mahmoudi et al., 2015)	Iran	100	First year	Attention and processing speed	Computer and games	5 weeks
(Höysniemi et al., 2003)	Finland, classroom	28	5-9	Attention and behaviour	Web camera, laptop computer with built-in mic, and video camera	1 or 2 hours per sessions
(Namgung et al., 2015)	Korea	2	7, 14	Attention, processing speed (timing), and behaviour skills	Interactive metronome program	3 weeks
(Kim et al., 2012)	Korea	10	5-9	Attention, processing speed, and behavioural skills	Interactive metronome program	4 weeks
(Richard et al., 2007)	France, school	93	7-11	Attention, behaviour, and cognitive	Augmented reality, sounds, 3D images, projector web cam, pictures and video recording the magic book	1 session 2 experiments
(Brown et al., 2002)	Spain	2	Primary age	Behaviour and cognitive	Computer graphics applications: 3D graphics, web pages, and computer with tactile screen	20-30 minutes per session
(Carpenter et al., 2016)	USA	39	8-14	Working memory and cognitive abilities	Computer, software, and interactive metronome	60 hours 15 weeks
(Smith et al., 2016)	USA and China	92	5-9	Cognitive abilities, behaviour, and social skills	Computer games, physical exercise, and social games	15 weeks

A systematic review table (Table 3.1) with all the included studies is presented. Effect sizes were calculated for each proposed method/feature. The highly effective methods were outlined. The random effect model was used to analyse the data due to the variety of methods applied across studies (Borenstein et al., 2010; Schmidt & Le, 2004). For the different sample sizes and outcomes, Cohen's *d* coefficient (Cohen, 1988) was calculated based on the reported post-test results from the control group and intervention group (in the case of only one group, the effect sizes were used to indicate the change in performance from the baseline to the intervention within the same group). Cohen suggested the effect sizes 'small, $d = .2$', 'medium, $d = .5$', and 'large, $d = .8$'. Therefore, we used the following equation to calculate Cohen's *d*:

$$\text{Cohen's } d = M_1 - M_2 / \sigma_{pooled}$$
$$\text{where } \sigma_{pooled} = \sqrt{[(\sigma_1^2 + \sigma_2^2) / 2]}$$

For simplicity, the online calculator by Dr Lee A. Becker (Becker, 2000) was used to calculate the effect sizes. In addition, an Excel worksheet was used to convert the effect sizes from one type to another (DeCoster, 2012). Studies were categorised as sufficient and non-sufficient datasets. For non-sufficient data studies, effect sizes were estimated depending on the charts, figures, conclusions, and outcomes.

The data analysis was conducted using R software (v 3.3.2). For homogeneity testing, Q and I^2 statistics were used (Borenstein et al., 2010). For publication bias, fail-safe N was used (Rosenthal, 1991). Based on the 49 studies included in this analysis, a total of 1,687 subjects were included.

3.4. Results and Discussion

In this section, we present the results grouped by attributes targeted in the included studies. Five units of analysis were done, targeting the following:

attention, working memory, processing speed, behaviour, and social skills. Two effect sizes were calculated for each group: the weighted effect size for each study and the effect size for each method/game feature with each study. We outlined the highly significant methods that have high effect sizes.

3.4.1. Attention-Targeted Studies

Twenty-two studies proposed and evaluated approaches to improve attention in children with ADHD, such as eye tracking, identifying a target that is flanked by non-targeted stimuli, motivational features, and feedback. We have calculated the weighted effect sizes for all category-related studies to measure the significance of the research using the random effect model.

For Hedges's method, the Q statistic is highly significant ($Q = 68.96$, $p < .001$). Likewise, the population effect size using the r metric and a 95% confidence interval (CI) is 0.77 (95% CI [0.45, 1.10]). This population effect size is significant ($z = 4.65$, $p < .001$). Figure 5.2 presents the funnel plot of the corresponding output.

Based on the homogeneity test, there was considerable variation in the effect sizes overall. In addition, based on the estimate of population effect size and its CI, we conclude that there was a strong effect on attention developing methods for children with ADHD compared to the waiting-list controls.

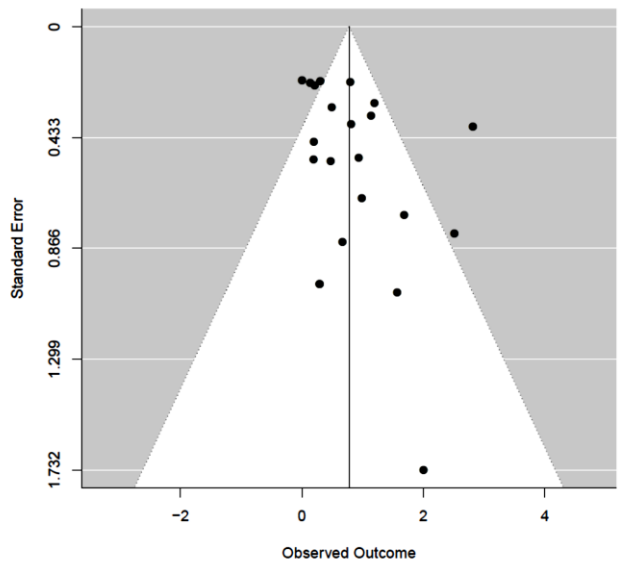

Figure 3.2. Funnel plot created using R for attention-targeted studies.

In the next stage, we separately presented the effect sizes for each method/game feature within each study to distinguish between them and point out highly significant methods (Table 3.2).

Table 3.2. Effect and sample sizes of studies targeting attention.

Study	***N*1**	***N*2**	**Effect size *d***
(Fernández-Molina et al., 2015)	26	26	2.853
(Ali & Puthusserypady, 2015)	5	6	2.741
(Thomas et al., 2013)	2	3	2.15
(Wegrzyn et al., 2012)	5	5	1.859
(Klingberg et al., 2005)	27	26	1.21
(Carpenter et al., 2016)	19	20	1.16
(Kim et al., 2012)	5	5	1.086
(Kim et al., 2014)	8	9	0.98
(Jiang & Johnston, 2015)	3	3	0.829
(Mahmoudi et al., 2015)	50	50	0.828
(Richard et al., 2007)	46	47	0.8
(Sack, 2016)	2	2	0.506
(Namgung et al., 2015)	1	1	0.5
(Fesakis et al., 2011)	2	2	0.5
(Rambli et al., 2013)	7	8	0.5
(Bul et al., 2015)	21	21	0.5
(Dovis et al., 2015)	44	45	0.304
(Rabiner et al., 2010)	38	39	0.2086
(Martínez et al., 2016)	8	7	0.2

Study	*N*1	*N*2	Effect size *d*
(Sonne et al., 2015)	10	10	0.2
(Chacko et al., 2014)	42	43	0.135
(Smith et al., 2016)	46	46	0

Note: *N*1 = control group sample size; *N*2=intervention group; *d* = Cohen's effect size.

Depending on the effect sizes, it is clear that 11 studies may be considered significant, but some studies (Klingberg et al., 2005; Richard et al., 2007; Fernández-Molina et al., 2015; Mahmoudi et al., 2015; Carpenter et al., 2016) were more likely to be significant due to reasonable sample sizes.

In the study by Richard et al. (2007), an educational augmented reality application was used. The estimated effect size was significant (Cohen's d = 0.8, n = 93). Children with ADHD were very enthusiastic while using the application and showed a high motivation compared to most other pupils.

In the study by Klingberg et al. (2005), the effect size was significant (Cohen's d = 1.21, n = 53). Students performed working memory tasks implemented in a computer program. Parent ratings showed a significant reduction in symptoms of inattention post-intervention. This finding clearly shows the relation of improving working memory with its positive effect on attention. Furthermore, animated layouts helped in grasping the children's attention and motivating them to continue using the system. Children follow their progress through the scoring feature; the scores are shown on the screen as a motivational method.

The effect size for the study done by Fernández-Molina et al. (2015) found to be significant (Cohen's d = 2.853, n = 52). One of its main targeted outputs was improving attention in young children by introducing attention training tasks and working memory training tasks. There was a reward/punishment feature. This is used as a motivational stimulus along with all the colourful pictures and drawings. Sounds are used for indicating right or wrong answers as feedback.

Mahmoudi et al. (2015) evaluated an animated puzzle game to improve attention. The calculated effect size for this study was significant as well (Cohen's $d = 0.828$, $n = 100$). It was about packing colourful puzzle pieces perfectly without leaving a space. A reward/punishment feature was used as motivation. The video game provided the user with recent scores as an instant evaluation feature. One of the impressive findings of playing this game was the attention improvement. The user must be very focused and attentive to complete each level correctly.

Carpenter et al. (2016) examined the changes in children's cognitive skills after completing a one-on-one training program with an interactive metronome technology. The calculated effect size for this study was significant as well (Cohen's $d = 1.16$, $n = 39$). The program included tasks targeting cognitive abilities and skills. It provided constant feedback and awarded points for mastery and effort. Participants were able to save and later exchange their points for small prizes or gift cards. Exercises were included as well to strengthen attention and concentration by rhyming with the metronome beats in the presence of distractions.

After analysing attention-targeted studies, and upon effective and highly significant methods used to grasp and improve attention, we clustered these methods/features into four main components: rising attention factors (training), using graphical interactive designs to gain attention, motivational factors, feedback factors, and a performance visibility factor.

3.4.2. Working Memory-Targeted Studies

Twenty-five studies proposed and evaluated approaches to improve working memory in children with ADHD, such as visuospatial working memory tasks, verbal tasks, categorising objects with certain characteristics or features, remembering sequence orders of numbers, letters, or objects, and reordering in reverse. We have calculated the weighted effect size for all category-related studies to measure the significance of the research using the random effect model.

The *Q* statistic is highly significant ($Q = 42.02$, $p < .001$). Likewise, the population effect size using the *r* metric and a 95% CI is 0.57 (95% CI [0.37, 0.78]). This population effect size is significant ($z = 5.47$, $p < .001$). Figure 3.3 presents the funnel plot of the corresponding output.

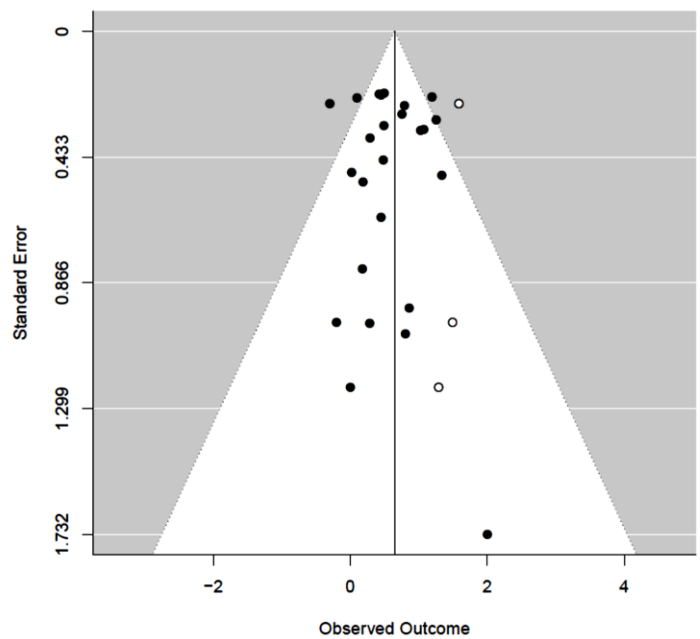

Figure 3.3. The funnel plot created using R for working memory-targeted studies.

Based on the homogeneity test, we see that there was considerable variation in effect sizes overall. Moreover, based on the estimate of population effect size and the CI, there was a strong effect of working memory developing methods on children with ADHD compared to the waiting-list controls.

In the next stage, we separately presented the effect sizes for each method within each study to distinguish between them and point out the highly significant ones (Table 3.3).

Table 3.3. Effect and sample sizes of studies targeting working memory.

Study	***N*1**	***N*2**	**Effect Size *d***
(Mautone et al., 2005)	1	2	1.44
(Simsek, 2016)	2	2	1.41
(Kourakli et al., 2016)	10	10	1.396
(Fernández-Molina et al., 2015)	26	26	1.271
(Richard et al., 2007)	46	47	1.204
(Jiang & Johnston, 2015)	2	3	1.1838
(Carpenter et al., 2016)	19	20	1.05
(Klingberg et al., 2005)	26	27	0.8
(Andreou et al., 2016)	33	33	0.8
(Koceski & Koceska, 2015)	5	5	0.5
(Fernández-López et al., 2013)	19	20	0.5
(Ruiz-Manrique et al., 2014)	1	1	0.5
(Fesakis et al., 2011)	2	2	0.5
(Bul et al., 2015)	10	11	0.5
(Smith et al., 2016)	46	46	0.5
(Chacko et al., 2014)	42	43	0.452
(Dovis et al., 2015)	44	45	0.427
(Mahmoudi et al., 2015)	50	50	0.298
(Wrońska et al., 2015)	3	3	0.22
(Martínez et al., 2016)	7	8	0.2
(Rabiner et al., 2010)	38	39	0.1
(Kim et al., 2014)	8	9	0.02
(Given et al., 2008)	32	33	-0.3
(Lee & Vail, 2004)	2	2	-0.355

Note: *N*1 = control group sample size; *N*2 = intervention group; *d* = Cohen's effect size.

It is clear that nine studies may be considered significant, but some studies (Klingberg et al., 2005; Richard et al., 2007; Carpenter et al., 2016; Fernández-Molina et al., 2015; Kourakli et al., 2016) were more likely to be significant due to reasonable sample sizes.

The study done by Klingberg (2005) evaluated a computer program that provides working memory training tasks. It included games for visuospatial working memory tasks as well as verbal tasks. The difficulty level was automatically adjusted on a trial-by-trail basis to match the working memory span of the child on each task. The exercises become increasingly challenging as the program progresses but calibrate to accommodate each child's individual level of progress. This study had a significant estimated effect size (Cohen’s d = 0.8, n = 53).

In the study by Fernández-Molina et al. (2015), one of the important exercises was identifying graphical objects depending on common features, for example, colour, shape, and size. The aim of this working memory training task was to classify them. Improvements were found in children’s academic performance, and the results indicated this was an effective educational method. The calculated effect size for this developing method is highly significant (Cohen’s d = 1.271, n = 52).

A study by Kourakli et al. (2016) presented positive findings for a pilot research study in inclusive classroom settings with children with special educational needs using the Kinems suite that contains movement-based educational games for children. The estimated effect size for this study was significant (Cohen’s d = 1.396, n = 20). Five mini games were evaluated for enhancing behaviour, physical motor control, cognitive abilities such as working memory, and finally, academic skills, especially in mathematics. One of the games was based on the concept of typical flash cards for improving visual working memory. As an effect, this game combines visual memory, early literacy skills, and linguistic development. Another game focused on sounds, aiming at the improvement of auditory working memory. A third game was for practising mental calculations up to 100. Appropriate feedback was given for correct and incorrect answers, thus resulting in improving a child’s mastery of mathematical operations. The results indicated that this was an effective academic approach. If a child’s performance was good enough, the researcher either changed the game difficulty level accordingly or launched a new game for meeting a new goal.

In another study, an educational augmented reality application was evaluated that allowed young children to handle 2D and 3D entities (Richard et al., 2007).

This application involved a working memory training task of pairing and provided visual, olfactory, or auditory cues to help children in decision making. The level of task difficulty could be adjusted. The estimated effect size for this method was highly significant (Cohen's d = 1.204, n = 93).

In the study done by Carpenter et al. (2016), an evaluation of memory training tasks was provided. One of the methods used was studying certain cards then recalling the numbers in the correct positions. We know from various studies that training the attention will improve working memory and vice versa, and this was demonstrated in this study as well. Thus, all attention improving tasks had a positive effect on working memory as well. The other working memory training task was listening to or reading descriptors, then selecting the object that matches the descriptions. An additional task was studying numbers and their positions on a card and recalling the digits and positions with each metronome beat. Additionally, the trainer called out numbers for a participant to perform a mathematical operation on *n*-back numbers using a timer and metronome. The participant studied the patterns of shapes and reproduced them from memory. Here, the calculated effect size was significant as well (Cohen's d = 1.05, n = 39).

After analysing studies targeting working memory, with effective and highly significant methods used to train and enhance memory, we clustered these methods/features into three main components: working memory enhancing factors, matching task difficulty with user abilities and skills, and using effective academic strategies. Increasing attention will lead to enhancing the working memory as well.

3.4.3. Processing Speed-Targeted Studies

Fourteen studies proposed and evaluated approaches to improve processing speed in children with ADHD, such as determining certain time limits to complete a task, adjusting time based on user performance, and using the interactive metronome, feedback, and motivation as stimuli. We calculated the weighted effect size for all category-related studies to measure the significance of the research using the random effect model.

For Hedges's method, the *Q* statistic is highly significant ($Q = 59.55$, $p < .001$). Likewise, the population effect size using the r metric and the 95% CI is 0.75 (95% CI [0.35, 1.14]). This population effect size is significant ($z = 3.73$, $p < .001$). Figure 3.4 presents the funnel plot of the corresponding output.

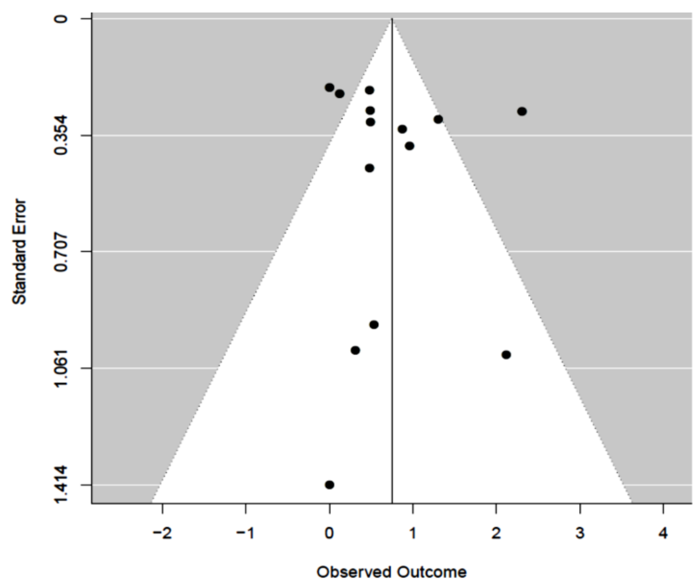

Figure 3.4. Funnel plot created using R for processing speed-targeted studies.

Based on the homogeneity test, there was considerable variation in the effect sizes overall. In addition, based on the estimation of the population effect size and CI, we conclude that there was a strong effect of attention developing methods for children with ADHD compared to the waiting-list controls.

In the next stage, we separately presented the effect sizes for each method within each study to distinguish between them and point out the highly significant ones (Table 3.4).

Table 3.4. Effect and sample sizes of studies targeting processing speed.

Study	***N*1**	***N*2**	**Effect Size *d***
(Klingberg et al., 2005)	26	27	0.4945
(Dovis et al., 2015)	44	45	0.486
(Chacko et al., 2014)	42	43	2.328
(Kourakli et al., 2016)	10	10	0.5
(Rabiner et al., 2010)	38	39	0.123
(Simsek, 2016)	2	2	0.545
(Wrońska et al., 2015)	3	3	2.646
(Thomas et al., 2013)	2	3	0.731
(Fernández-Molina et al., 2015)	26	26	1.324
(Mahmoudi et al., 2015)	50	50	0.988
(Namgung et al., 2015)	1	1	0
(Carpenter et al., 2016)	19	20	0.89
(Bul et al., 2015)	21	21	0.5
(Smith et al., 2016)	46	46	0
(Klingberg et al., 2005)	26	27	0.4945

Note: *N*1 = control group sample size; *N*2 = intervention group; *d* = Cohen's effect size.

It is clear that five studies may be considered significant, but some studies (Chacko et al., 2014; Fernández-Molina et al., 2015; Mahmoudi et al., 2015; Carpenter et al., 2016) were more likely to be significant due to reasonable sample sizes.

In the study done by Chacko et al. (2014), a program called 'Cogmed' Working Memory Training (CWMT) was used as an intervention to decrease ADHD symptoms in children. It is a computerised training program that targets working memory and processing speed. The estimated effect size for this training method was significant (Cohen's d = 2.328, n = 85). The CWMT active trials used an automated adjusting feature that modifies the level of task difficulty on a task-by-task basis that suits the child's abilities. After a few trials, upon child mastery, the task difficulty will increase. In addition, the time needed to finish a particular task will vary depending on a child's pace. After more practice, the time will decrease gradually once the child enhances performance and increases speed.

In the study by Fernández-Molina et al. (2015), each child finishes each task at their own pace. This is a dynamic time-span scheme; thus, there is no certain end of task time. Another aspect of the study is the speed at which the children performed the task, which appeared to improve with more exercises. Thus, the calculated effect size for this study (Cohen's $d = 1.324$, $n = 52$) can be considered highly significant.

Mahmoudi et al. (2015) found that playing a video game improved the processing speed of children, with a significant effect size (Cohen's $d = 0.988$, $n = 100$). Users had to stack objects as quickly as possible and correctly without leaving any spaces. More time needed means less points gained, and without enough points to score at a certain level, users cannot proceed to further levels.

In another study (Carpenter et al., 2016), many tasks were evaluated and demonstrated a positive effect on attention, memory, and processing speed. Each task targeted one or more cognitive abilities. The estimated effect size was significant (Cohen's $d = 0.89$, $n = 39$).

After analysing the processing speed-targeted studies, based on the effective and highly significant methods used to increase and enhance the children's processing speed, we clustered these methods/features into three main components: matching task duration with user abilities and skills, using a dynamic time-span scheme and rhythmic (beats), and movement training exercises. It is important to mention that increasing attention will lead to enhancing the processing speed as well.

3.4.4. Behaviour-Targeted Studies

Eighteen studies proposed and evaluated approaches to improve behaviour skills in children with ADHD, such as using sensing and training tools, Kinect tools, and physical activities. We calculated the weighted effect size for all category-related studies to measure the significance of research using the random effect model.

For Hedges's method, the Q statistic is highly significant ($Q = 59.55$, $p < .001$). Likewise, the population effect size using the *r* metric and the 95% CI is 0.75 (95% CI [0.35, 1.14]). This population effect size is significant ($z = 3.73$, $p < .001$).

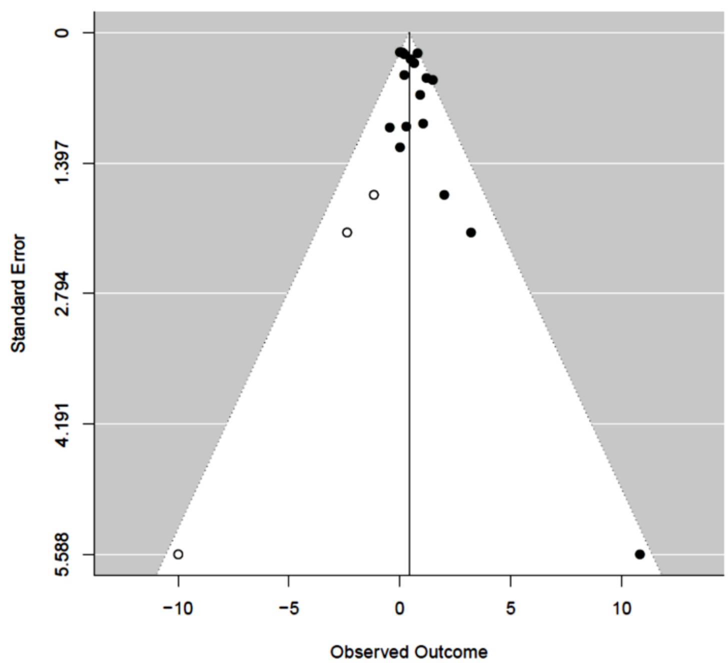

Figure 3.5. Funnel plot created using R for behaviour-targeted studies.

Based on the homogeneity test, there was considerable variation in effect sizes overall. In addition, based on the estimate of population effect size and CI, we conclude that there was a strong effect of behavioural development methods on children ADHD compared to the waiting-list controls.

In the next stage, we separately presented the effect sizes for each method within each study to distinguish between them and point out the highly significant ones (Table 3.5).

Table 3.5. Effect and sample sizes of studies targeting behaviour.

Study	***N*1**	***N*2**	**Effect Size *d***
(Sonne et al., 2015)	10	10	1.252
(Klingberg et al., 2005)	26	27	0.492
(Dovis et al., 2015)	44	45	0.1
(Sack, 2016)	2	2	0.5
(Jiang & Johnston, 2015)	2	3	1.433
(Mautone et al., 2005)	1	2	1.78
(Chacko et al., 2014)	42	43	0.155
(Kourakli et al., 2016)	10	10	1.549
(Rabiner et al., 2010)	38	39	0.2
(Olounabadi, 2014)	20	20	0.66
(Sonne et al., 2016)	10	10	0.2
(Namgung et al., 2015)	1	1	2.703
(Kim et al., 2012)	5	5	1.01
(Ruiz-Manrique et al., 2014)	1	1	0.5
(Shih et al., 2014)	1	1	0.8
(Richard et al., 2007)	46	47	0.8
(Fesakis et al., 2011)	2	2	-0.8
(Smith et al., 2016)	46	46	0

Note: *N*1 = control group sample size; *N*2 = intervention group; *d* = Cohen's effect size.

It is clear that nine studies may be considered significant, but some studies (Richard et al., 2007; Sonne et al., 2015; Kourakli et al., 2016) were more likely to be significant due to reasonable sample sizes.

In the study by Richard et al. (2007), an augmented reality educational application was developed and evaluated for children with cognitive weaknesses. It allowed young children to handle 2D and 3D plant entities, such as fruit, leaves, flowers, and seeds in a simple and intuitive way. These entities were presented in a magic book–like user interface. This approach had a significant estimated effect size (Cohen's $d = 0.8$, $n = 93$). Tasks included exciting physical activities for matching and arranging vegetal objects. The application encouraged children to touch, feel, and smell the objects as a clue to complete the task correctly. The study reported an improvement in some of the children's behaviour after the intervention; they were more organised and tended to be less hyperactive.

Sonne et al. (2015) designed the Child Activity Sensing and Training Tool (CASTT), a real-time assistive wearable prototype. It captured activities and assisted the child in maintaining attention and controlling behaviour. The choice of a quiz application was chosen, as it included rewards for correctly answered questions as motivation and facilitated a natural termination after a fixed time. We estimated the effect size from available data and found it to be significant (Cohen's d = 1.252, n = 20).

Kourakli et al. (2016) presented positive findings for a pilot research study in inclusive classroom settings with special educational needs children, using the Kinems suite that contains movement-based educational games for children with special needs. The following five mini games were tested: *Farm Walks*, *Space Motif*, *UnBoxIt*, *Melody Tree*, and *Mathloons*. The first two were for enhancing behaviour and physical motor control. The other two were for improving cognitive abilities, such as working memory. The last game, *Mathloons*, was for improving academic skills, especially in mathematics. In the *Farm Walks* game, a child uses the hand delay gesture to pick the farmer to drive him along paths of different shapes. The farmer can make stops to pick up carrots. He should also avoid snakes that appear as obstacles. In *Space Motif*, the child needs to recognise and repeat a given pattern of planets and space objects by driving them from outer-space into a tube in the right order. The game can become challenging when players are called to select and move objects, while avoiding collisions with other planets, space objects, and black holes. These games train behavioural management and enhance behavioural control in children. The effect size here indicates significance (Cohen's d = 1.549, n = 20).

After analysing behaviour-targeted studies, based on the effective and highly significant methods/features used to decrease hyperactivity and control behaviour in children with ADHD, we clustered these methods into two main components: behaviour control and management factors, and physical activity inclusion. It is important to mention that increasing attention will lead to decreased hyperactivity as well.

3.4.5. Social Skills-Targeted Studies

Ten studies proposed and evaluated approaches to improve social skills in children with ADHD, such as peer tutoring, collaborative tasks, interactive communication, and monitored links to multimedia and social media. We have calculated the weighted effect size for all category-related studies to measure the significance of the research using the random effect model.

In the R data editor, we created four new variables, as in the previous category. Once the data are entered, we ran the program. We opted for a random-effects analysis. Yet again, for Hedges's method, the Q statistic is highly significant ($Q = 1.12$, $p < .001$). Likewise, the population effect size using the r metric and the 95% CI is 0.58 (95% CI [0.34, 0.82]). This population effect size is significant ($z = 4.73$, $p < .001$). Figure 5.6 presents the funnel plot of the corresponding output.

Based on the homogeneity test, there was considerable variation in effect sizes overall. Furthermore, based on the estimate of population effect size and CI, we conclude that there was a strong effect of attention developing methods on children with ADHD compared to the waiting-list controls.

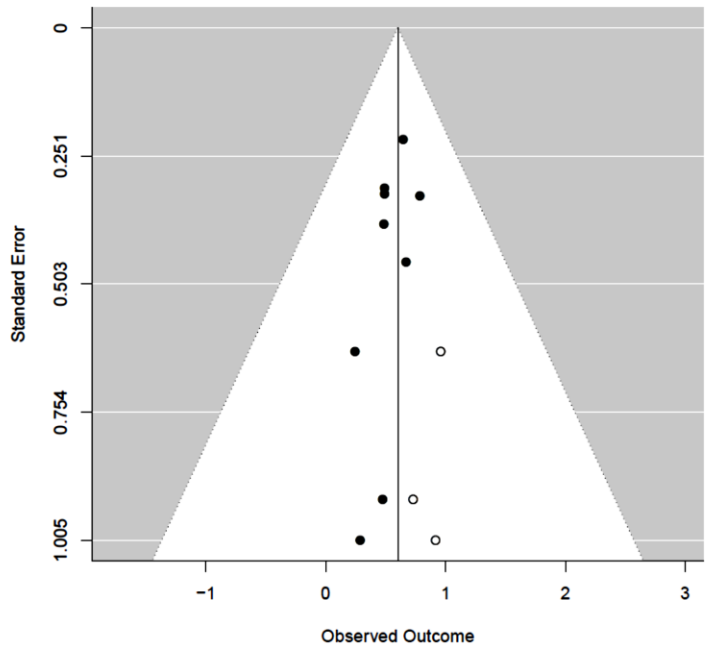

Figure 3.6. Funnel plot created using R for processing speed-targeted studies.

In the next stage, we separately presented the effect sizes for each method within each study to distinguish between them and point out the highly significant ones (Table 3.6).

Table 3.6. Effect and sample sizes of studies targeting social skills.

Study	***N*1**	***N*2**	**Effect size *d***
(Dovis et al., 2015)	44	45	0.6521
(Jiang & Johnston, 2015)	2	3	0.652
(Kourakli et al., 2016)	10	10	0.7
(Olounabadi, 2014)	20	20	0.8
(Wegrzyn et al., 2012)	5	5	0.271
(Fernández-López et al., 2013)	19	20	0.5
(Höysniemi et al., 2003)	14	14	0.5
(Fesakis et al., 2011)	2	2	0.5
(Bul et al., 2015)	21	21	0.5
(Smith et al., 2016)	46	46	0

Note: *N*1 = control group sample size; *N*2 = intervention group; *d* = Cohen’s effect size.

Only one study (Olounabadi, 2014) was considered significant with a reasonable sample size (with an estimated effect size Cohen's $d = 0.8$, $n = 40$).

Olounabadi (2014) developed a simulation game named TARLAN. It teaches children with ADHD different steps of solving various social problems they may face in real-life situations. One of the main goals of the game was to improve inhibition, so children with ADHD will be able to inhibit early responses. The other goal was focusing on combining problem-solving strategies with social-skill training to improve ratings of social adjustment. Animated scenarios were developed wherein children can practise solving social problems step by step to gain social competency. The scenarios were goal oriented. Moreover, they also practised inhibition, as they must go through the process step by step and cannot skip any steps to reach the final point faster. Uniquely, instead of acting based on trial and error in which children click on different objects randomly to move on, children play the game more thoughtfully by trying to solve the problem in the game. It provided an attractive yet very simple layout to grasp children's attention without distracting them from the main subject. There was an agent feature that read instructions (audio) and gave immediate feedback to children. The agent motivated children by demonstrating facial emotions for the answers and rewarded the child for solving the problem. Another effective feature was a self-avatar, which represented the child in the game. Personalising the interaction between the child and the system improved learning gain, knowledge retention, and engagement with the game. From an HCI point of view, TARLAN was considered attractive and easy to learn, owing to the inclusion of explanatory pictures with words.

After analysing social-skill-targeted studies, based on the effective and highly significant methods/features used to engage children with ADHD socially within their environment, we clustered these methods into three main components: problem-solving strategies, social-skill training, and emotion-like feedback from virtual embodiments (avatar or agents).

3.5. Summary

This chapter reports a grounded meta-analysis with 49 empirical studies on enhancing skills and abilities for children with ADHD using technological interventions with game elements. Five units of analysis were done separately, targeting the following five attributes of abilities and skills: attention, working memory, processing speed, behaviour, and social skills. After analysing each method/game element in those studies, we highlighted the significant and effective ones which have positive impact on targeted abilities and skills. As a conclusion, we drew out a list of 13 design components that could be included and used by designers or developers as guidelines; to build effective educational application/game targeting children with ADHD:

- Effective educational elements: The core element of any effective educational system is to deliver high-quality content that ensures the best outcomes. The content must be suitable to the user’s age and commensurate with what is given to peers in school. In addition, it must be given by clearly known and trustable resources. The content should be introduced in multiple levels, in which the progress in these levels requires the mastery of the previous level. The educational content is best provided as a set of exercises, quizzes, games, and puzzles. It is also recommended to use supportive media, such as informative video clips, sound clips, and 3D and interactive tangible objects. In addition, it must be presented in a way that keeps students engaged, active, and enthused. Mixing too many methods in a single exercise or task is not recommended, as it will lead to distraction and difficulty understanding the information. The simpler and less complex the task is, the better the results will be.

- Attention reinforcement: Inattentiveness is one of the common weaknesses in children with ADHD. Systems intended to strengthen attention must focus on the use of moderate attractive elements and effective attention training exercises. These exercises may require the user to focus on certain objects and then recall from memory or focus on moving objects and request a quick reaction from the user. Basically, the best practice to reinforce attention is to combine the request of accurate reasoning and fast response. It is recommended to integrate enthusiastic technologies that grasp children's attention, such as augmented and virtual reality, animation, and video games. It is also recommended to use sounds and images moderately to keep the child focussed and minds-on the task, as distraction may occur if these elements were excessively used.

- Working memory stimulation: As shown in the meta-analysis, improving attention will lead to improvements in working memory and vice versa. These two executive functions are linked together and must be considered when developing an application targeting ADHD. It is recommended to develop tasks that require object sorting, pattern recognition, categorising, reasoning, remembering the location and order of objects (visuospatial working memory tasks), backward object verbal recall (verbal working memory tasks), and recalling a sequence of objects, text, or numbers. These tasks aim to train short-term memory to store information for a period of time and sometimes to manipulate them as well. If the child succeeds, more items to remember or match are added. However, if students struggle in remembering the exact order or pick the wrong item, less items are provided, and more time is offered.

- Processing speed stimulation: Usually children with ADHD suffer from slow processing speed and that affects the time they need to complete a certain task. An effective feature found to improve processing speed is the use of a dynamic visual timer; in which the child could track the remaining time for the task. The 'dynamic' attribute represents the continuous adjustment of needed time to match the child's ability and pace. The more errors the child performs, the longer time will be given to master the given exercise. In addition, visual timers were found to enhance time awareness in children. Another effective feature found to improve processing speed is linking the rewards with accurate and fast responses from the user. The child will try to give a correct answer as quickly as possible to collect more rewards and prizes. Furthermore, the use of the metronome beats was found effective in enhancing the child's timing. It is also recommended to introduce time breaks between tasks to emphasise time management perception.

- Behaviour management strategies: Hyperactivity, impulsiveness, and unpredictable behaviours are among the most obvious symptoms of ADHD. It is recommended to develop tasks that require organising and aligning objects, fine motor skills, precision, and formation. Moreover, reminders were found to be one of the effective features that assist in behaviour management, either using certain sounds, colours, images, or text. In addition, reward and punishment are considered two effective behaviour management approaches. It is also suggested to develop a system of various reactions depending on the measured activity level. For example, excessive activity will lead to a decrement in the child's score points. Furthermore, it is recommended to increase the quantity of instructions or hints given verbally or textually when the child's error rate increases and vice versa.

- Problem-solving strategy: Children learn from their mistakes; thus, developing challenging tasks will promote thinking skills, creativity, and the ability to learn from one's mistakes. Children must use trial, error, and flexibility to solve problems. It is recommended to develop tasks that require decision making and step-by-step problem solving. It is also recommended to create real-life scenarios and use the storytelling method to resonate with children's daily lives. Furthermore, training response inhibition and self-control have been found to improve problem-solving skills.

- Ongoing assessment: The child's error rate, response time, and accuracy are important inputs to any developmental application. They affect the task difficulty level and duration. These inputs must be assessed as long as the child interacts with the system. Furthermore, the child must be updated about the progress level, results, and mistakes. It is also recommended to generate reports that summarise the child's achievements, measured EFs and improvements gained, with tips and suggestions on how to strengthen some of the detected weaknesses that still need to be worked on.

- Motivational factors: To maintain motivation, tasks must be designed to keep children engaged, active, and enthusiastic. One of the effective motivational factors is to display the scores of all participating children in the same activity to each of them. This feature will revive competition among children and encourage them to improve their performance and score. In addition, children are encouraged and motivated by positive feedback, whether it is by text or sound. Other children will be motivated to improve their performance, so they could hear the same encouraging sound or positive pep talk. Furthermore, the reward and punishment approach will motivate children to do better. It is recommended to enable children to collect e-items rewards that could be used in another activity. For example, girls could collect gems to design their own accessories, and boys could collect car parts to design or decorate a car.

- Systematic feedback: Different feedback responses should be designed for each possible action. Negative feedback was found to frustrate and decrease enthusiasm in children. Feedback could be positive or encouraging using text, sound, or image. Descriptive feedback is also recommended; the child could be informed about the errors and given hints to overcome the obstacle.

- Dynamic task difficulty: Using cognitive load theory, task difficulty should match the child's abilities. The complexity of the task level will increase or decrease depending on the measured child's accuracy or error rate while performing tasks. Struggling children will eventually go to the next level after multiple training and mastering that task.

- Physical activities: It is recommended to integrate physical activities in developmental systems due to the positive effect on ADHD symptoms. Tasks could be designed to be controlled or affected by body movements. Different senses could be activated to solve a certain quiz by introducing tangible objects that children can touch, feel, and smell. In addition, hyperactivity management tasks could be designed to react or respond only when the child is moving less. Furthermore, it is suggested to support physical exercise and activities in the breaks between tasks.

- Virtual embodiments: Children will feel the attachment to a system by being given the capability of creating their own customised avatars. Yet, the avatar must be limited to child-friendly and inoffensive design elements owing to the influence on shaping children's behaviour. In addition, virtual agents could be used to express emotional facial feedback that could be easily understood by the child.

- E-collaboration: It is found that children who collaborate on a certain activity will learn better by exchanging knowledge and experience, motivating each other, and socialising positively. It is recommended to develop tasks promote communication, peer-tutoring, group activity, planning, and discussion in a monitored and secured closed community. Collaboration will increase competition and challenge among students, especially if it is associated with score display. This strategy will improve skills, such as thinking, reading, creativity, communication, and social skills, more quickly and noticeably.

After exploring available online games and applications for ADHD, we chose an e-game for further evaluation to examine its effectiveness and usability. Thus, ACTIVATE was selected based on the following criteria:

1) It targets young children with ADHD;
2) It targets the eight core cognitive capacities: sustained attention, working memory, and speed of information processing;
3) It is a research-based product by a senior research scientist;
4) It does not need specified setup settings or software/hardware, only a tablet with a browser, such as Google Chrome or Safari.

The e-game was evaluated regarding its effects on improving cognition, behaviour, and social skills for children with ADHD. Details about the experiment and findings were presented in Chapter 4.

In Chapter 5 we developed and evaluated an online chatting tool to enhance social skills for children with ADHD.

Chapter 4

Cognitive, Behavioural, and Social Effects of e-Games on the Development of Saudi Children with ADHD

In the Kingdom of Saudi Arabia (KSA), ADHD is a widely spread disorder among young school-age children (Jenahi, Khalil, & Bellac, 2012). Usually, they suffer from distraction, lack of focus, and hyperactivity, which holds them back academically. They do not fully understand lessons because of their lack of attention rather than because of any mental problem. Students with ADHD are relatively slower in delivering tasks on time than normal students; thus, it is very frustrating for them, their teachers, and their parents.

Many suggested educational interventions and traditional approaches have been applied in classrooms by educators, as demonstrated in the literature. Even medical treatments are no longer desirable by parents and caregivers. There is no denial of the positive effectiveness and improvement of some of these traditional methods on the overall academic performance of these children. However, considering the development in all areas, it is necessary to introduce modern techniques and tools instead of traditional ones and to investigate their effectiveness towards developing capabilities of children with ADHD.

Technology is now considered an integral part of life, especially for children. They use it whether they watch their favourite shows on TV or play entertaining or educational games on handheld devices. Many studies have assessed the use of technology in classrooms (Edyburn, 2004; Fails, 2009; Tavakkoli et al., 2014) to facilitate the delivery of information for students, to prompt collaboration among students with each other, and to make learning fun. Several types of technologies were used to enhance and facilitate the educational process, such as the use of electronic boards, data display devices, speakers and microphones, and educational applications using smart devices.

Some of these technologies were applied in many schools in KSA on students with and without ADHD, but to my knowledge, unfortunately, there was no reported study found regarding the effect of using any type of technology to improve the academic performance for Saudi students with ADHD.

Utilising these technologies for improving ADHD deficiencies is encouraged. Yet, lots of applications and games are being introduced constantly, claiming the capability of solving all ADHD issues. Users need some sort of guidelines that could help them pick and use a good application with effective features. Additionally, software developers could use a list of design guidelines that suggests effective interface features, especially for enhancing the abilities and skills of children with ADHD.

A list of design guidelines was suggested to assist the development of effective interfaces for children with ADHD. To support this outcome, we need to investigate one of the many existing applications and games in cyberspace that claims to improve children's cognition and behaviour. We need to discover whether the application or game methods have a direct influence on children's abilities and skills and whether these guidelines applies.

Our objective in this part of the study was to investigate the effectiveness of an e-game called ACTIVATE toward improving abilities and skills for children with ADHD. ACTIVATE and iPads were selected as test tools via the criteria mentioned in Chapter 3. Two issues were inspected. The first was to what extent the game elements and methods fit our guidelines. The other was whether these game elements and methods were effective in improving the abilities and skills of children with ADHD. The usability and desirability of the game user interface were studied.

Research Questions

In this chapter, we investigated the following research questions:

- What are the effects of using an e-game to develop abilities and skills for Saudi children with ADHD?
- What is the user experience upon interacting with the e-game interface in terms of usability and desirability?
- What are the recommended amendments that could be done to improve the investigated e-game?

4.1. Overview of the utilized instrument "ACTIVATE"

ACTIVATE is a web-based application that provides certain brain-training exercises for children with ADHD to enhance and develop their learning skills in classroom settings. As Dr Wexler's (2013) research has identified, the executive functions are divided into eight core cognitive capacities: sustained attention, working memory, speed of information processing, response inhibition, cognitive flexibility, category formation, pattern formation, and multiple simultaneous attention. These capacities can be strengthened in children with ADHD by stimulating them through the game. The executive functions or the eight cognitive capacities were mentioned in detail in the background chapter. The application has three portals: teacher, student, and test portals (Wexler, 2013), which will be described in the following sections.

The Teacher Portal

The educator can manage the students with their accounts through the teacher portal (Figure 4.1), monitoring their scores in games and their progress, error rate, and response speed (Figure 4.1). In addition, the teacher can compare tests results of each student to measure improvement. Finally, the system generates reports for students, which gives details about their strengths and weaknesses and how much they have improved since they began using the application (Figure 4.2).

The Student Portal

This portal contains six mini games that target eight cognitive skills necessary for executive functions (Figure 4.3). The games train the student's ability to move between different tasks, remember sequences, classify items, and reinforce thinking strategies. The game can detect the students' strengths, weaknesses, and errors. It encourages students to correct their errors using independent thinking strategies, which are stimulated while playing.

The target is to complete one thousand minutes of playing. Each class must stick to a training schedule of exercise sessions, 20 or 30 minutes per session, from three to five times a week. The schedule is flexible and could be simply modified to meet the demands of any school. The beginning sessions are easy and short to sustain students' enthusiasm and then gradually begin to increase the difficulty level. However, the level of difficulty is adjusted up or down every 10 to 15 seconds to meet the student's abilities based on their error rate, reaction time, and accuracy.

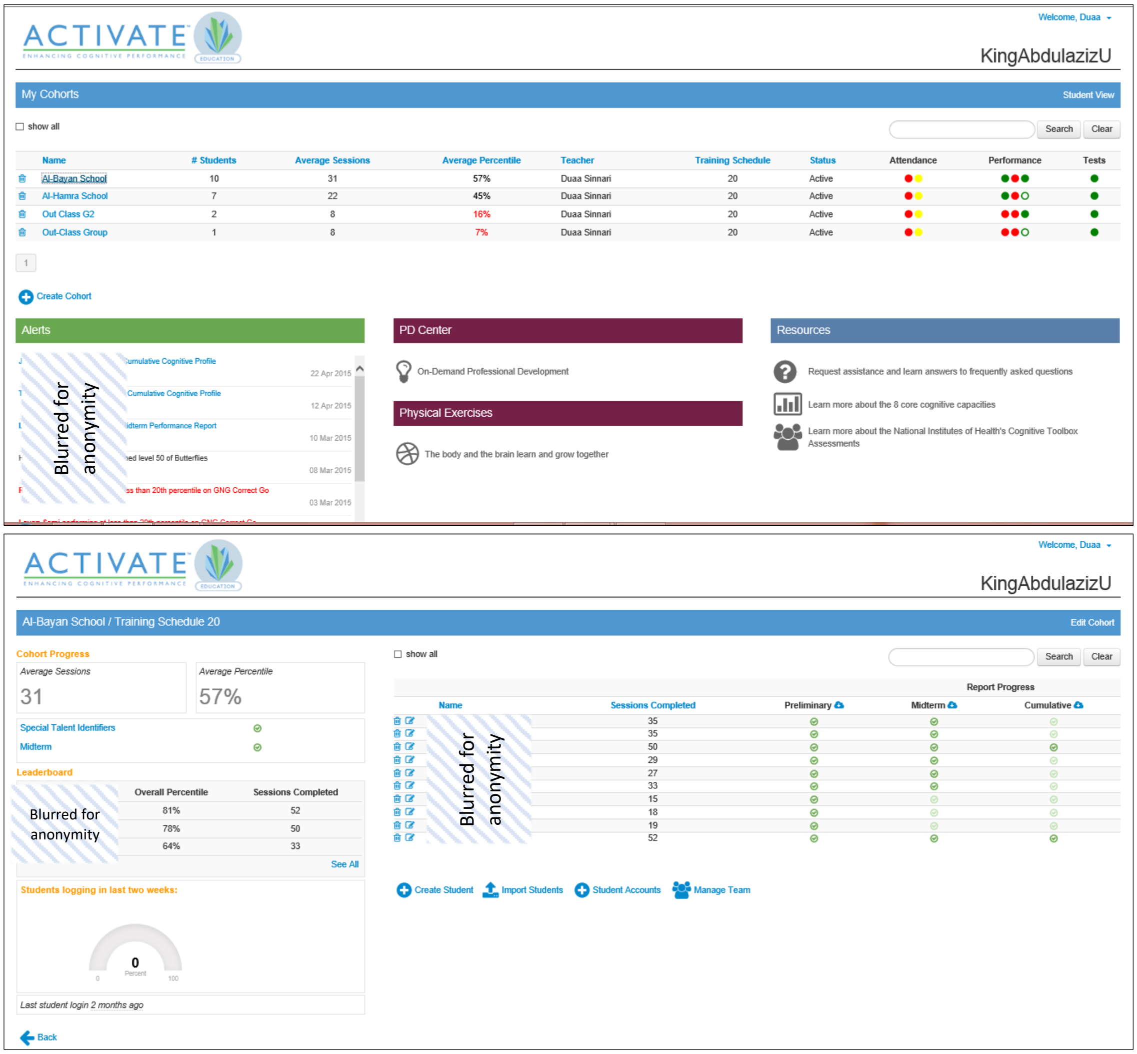

Figure 4.1. Teacher Portal in ACTIVATE (above: adding cohorts and students) (below: monitoring students' progress).

The theme of the games is an island that discovered by Captain Blue Feather and his crew. The student must help them complete levels and collect scores. The captain introduces each game and gives audio instructions to help students understand their tasks. These tasks range from feeding the crew, categorising items, helping animals, and more. The figure represents the sample of mini games offered to the students. Each game has hundreds of challenging levels. Students are allowed to play each game for five minutes only, with four or six games per session according to the session timing.

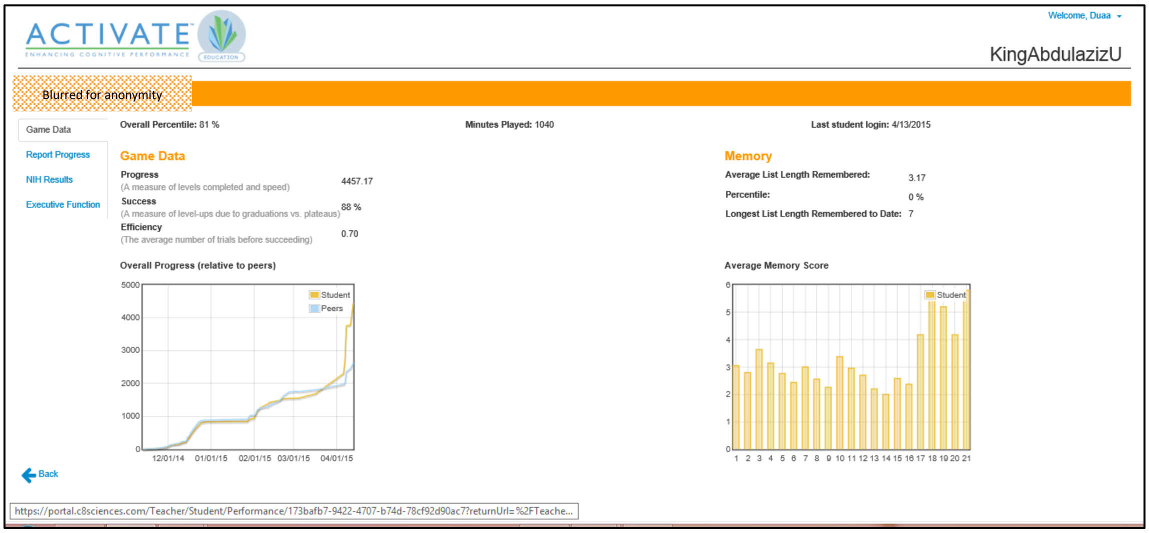

Figure 4.2. Teacher Portal in ACTIVATE (Viewing Results and Statistics).

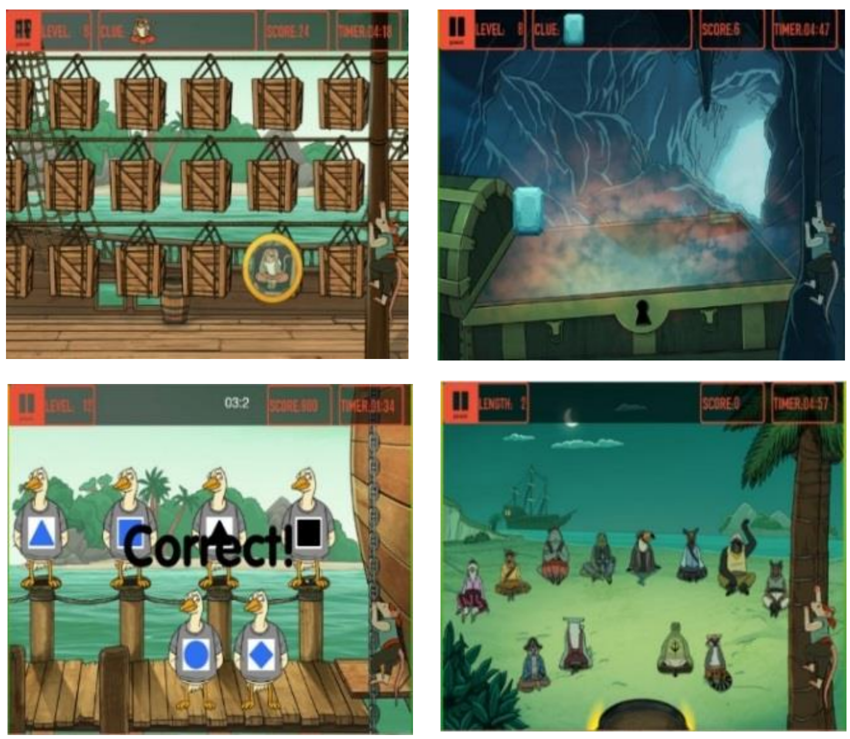

Figure 4.3. Samples of mini games in ACTIVATE.

The games are *Treasure Trunk*, *Grub Ahoy*, *The Magic Lens*, *Pirate Pete*, *Ducks*, and *Monkey Trouble*. In the *Magic Lens* game, the students must point to the monkey as soon as it appears from the box to free him. The game will go faster with correct responses. If mistakes are made, the game will go slow. If the goal was reached with no mistakes, the student will move to the next level. It presents cognitive tasks that help them learn how to organise information, abstract thoughts, exercise sustain attention, and improve their processing speed and working memory. In *Treasure Trunk,* the student must collect gems, depending on the clue shown, before they disappear. In the first 20 levels, one target appears on screen, after that, it gets more complex when the clue changes and there is more than one target to collect.

Both of these games develop memory skills, speed of information processing, and pattern formation. In *Pirate Pete*, which is a cognitive task, the student is asked to collect as many flying objects as he or she can, depending on a specific category mentioned as a clue. In the beginning, there will be two objects, then the number of objects will increase as well as the speed. When students select the correct object, it will go directly to the treasure trunk, but when a wrong object is selected it will fall down. The teacher can clearly notice a student who struggles in the task using this feedback.

In the *Ducks* mini game, the student will see three ducks, each holding a shape, and he or she must figure out the missing fourth shape. The clue here is to pick the same colour or same shape that matches the pattern. When the student correctly answers, the shapes will be more difficult to categorise while the time becomes shorter. Pictures of objects, at an advanced level, will appear to figure out the missing one from the same category. This game will improve pattern recognition, sustained attention, processing speed, and response inhibition. It also enhances multiple simultaneous attention in which the student must scan the pattern and the given objective to detect the missing one.

Complex principles and patterns will be mastered along the way by realising the correct sequence each time. Again, the teacher can note the struggling student if there were no flying ducks on his or her screen, or simply by seeing a red X indicator.

The *Monkey Trouble* and *Grub Ahoy* mini games target spatial location working memory training. The first one is about a monkey running and messing up different spots on the island, and the second one is about feeding hungry pirates in a first-come-first-serve strategy. Both games display a certain path sequence, and students are asked to repeat them. It starts with fewer elements and a shorter sequence, then the duration becomes longer in the upper levels. The student must remember the correct series to go to the next level. If the student fails to remember the series, it will become shorter until it becomes easy to repeat. At the next level, the student will be asked for a reversed version of the series displayed to challenge the student's memory. These games improve the special working memory, sustained attention, and cognitive flexibility.

The Test Portal

In the test portal, students undertake three tests: pre-, mid-, and post-experiments, which are recommended by the National Institute of Health (NIH) to measure the amount of enhancement in cognitive skills for each student (Bauer & Zelazo, 2014). These tests are done by each participant at the beginning, middle, and the end of the training programme. The NIH toolbox contains a flanker task test (attention), working memory test (memory), and go/no go test (self-control) (Figure 4.4). These kinds of assessments can help teachers measure the amount of cognitive growth using real-time data and analyse the amount of success, which affects the academic future of students.

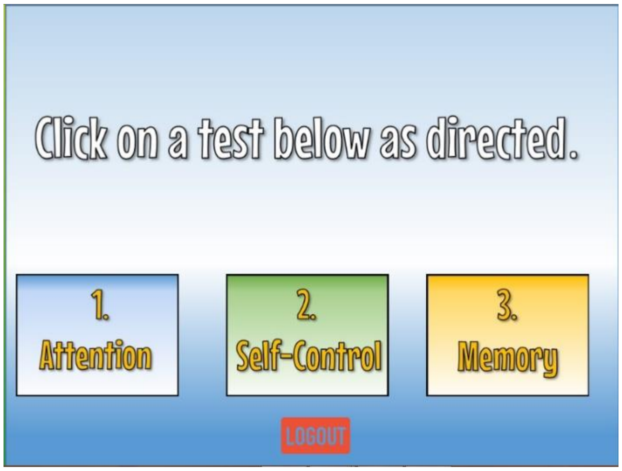

Figure 4.4. Test Portal in ACTIVATE

The flanker test assesses sustained attention and inhibitory control. It displays five arrows in a row, each is pointing either to the left or right (Figure 4.5). The student must identify which way the middle arrow goes. In simple trials, all five arrows are pointing in the same direction, but in the difficult ones, the middle arrow points to the opposite direction from the rest of the arrows. There are two factors measured, reaction time (RT) of the correct response and accuracy.

Figure 4.5. Flanker Task Test by NIH

The go/no go test measures the speed of information processing, inhibitory control, and cognitive flexibility. It has three parts. In the first part, students must tap on the go button whenever the letter *P* is displayed as fast as they can but must not tap when the letter *R* appears. In contrast, in the second part, they must tap whenever they see the *R* but not the *P*. In the third part, they tap the go button when they see a household picture but not when they see pictures of food. Here, the results depend on the correct 'no-go' trials skipped by the student in the test.

The working memory test measures the ability of the brain to retain and comprehend information needed to accomplish any task. It asks students to repeat a sequence of pictures appearing on the screen but in a different order based on the requested criteria, such as from smaller to bigger. They must remember the pictures, re-order them in their minds, then present them in the new order. In the second part, mixed pictures from two categories are shown, and the student must re-order two sets separately in the correct order. Thus, in this test, accuracy is measured rather than RT.

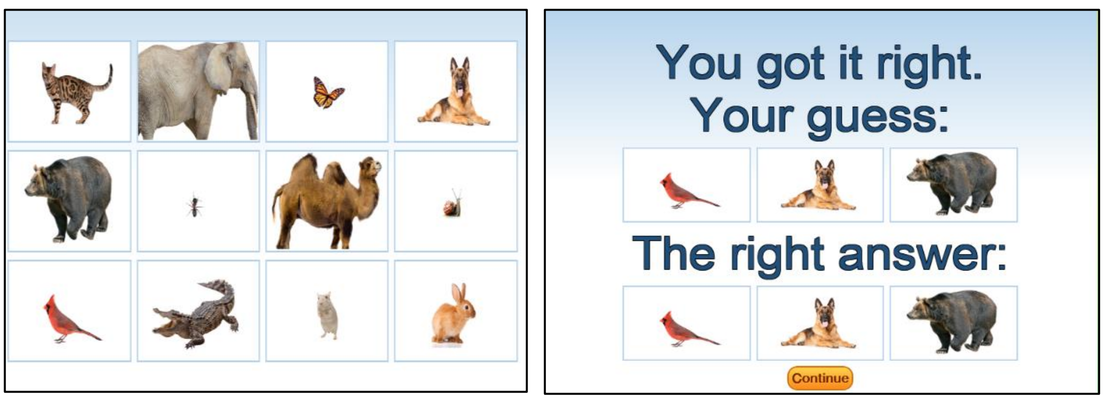

Figure 4.6. Working Memory Test by NIH

4.2. Technical Specification

iPads: King Abdul-Aziz University Higher Education Department has provided six iPads (Air Apple) for this study as tools to run the application with the following specifications.

Capacity	16 GB
Operating System	IOS 8.1.1
Dimensions	9.4 inch * 6.6 inch
Resolution	264 pixels/inch
Support Wi-Fi	Yes
Browser	Safari

Researcher Laptop: The laptop was used to monitor the students' progress and results and to generate reports. The following are the Laptop specifications:

Operating System	Windows 8.1
Processor	Intel® i5-4210U
CPU	2.40 GHz
RAM	6 GB
System Type	64-bit

Browser: The Safari browser from Apple was used to run the web-based application. It was recommended by the application developers due to its fast response time and quick download.

Web-based Application: The developers of the application allowed us to use ACTIVATE with no charges and provided us with accounts for the sake of research and scientific exchange. Students accessed their accounts using the students' portal: KingAbdulazizU.c8sciences.com. The researcher monitored the students' progress through the teacher portal: Portal.c8sciences.com. Tests were conducted by students through the test portal: Test.c8sciences.com, each using his or her own account credentials.

4.3. Legal Authorisations

This experiment was approved by the Ministry of Education Planning and Development Department. The head of the school approved performing the investigation in the school with the students, and information sheets and consent forms were signed by the parents of the participants as well.

4.4. Experiment Design and Methodology

In research, when targeting special education participants, it is acceptable and common to use the one-group pre- and post-approach, applying mixed methodologies (Gersten et al., 2005). The reason is the variability of cases within a single condition; for example, children may vary in severity or have different types of ADHD disorder. Another challenge is the heterogeneity of their characteristics, which complicate the design of comparable experimental groups. In addition, some disorders, such as ADHD, have low prevalence in small communities, such as schools, and there can be a low willingness to participate in any experiment or intervention (Odom et al., 2005). In our study, a research question such as ‘Are e-games effective in improving the academic performance of children with ADHD?’ may not be investigated through approaches that involve random assignment to a ‘control group’. The use of a mixture of qualitative and quantitative research approaches to answer different research questions will elevate the quality of research in special education (Gersten et al., 2005; Odom et al., 2005).

Relying on our research objectives, we designed a one-group pre- and post-experimental study and applied qualitative and quantitative methods. The independent variable was the e-game (ACTIVATE application), and the dependent variables were academic performance, cognition, behaviour, and social skills. The usability and desirability of the user interface were tested by observation and a post-experiment interview with the participants.

The experiment was performed in a classroom setting, after a school day. In the first session, students logged into the test portal and performed all three tests to measure their cognitive levels before the experiment. In the next session, they started to play games. The target was to complete one thousand minutes of playing. Each class must maintain a training schedule of exercise sessions, 20 or 30 minutes per session, from three to five times a week. The schedule was flexible and could be modified to meet the demands of any school.

Sessions start as easy and short to sustain students' enthusiasm, then gradually begin to increase in difficulty level. However, the level of difficulty is adjusted up or down every 10 to 15 seconds to meet the student's abilities based on their error rate, RT, and accuracy. Each student picked up an iPad, logged into an account, and started playing one of the six games. The students could play four to six games depending on the time provided. The application then automatically terminates the sessions when the time is up. There was an animated timer for students to track time. Instant feedback was given for both wrong and right answers. Features such as colours, sounds, and animated objects were motivating and stimulating for the students while playing. After the experiment, approximately four months later, the students logged into the test portal again to redo the three tests to measure the improvement.

4.5. Participants

The experiment took place in a classroom setting with a group of female students aged between 6 and 12 years old. It is important to indicate that the nature of the KSA environment separates males from females due to the culture in some organisations including educational organisations. Because of that, as a female researcher, the possible and easy choice was to work with female students.

For our case studies, two international schools approved participation in the experiment. The researcher intentionally selected international schools due to the interface language for ACTIVATE, which is English. A survey was distributed among the parents that contained Conner's scale to assess ADHD. The goal was to initially discover whether there were signs of ADHD in those who were not yet diagnosed and to detect whether there were any diagnosed

ADHD cases. After detecting students with ADHD symptoms, consent forms were sent to their parents explaining the game, its assumed benefits, the session timing and how long the experiment would take.

Eventually 17 families signed and agreed for their daughters to participate. Thus, 17 students enrolled out of 25 who were identified to have signs of ADHD. For ethical reasons and anonymity, codes were used instead of their real names. The first school was Al-Hammra International School – English sector, where six students participated: one student from the first grade (Std 1H), three from second grade (Std 2LB, Std 3K, Std 4LW), one from third grade (Std 5T), and one from fourth grade (Std 6M). The second school was Al-Bayan Model School – English sector, where 11 students participated: one student from the fourth grade (Std 17LH), four from the fifth grade (Std 7JN, Std 8LN, Std 9LS, and Std 10JR), and six from the sixth grade (Std 11RG, Std 12I, Std 13RL, Std 14T, Std 15D, and Std 16RF). Background information on the participants, gathered from Conner's scale survey and parents' interview, is listed in Table 4.1.

Table 4.1. Background information on participants

Student	Age (Years)	ADHD Type	Any Medication
Std 1H	6	Inattentive	No
Std 2LB	7	Inattentive	No
Std 3K	7	Inattentive	Yes
Std 4LW	7	Combined	No
Std 5T	8	Inattentive	No
Std 6M	9	Hyperactivity	No
Std 7JN	10	Combined	No
Std 8LN	11	Hyperactivity	No
Std 9LS	10	Hyperactivity	No
Std 10JR	10	Combined	No
Std 11RG	12	Inattentive	No
Std 12I	11	Inattentive	No
Std 13RL	12	Inattentive	No
Std 14T	11	Hyperactivity	No
Std 15D	11	Hyperactivity	No
Std 16RF	12	Combined	No
Std 17LH	9	Combined	No

The ADHD type for each case was diagnosed depending on the most noticeable symptoms and signs observed frequently by teachers and parents, using the DSM-IV-TR criteria (Brown, 2006). The participants were seated together in a classroom, each with an iPad, with encouragement to think aloud.

4.6. Data Collection and Analysis

Data were gathered from six sources:

- Conner's rating scale,
- Teachers' and parents' interviews,
- Observations and notes taken during the experiment,
- Short talks with the participants after each session and after finishing the experiment,
- Gathered participants major course scores before and after the experiment, and
- Gathered data by the system, such as the error rate, duration, progress points, etc.

Conner's rating scale was used in this study by the researcher to measure the child's behaviour and habits as a preliminary screening for ADHD (Figure 4.7). 'Not only does this help to diagnose children who otherwise may have been overlooked, but it also offers a point of comparison for those who do suffer from ADHD' (Kessler et al., 2006).

1) excessive activity and movement
☐often ☐always ☐few ☐No

2) fast enthusiasm and excitement, impulsive and reckless
☐often ☐always ☐few ☐No

3) disturb other students
☐often ☐always ☐few ☐No

4) is not able to complete what had begun (lesson or play)
☐often ☐always ☐few ☐No

5) can't sit down a reasonable period, a lot of tampering
☐often ☐always ☐few ☐No

6) No attention and very little focusing
☐often ☐always ☐few ☐No

7) must perform all demands at once (No patience)
☐often ☐always ☐few ☐No

8) cry quickly and easily without a real reason
☐often ☐always ☐few ☐No

9) quick change in the mood radically, quick anger and frustration
☐often ☐always ☐few ☐No

10) quickly explode and unexpected behavior
☐often ☐always ☐few ☐No

Figure 4.7. Connor Rating Scale for ADHD Screening

Teacher and parent interviews were done at various stages. In the beginning, teacher interviews helped select the proper participants for our experiment by pointing out those who have some attention or hyperactivity problems in class (severe learning difficulty cases are excluded from this study owing to concentrating on ADHD symptoms only). After that, other interviews with the same teachers gradually took place to sense any improvements in the students' behaviour and academic performance during regular classes.

Regarding parent interviews, nearly all of them were done via phone, but we were fortunate to meet some of the mothers at the schools. General information was collected about the student's behaviour, social skills, diagnosis of ADHD, any medications, etc. Later, a couple of interviews were done to determine whether the students were positively affected by the application, and whether the parents sensed any enhancements in their daughters' lives. Feedback from interviews was very supportive and beneficial for this study, and it added value to the outcomes.

During testing sessions, the researcher tried not to interact with the students unless there were technical problems or difficult queries from any student. It was also necessary to maintain control in class due to their movements and loud voices. The ethnographical method was used as our qualitative measure, with observations and note taking for each participant as a separate case. The researcher documented the students' conversations while playing the games, their most important reactions and attitudes, the problems they faced, the way they helped each other, their hand movements and gestures, and their opinions and judgements about the games. The study analysis included quantitative measures as well. The NIH recommended measuring the amount of enhancement in cognitive skills for each student using the NIH toolbox (Wexler, 2013). It was used to gather data about the students' improvements during the experiment. Pre-tests were taken before playing the game, and post-tests were taken after finishing the required sessions. The evaluation was done depending on two perspectives: the human-computer interaction (HCI) perspective, which assessed usability and desirability and the acceptability and adaptability of the user interface for the game. The second perspective was evaluating the application to determine whether it was effective and beneficial for ADHD students. To statistically analyse their performance, we used the paired t-test to evaluate the significance by calculating the *p*-value.

Finally, the system generates four individual reports for each participant during the experiments. Each report presents numerical and statistical data about the level reached, errors, correct and wrong clicks, the time of reaction, and the progress of each executive function. These reports were very helpful in analysing and evaluating the interaction. In addition, they highlight the points of strengths and weaknesses for each participant and list some of the effective teaching tips for each case to be passed on to their teachers.

4.7. Findings and Discussion

Our main objective was to evaluate the effectiveness of game-based technology developed to help ADHD students overcome their attention and processing problems and trigger their cognitive capacities. A discussion of the results follows, quantitative results generated by the system and NIH tests, as well as, qualitative findings from the researcher observations.

4.7.1. Measuring improvements

Throughout testing, the system generates quantitative data that help in detecting the average development in cognitive capacities for each student. Table 4.2 demonstrates each student's improvement in the eight core cognitive capacities throughout the testing period.

Table 4.2. Improvement averages in cognitive capacities of participants

Core Cognitive Capacities							
Participants	Sustained Attention	Response Inhibition	Speed of Processing	Cognitive Flexibility	Working Memory	Formation and Use	Pattern Recognition
Std 1H	7%	30%	33%	0	0	0	31%
Std 2LB	12%	26%	54%	30%	10%	0	0
Std 3K	18%	0	7%	19%	37%	0	33%
Std 4LW	12%	14%	54%	19%	60%	0	0
Std 5T	25%	80%	16%	0	7%	0	0
Std 6M	25%	40%	31%	60%	10%	0	0
Std 7JN	32%	7%	28%	83%	0	0	39%
Std 8LN	35%	64%	80%	42%	0	0	66%
Std 9LS	22%	39%	85%	42%	0	0	66%
Std 10JR	60%	0	70%	42%	7%	50%	66%
Std 11RG	70%	47%	39%	29%	7%	0	0
Std 12I	34%	4%	24%	42%	0	0	0
Std 13RL	15%	0	55%	42%	0	64%	20%
Std 14T	9%	29%	68%	22%	0	98%	80%

Core Cognitive Capacities							
Participants	Sustained Attention	Response Inhibition	Speed of Processing	Cognitive Flexibility	Working Memory	Formation and Use	Pattern Recognition
Std 15D	25%	23%	71%	15%	0	0	88%
Std 16RF	15%	29%	55%	42%	0	0	51%
Std 17LH	25%	0	55%	42%	7%	23%	0

Cognitive capacities marked by zero ‘0’ could not be calculated, as the student did not reach the required level in the games. In fact, all participant received zeros in the cognitive capacity called ‘multiple simultaneous attention’, which is eliminated from the table, due to the unreached required levels. In normal children, we could see how difficult it is for them to do multiple things at the same time; therefore, in contrast, it is harder for children with ADHD to concentrate on one thing rather than multiple things. Because of that, the capacity for ‘multiple simultaneous attention’ is an important skill that must be enhanced by considerable training, but it would take longer time than other capacities to see clear improvement.

Furthermore, it is obvious from the results presented in Table 4.2 that students demonstrated improvement in the main cognitive capacities, such as sustained attention, processing speed, and cognitive flexibility. However, the average improvement varies between students due to the severity of their impairment. In addition, it is considered an improvement even if it was a slight increase in measurement (Wexler, 2013).

By examining the percentages presented in the table; for instance, Std 3K is slow in terms of processing tasks (speed of processing 7%), with lack of focus (sustained attention 18%). Furthermore, when a subject is changed, she seems to be stuck in the previous subject (low cognitive flexibility 19%). On the other hand, she has a very good memory (working memory 37%), and she is good at guessing and figuring things out (pattern recognition 33%).

The student with the least benefit from the intervention was Std 1H. Even though she had the minimum improvement percentages, her progress was noticeable by her teachers and parents. One of her teachers asked about what we were doing with them during the experiment sessions: ‘Are you giving them additional strengthen lessons?’ Other teachers were impressed by her good marks and unusual focus in class. Her attention and concentration improved 7%, and her speed of processing also improved by 33%. She thinks and replies faster now. In addition, her mathematical skills were enhanced by 33% (in pattern recognition).

Another student, Std 9LS, improved her attention by 22%. She gained the highest improvement in processing speed (85%), and her teacher acknowledged that she understands better and faster. Her mother noticed that she is more organised in studying and generally in her life than before, which is not surprising, as her cognitive flexibility has improved by 42%.

Participant Std 10JR was the perfect model of this experiment. She transformed from a very hyperactive inattentive student to a better student in all standards. The teacher previously indicated her uncontrollable behaviour in class. She moves a lot, has low academic performance, is unorganised and impulsive with her friends, and she does not focus. The results showed that, after four months of using the brain-training game, she is 60% more focused and less hyperactive and has enhancement in language and math (formation and use 50% and pattern recognition 66%). She understands and does what she is asked to do immediately (processing speed 70%).

Overall, the improvements in cognitive capacities for all students were remarkable. By calculating the averages, we found that sustained attention improved by 23%, response inhabitation by 28%, speed of processing by 49%, and cognitive flexibility by 38%. The capacities will continue to improve as long as students continue to play. Many parents have asked on behalf of their daughters to continue using the brain-training games due to the changes they effected in their children's behaviours and skills.

4.7.2. NIH test results

In addition to the previous data, other data were generated from the tests. Students took the NIH tests in the first and last sessions to measure their improvement. In the following results tables, the "improvement" column was calculated automatically by the system to measure enhancements depending on each user's accuracy in solving tasks and how fast their reaction time was.

In the first test, the flanker task, the students did very well in the congruent trials (Table 4.3). Moreover, 99% of students selected the correct arrow direction with 100% accuracy, with an acceptable RT. In the pre-test, more than half of the students selected the correct direction with an average accuracy of 72% and average RT of 1645 ms. In the post-test, after intervention, nearly 98% of the students selected the correct direction with 100% accuracy, and faster RT with an average of 1163 ms. The accuracy and RT have been clearly enhanced after intervention. The average of overall enhancement in the flanker test was by 20% (figure 4.8).

Table 4.3. Flanker task results

Participants	Accuracy		Reaction time		Improvement
	Pre	Post	Pre	Post	
Std 1H	100%	100%	3049 ms	1597 ms	28%
Std 2LB	94%	100%	1465 ms	1191 ms	13%
Std 3K	82%	100%	1801 ms	1754 ms	10%
Std 4LW	94%	94%	1548 ms	1292 ms	11%
Std 5T	18%	100%	5148 ms	3641 ms	30%
Std 6M	94%	100%	2103 ms	1007 ms	35%
Std 7JN	94%	100%	1097 ms	831 ms	21%
Std 8LN	94%	100%	1035 ms	758 ms	27%
Std 9LS	88%	100%	1832 ms	935 ms	29%
Std 10JR	94%	100%	812 ms	645 ms	20%
Std 11RG	100%	100%	887 ms	852 ms	3%
Std 12I	94%	100%	812 ms	768 ms	4%

Participants	Accuracy		Reaction time		Improvement
	Pre	Post	Pre	Post	
Std 13RL	94%	100%	812 ms	768 ms	4%
Std 14T	88%	100%	1478 ms	825 ms	32%
Std 15D	88%	100%	1285 ms	827 ms	27%
Std 16RF	94%	100%	1017 ms	730 ms	30%
Std 17LH	88%	96%	1793 ms	1364 ms	25%

Note: ms = milliseconds

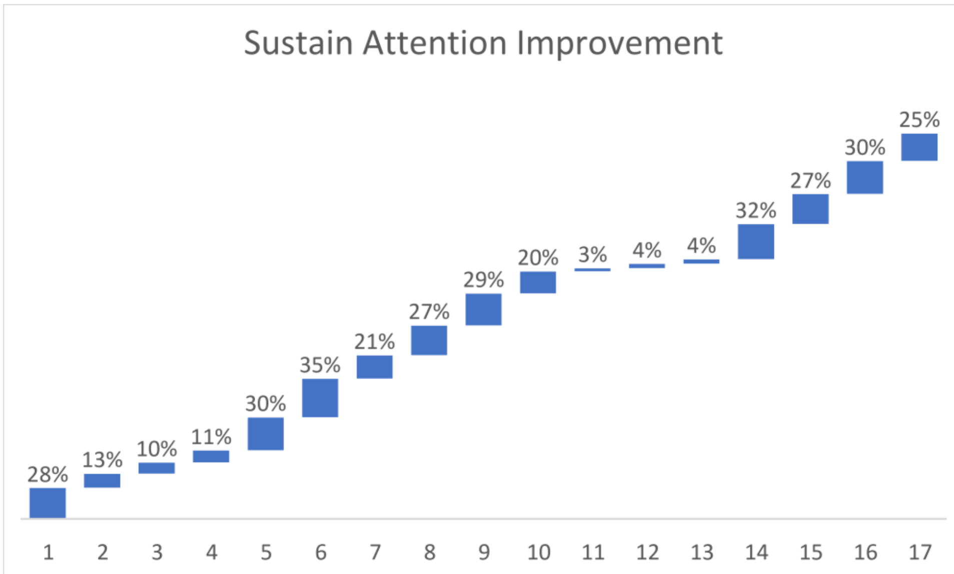

Figure 4.8. Sustain attention improvement measured by the flanker test

Table 4.4 shows the results of the go/no go test. Here, we considered no go results due to the difficulty to hold back when no action must be taken. Before intervention, the average correct 'no goes' was 52%, while after intervention, the average correct 'no goes' was 74%. In the case of Std 1H, we noticed that the score of her pre-test was better than her score in the post-test by 5%, which is considered normal in children with ADHD due to their lack of focus during the test. Despite that, she showed clear progress in response inhabitation and processing speed in Table 4.2, which is what the go/no go test measures. The average overall improvement in this test was 24% (figure 4.9).

Table 4.4. Go/no go test results

Participants	Accuracy		Improvement
	Pre	Post	
Std 1H	93%	87%	5%
Std 2LB	50%	60%	15%
Std 3K	17%	37%	28%
Std 4LW	50%	57%	10%
Std 5T	47%	50%	5%
Std 6M	50%	70%	31%
Std 7JN	20%	73%	73%
Std 8LN	47%	67%	29%
Std 9LS	50%	57%	10%
Std 10JR	50%	85%	31%
Std 11RG	80%	90%	7%
Std 12I	33%	80%	67%
Std 13RL	73%	80%	5%
Std 14T	73%	80%	5%
Std 15D	78%	97%	41%
Std 16RF	47%	92%	21%
Std 17LH	33%	97%	33%

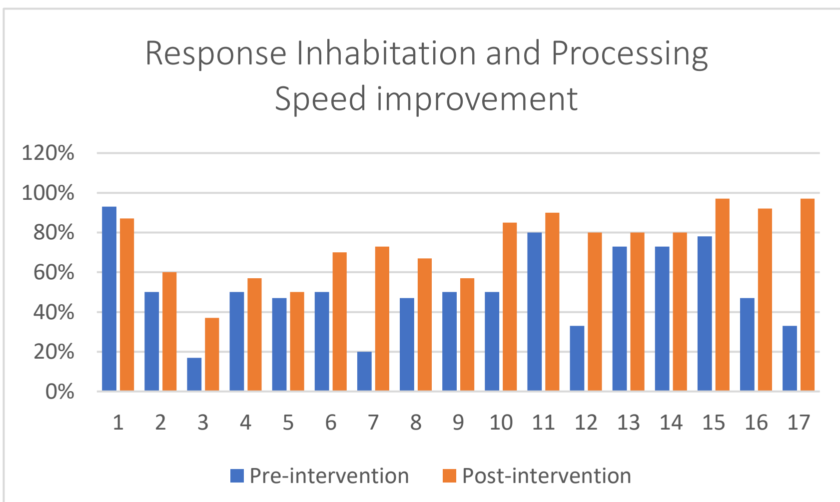

Figure 4.9. Response Inhabitation and Processing Speed improvement measured by the go/no go test

In the third test (Table 4.5), the working memory test, the pre-test has shown weakness in the working memory function before intervention since the average accuracy was 15%. The post test scores showed positive improvements with an average of 27% increased accuracy (figure 4.10).

Table 4.5. Working memory test results

Participants	**Accuracy**		**Improvement**
	Pre	**Post**	
Std 1H	6%	50%	49%
Std 2LB	7%	11%	19%
Std 3K	12%	18%	17%
Std 4LW	20%	34%	11%
Std 5T	7%	12%	14%
Std 6M	5%	7%	8%
Std 7JN	26%	35%	8%
Std 8LN	5%	12%	30%
Std 9LS	22%	48%	21%
Std 10JR	29%	40%	17%
Std 11RG	10%	13%	11%
Std 12I	42%	59%	12%
Std 13RL	29%	40%	17%
Std 14T	7%	21%	48%
Std 15D	9%	22%	42%
Std 16RF	7%	12%	21%
Std 17LH	13%	22%	10%

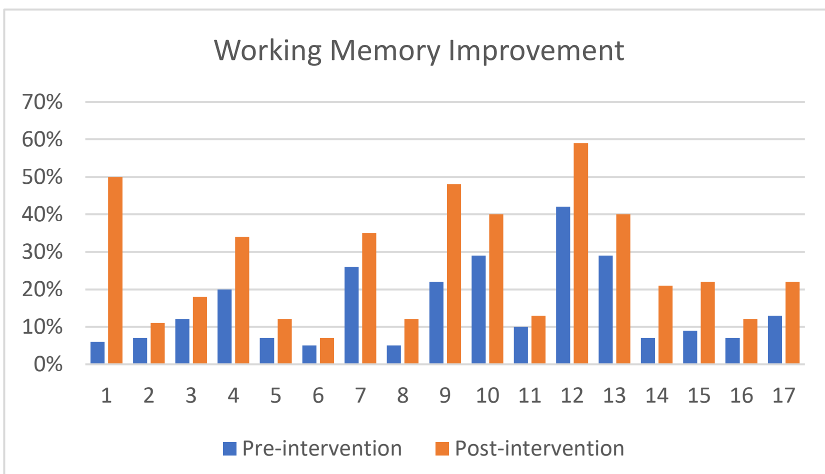

Figure 4.10. Working memory improvements measured by working memory test

After discussing and analysing the quantitative data generated by the system, in Sections 4.7.1 and 4.7.2, depending on the level of remarkable improvements measured, the application is effective. This is clearly shown from the positive influence on the behaviour of students as teachers and parents declared and on their academic level.

4.7.3. Measuring interaction and user experience

In the area of HCI, systems are evaluated based on various user interface elements. In our study, three elements were assessed to produce the qualitative part: usability, acceptability, and adaptability.

According to Nielsen's (1994) usability parameters, five attributes were tested: learnability, efficiency, memorability, small error rate, and satisfaction. In addition, acceptability and adaptability were tested as well. We can summarise the following results:

- The majority of students (99%) found the game easy to use in terms of completing levels easily as soon as they encountered the design. When the system detects frequent mistakes, the level of difficulty will decrease automatically to meet the students understanding. The content was created to suit their age group. The interface was simple. Any child from six years old could understand and use it. Tasks are clarified by text and audio in a pleasant and interesting way. Thus, it is shown that the game was learnable and easy to use.

- To declare the game efficiency, academic grades for each student were obtained before and after the intervention for three major courses: English, mathematics, and science (Table 4.6).

Table 4.6. Student grades in three major courses

Participants	English		Math		Science	
	pre	post	pre	post	pre	post
Std 1H	8.5/10	8/10	8.75/10	9/10	7.5/10	8/10
Std 2LB	7.70/10	8/10	10/10	10/10	8/10	10/10
Std 3K	7/10	8/10	8.60/10	8.75/10	9/10	9.5/10
Std 4LW	8.70/10	9/10	9.5/10	10/10	9/10	10/10
Std 5T	6/10	7.5/10	6.70/10	8/10	6.5/10	7.5/10
Std 6M	6/10	7.5/10	7.6/10	8.5/10	8/10	10/10
Std 7JN	6/10	8.5/10	10/10	10/10	9.25/10	10/10
Std 8LN	5.3/10	8/10	10/10	10/10	10/10	10/10
Std 9LS	10/10	10/10	10/10	10/10	10/10	10/10
Std 10JR	9.5/10	10/10	9.25/10	9.5/10	10/10	10/10
Std 11RG	6.2/10	8/10	10/10	10/10	10/10	10/10
Std 12I	7.3/10	8/10	6/10	8/10	10/10	10/10
Std 13RL	6.2/10	8/10	10/10	10/10	9.5/10	10/10
Std 14T	7.3/10	8/10	7/10	8/10	8/10	10/10
Std 15D	7/10	8.5/10	9/10	10/10	8.75/10	10/10
Std 16RF	9.75/10	10/10	10/10	10/10	10/10	10/10
Std 17LH	8/10	8/10	8/10	10/10	9/10	10/10

Comparing their pre- and post-intervention academic scores, it was clear that students gained better scores after training and exercising their brains using the system (figure 4.11). Thus, it was efficient.

- There were six different games in the system. Each one had unique rules for playing. Two were specialised in memory training. Moreover, 98% of the students remembered how to play each game each time they logged in. Therefore, the games were memorable.

- Each student had the possibility of making an error while playing a game. The system had the advantage of decreasing the difficulty level of a game once the student made an error. The student then can play at his or her comfort level with nearly with no errors. The student goes to the next difficulty level after mastering the previous level. By observation, the game had a small error rate.

- The system was clearly designed for young children. It was colourful, supported by animation with a pirate theme, and had many sound effects. According to the students, 93% found the design pleasing and exciting. They were enthusiastic to play each session. Therefore, the game was subjectively pleasing.

By proving those five parameters, the system was usable.

The acceptability of an application is a combination of its social and practical acceptability (Nielsen, 1994). The cost of the system was reasonable compared to its capabilities. The developing company sets a certain cost for educational facilities according to the number of users. The greater the number, the lower the price. In addition, it was compatible with most tablets with different operating systems. One of the students used a Samsung tablet in the beginning of the test, and no problems occurred. Furthermore, the system worked properly with no failure as long as devices were charged and connected to the Internet; therefore, it was reliable. It provided teachers and parents with detailed and accurate data about the students' progress, scores, and RTs. Finally, the usefulness of the system was proven previously. It could be used by children with ADHD to improve their cognitive capacities and develop their skills. It also helped them improve their social skills. They were collaborating while playing and had conversations about instructing each other regarding how to play, how to manage tricks, and how to use hints. Therefore, the system was acceptable.

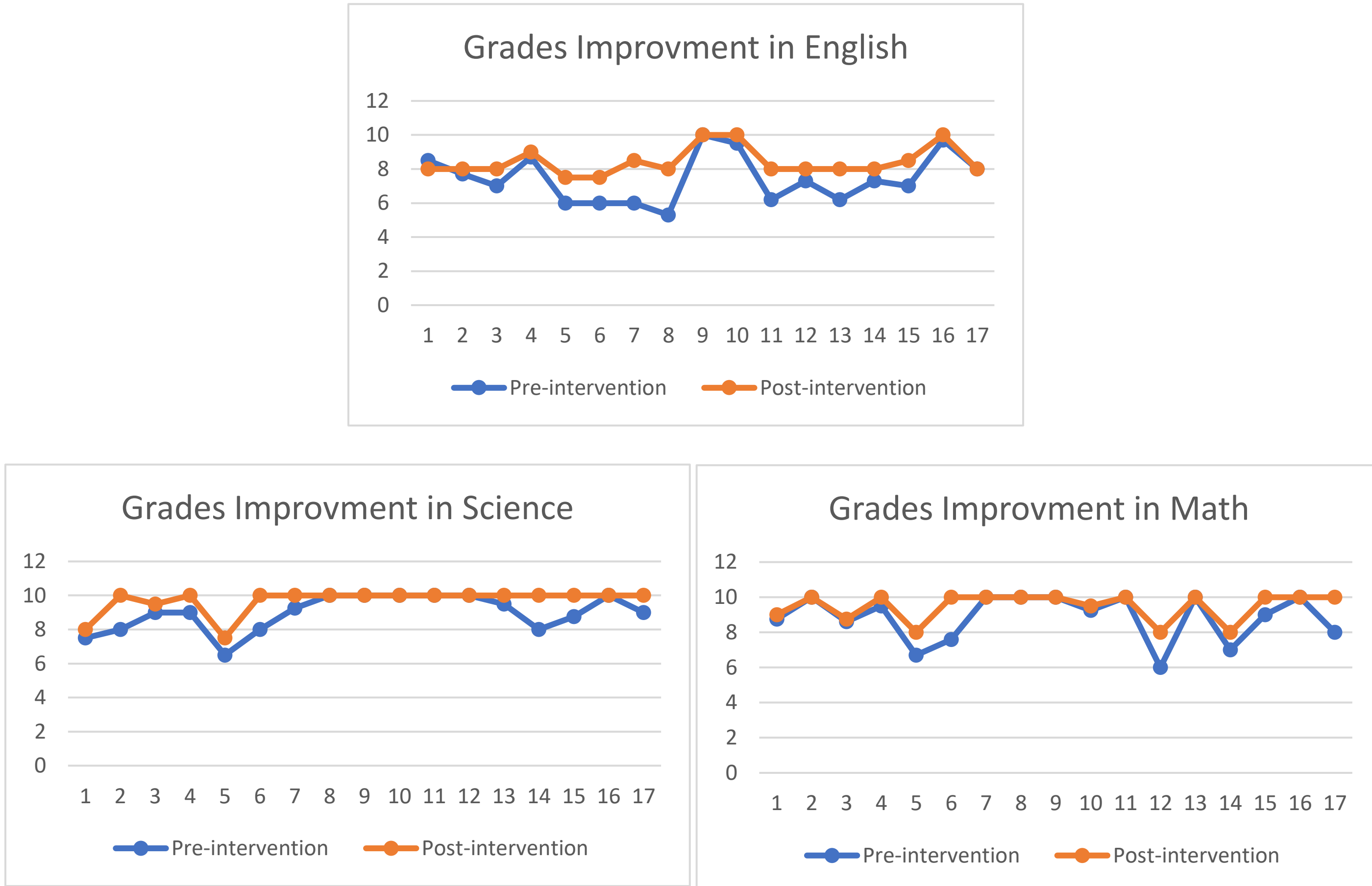

Figure 4.11. Grades improvements in three major courses

One of the system features was ‘automatic individualisation of treatment’, as mentioned in the background. It means moving users between levels of the game quickly in the areas of their strengths and using more repeated exercises in areas of their weaknesses. The second feature was ‘instant error diagnostics’, which means that, when the user makes an error, a message that includes a helpful hint appears. If the same error is repeated, the system automatically lowers the level of complexity, so that the students could exercise more until they master that level. If no more errors are generated, the user goes to the next level. By analysing these errors, the system generates a report that shows strengths and weaknesses for each user. Based on these two features, the system was adaptable.

4.7.4. Measuring statistical significance:

The statistical significance of our quantitative results was determined by a paired t-test using GraphPad PRISM (v. 5.0, GraphPad Software, Inc.). A *p*-value of less than 0.05 was considered significant. As our research hypothesis stated, utilising the independent variable (the e-game) by children with ADHD will positively affect their academic performance and improve their attention, working memory and processing speed. Thus, the null hypothesise was that the independent variable (the e-game) will negatively affect the children’s academic performance, their attention, working memory and processing speed or have no effect at all.

Table 4.7 shows the calculated mean and standard deviation for the collected data from four sources: the flanker test, go/no go test, working memory test, and the participants academic grades; before and after the intervention. It also presents the p-value estimated by the t test.

Table 4.7. Paired t test results to detect significance

		pre-intervention M (SD)	post-intervention M (SD)	test statistics
Flanker test	Accuracy	88.12 (18.62)	99.41 (1.70)	p=0.0125, t = 2.4751, df = 16, se= 4.563
	Reaction time (ms)	1645.53 (1074)	1163.82 (714.94)	p=0.0004, t = 4.1490, df = 16, se = 116.10
Go/no Go	Accuracy	52.41 (21.04)	74.06 (17.36)	p=0.0002, t = 4.4627, df = 16, se = 4.851
Working memory	Accuracy	15.06 (10.97)	26.82 (16.08)	p=0.0001, t = 4.7380, df = 16, se = 2.483
Academic performance	Subject grades	8.42 (1.44)	9.2 (0.97)	p= 0.0221, t = 2.0955, df = 32, se = 0.422

Note. M=mean; SD=standard deviation; p= probability value; t=; df= degrees of freedom; se= standard error of the mean difference.

In the flanker test, which evaluates attention, the mean of participants' accuracy pre-intervention was $M = 88.12$ with a standard deviation $SD = 18.62$. After intervention, they were $M = 99.41$, and $SD = 1.70$. The estimated one-tailed p-value was p=0.0125 ($p \leq 0.05$) with t(16) = 2.4751. While for participants' reaction time, pre-intervention M=1645.53 and SD=1074. After intervention they were M=1163.82 and SD=714.94. The estimated p-value was p=0.0004 ($p \leq 0.05$) with t(16) = 4.1490. In the go/no go test, which measures response inhabitation and processing Speed, the mean of participants' reaction time pre-intervention was M=1645.53 with a standard deviation SD=1074. Post-intervention they were M=1163.82, and SD=714.94. The estimated p-value was p=0.0002 ($p \leq 0.05$) with t(16) = 4.4627. In the working memory test, the mean of participants' accuracy pre-intervention was M=15.06, and the standard deviation was SD=10.97.the p-value was p=0.0001 ($p \leq 0.05$) with t(16) = 4.7380. Regarding the participants' academic performance, we calculated the M and SD of students grades before intervention: M=8.42, SD=1.44, and after intervention M=9.2, SD=0.97. The estimated p-value was p= 0.0221 ($p \leq 0.05$) with t(16) = 2.0955.

By conventional criteria, all these differences considered statistically significant. As a conclusion, participants' academic performance, attention, working memory and processing speed was positively affected by using the e-game ACTIVATE.

4.8. Recommendations to improve the used instrument "ACTIVATE"

In this section, we highlight some suggestions that may assist in the process of enhancing the brain-training game ACTIVATE. We compared ACTIVATE's game elements with the suggested guidelines. Two lists of supported and unsupported e-strategies by ACTIVATE were produced. A report including these suggestions and our proposed guidelines was sent to the developing company and founder of ACTIVATE.

- Supported e-strategies by ACTIVATE:
  - Matching task difficulty and duration with student abilities and skills;
  - Instant error analysing and feedback;
  - Attention management measures;
  - Working memory training;
  - Dynamic time-span scheme;
  - Motivation and feedback aspects;
  - Effective educational strategies;
  - Behavioural enhancement strategies;
  - Virtual embodiments; and
  - Physical activity inclusion.

All these game elements were supported by the brain-training system and positively affected the children's abilities and skills, as concluded from our evaluation.

These elements initially backed up the recommended guidelines. 'Physical activities inclusion' strategy was encouraged by the ACTIVATE program, but due to time and schedule limitations, and it was a non-technological stand-alone activity, we did not include it in the evaluation scheme. In the other hand, the technological 'physical activities' component was recommended in the guidelines as concluded from the meta-analysis approach for relevant empirical studies discussed in chapter 3.

- Unsupported e-strategies in ACTIVATE:
  - e-collaboration; and
  - Real-life problem solving.

One of the e-strategies proposed in the guidelines was 'e-collaboration'. The game system does not offer any type of e-connection between users (student-peers or student-teacher). Creating an instant/live online communication channel will support the concepts of e-interaction and e-collaboration to promote peer-tutoring and social skills (Gabrielle & Montecinos, 2001). Students will be able to give hints to each other, exchange experience and knowledge about certain tasks, and encourage social relations (Fawcett & Garton, 2005). In addition, collaboration can increase competition and challenge and motivate them. Privacy and security are two important aspects that need to be associated with e-collaboration in special education (Järvelä et al., 2015; Kourakli et al., 2017).

Another unsupported e-strategies of the game, 'real-life problem solving' is one of the e-strategies proposed by our guidelines. This strategy is closely linked to the level of development of social skills (Olounabadi, 2014). Children with ADHD need to learn how to solve various social problems they may face in real-life situations using different methods. This strategy also aims to improve inhibition, so that children with ADHD will be able to inhibit early responses. Yet, developing problem-solving skills will always come as the next stage after nurturing students' community outreach and developing the skills required to do so.

Dr Bruce Wexler (2016), the founder of ACTIVATE, appreciated our ideas and suggestions. One of his motivational remarks regarding our suggested guidelines was: '*I think taking a comprehensive and multicomponent approach as you recommend is excellent. We have thought about some of the things you suggest, but others are new ideas for me*'.

In addition, he admired the suggested features that could be added within ACTIVATE to elevate its efficiency and widen the effect range: '*These are certainly relevant dimensions for many children with ADHD. We are not prepared now to add them, but your ideas could make a more comprehensive and effective intervention*' (Wexler, 2016).

4.9. Conclusion

In this study, we investigated an e-game system to measure its effectiveness and whether it could help children with ADHD to overcome their impairments and improve their cognitive capacities that could affect skills and behaviour. The system consists of six different brain-training games, each triggering one or two cognitive capacities. The iPad was used as the tool of the study. Seventeen students were selected from two international schools in Saudi Arabia, who showed clear signs and symptoms of ADHD. Testing took place in school settings in in-class sessions. Students played three sessions a week for 20 minutes each session. The NIH tests were done pre- and post-intervention, to measure improvement.

The results show significant improvements in cognition and performance quantitatively and improvements in behaviour and social skills qualitatively. Returning to our objectives, the selected e-game ‘ACTIVATE’, with its game features targeting executive functions effectively improved the cognition, behaviour, and social skills for children with ADHD. Their academic levels have been enhanced and evolved as well. Regarding the second objective, after studying the interaction between students and the interface, we found that the game was easy to use and pleasant, adaptable, and accessible.

By this stage, we were able to demonstrate supportive evidence of the reliability of our suggested guidelines. In the next chapter, we developed and evaluated a chatting tool designed for children with ADHD.

Chapter 5

Effectiveness and Usability of a Developed Online socialization Tool for Children with ADHD: “Chit-Chat” Intervention

Learning in groups and collaboration is a commonly used approach in classrooms via teachers and educators to promote peer tutoring and social skills among students (Fawcett & Garton, 2005). It comprises students working together, contributing by different inputs to discuss an issue or solve a certain problem as a group. Studies have indicated that students working as groups and on the same task will gain better performance and results than students working independently (Fawcett & Garton, 2005). Other studies stated the positive outcomes of merging low progress with high progress students will assist in improving cognitive abilities and social skills and increasing self-confidence (Gabrielle & Montecinos, 2001). With the development of technology and the emergence of many applications and educational programmes, it has become easy to implement many of the effective educational strategies, and utilise these tools daily in schools and classrooms, starting from preschool-age students to university students.

Evidence shows an optimistic effect of such applications that support team work and collaboration among students in their motivation to learn, engagement with others, knowledge sharing, social skills, and problem solving (Järvelä et al., 2015). Therefore, many researchers, developers, and healthcare specialists were encouraged to extend their work in the last decade by developing special applications and serious games that target and promote some healthcare students' weaknesses. In fact, many technological interventions were and still are investigated to explore their effects on children's cognitive abilities and social and behavioural skills (Kourakli et al., 2017). However, few of them explored the effects of e-collaboration and actually integrated this strategy in their studies. There was a study found on the effect of collaborative intervention using different tools for children with dyslexia (Vasalou et al., 2017), which emphasised their social engagement. Another explored autistic children (Holt & Yuill, 2017) using a double-iPad approach to encourage and facilitate communication with peers and adults. For younger children, a study found a promising benefit of a collaborative experience for kindergarten children with learning difficulties (Drigas et al., 2015). This strategy helped them learn simple math in a fun way. Another study targeted children with autism by developing a collaborative game that encouraged social interaction and cognitive abilities (Barajas et al., 2017).

There was only one study, to my knowledge, at the time this thesis was written, that investigated the effectiveness of a serious game *Plan It Commander*, on children with attention deficit hyperactivity disorder (ADHD; Bul et al., 2015). The game included three mini games that offer neurocognitive and behavioural training tasks. Children collaborate with their parents on only some behavioural daily life tasks, such as planning, time management, responsibilities, and problem solving. *Plan It Commander* focuses on resolving cognitive, behavioural, and social issues for real-life problem solving.

There is a lack of research on the effectiveness of using a collaborative online closed-communities designed especially for children with ADHD that might have an effect on their abilities, skills, and performance in educational activities. Moreover, in our previous work, we investigated ACTIVATE alone as a case study, and positive results were reported. Yet, one of the important issues that arose was not having any kind of live interaction or communication between the children who played with it, as each child played individually.

According to the reviewed literature, collaboration is one of the most effective learning strategies. It reinforces motivation and knowledge exchange and builds social skills (Huang et al., 2017). Children learn by communicating, interacting, and imitating. By letting them work closely together, they will experience high levels of engagement, motivation, and enjoyment (Xie et al., 2008).

In addition, we managed earlier to draw out a list of design guidelines from empirical studies. It suggests strategic features might be used by designers or developers that would enrich any educational system developed for children with ADHD. Our first intention was to explore e-collaboration, which is one of the recommended components in our list. Therefore, we developed a chatting tool, Chit-Chat, as an add-on for user engagement. But due to time limitations, mentioned in detail in limitations section, we did not have the chance to evaluate a collaborative work. Instead, we evaluated the chatting act and investigated its impact on children's skills. The overview of Chit-Chat, the research methodology, and the results are reported in this study.

Research Questions

This case study investigated the following questions:

- How does the use of the chatting tool by children with ADHD in school settings affect their motivation towards e-learning activities?
- How does the use of the chatting tool by children with ADHD in school settings affect their knowledge and experience towards e-learning activities?
- How does the use of the chatting tool by children with ADHD in school settings affect their social behaviour towards their teachers and peers?

- Does the presence of a teacher as a contributor in the chatting activity affect the behaviour of children with ADHD? Is the teacher a supportive or inhibitive element?
- Is the developed chatting tool interface usable and subjectively pleasing for children with ADHD?

5.1. Chit-Chat Overview

The Chit-Chat tool is a web-based application that offers a chatting panel, which is managed and monitored by teachers, for children with ADHD. The Chit-Chat interface was designed and developed to complement ACTIVATE (i.e. an add-on feature to help children interact between mini games). Regarding the design, the colours and themes were mostly inspired by the ACTIVATE system, which has a pirate theme. We aimed to let participants feel that they were still using the same system when shifting between ACTIVATE and Chit-Chat. We used the 15 guidelines proposed by McKnight (2010) to design usable interfaces for children with ADHD. It contains two portals: one for teachers with more control and the other for children. Each user has to log in to the system using a unique user name and password (Figure 5.1). Before each intervention, the researcher logged in to ACTIVATE and Chit-Chat for each participant and made both applications ready and easy to access.

Figure 5.1. Login screen for Chit-Chat web application.

In the student account, they can chat, send emojis, view their achieved progress scores in ACTIVATE, view their friends' progress scores, change their character avatar, and convert text to audio by tapping posted text/chat. The teacher account provides controls to activate or deactivate chat, clear/delete chat, change the character avatar, create multiple-choice challenges with timer options, print chat history, and generate progress reports for each child showing accuracy and speed averages in challenges (Figure 5.2).

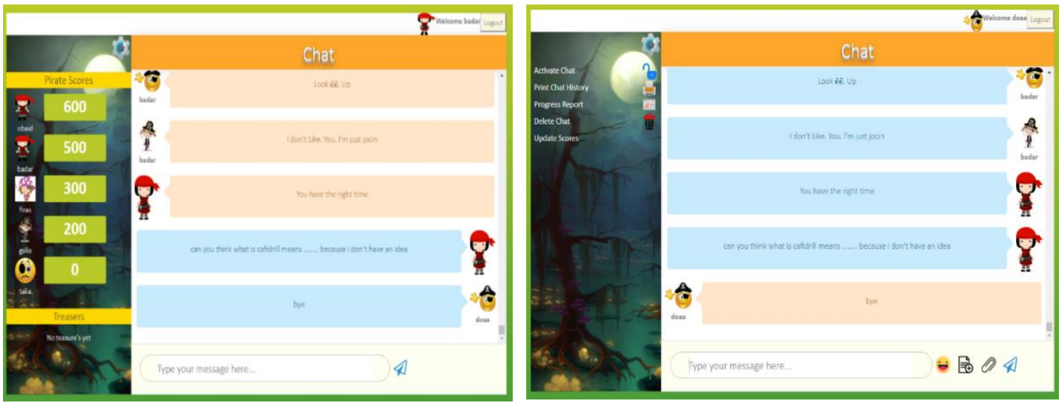

Figure 5.2. Teacher portal with controls (right) and children portal (left).

The features of submitting challenges, time-awareness (timer), and generating reports were not discussed in this work due to the different scope. Future interventions will explore the capabilities and effectiveness of the remaining features (Figure 5.3).

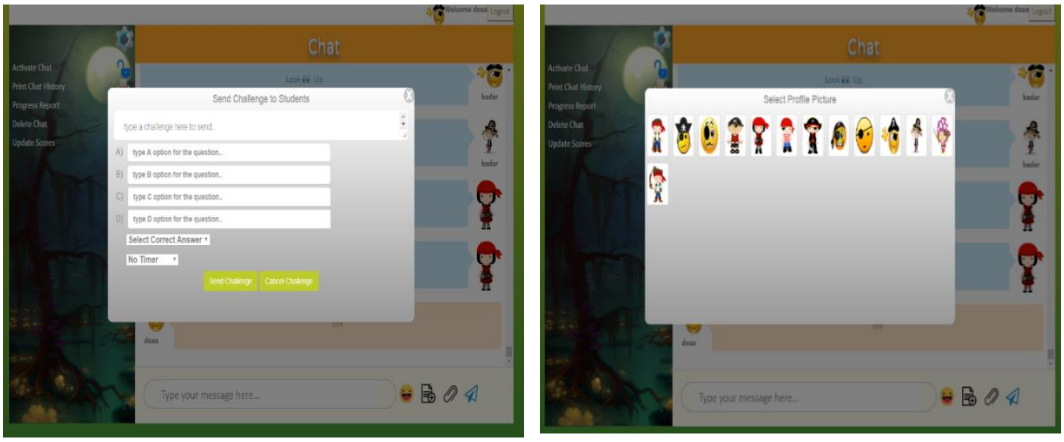

Figure 5.3. Teacher portal: Creating a challenge (left) and selecting an avatar (right).

5.2. Technical Specifications

As for the technical specifications, we summarised the software elements used to successfully launch our web application (Chit-Chat) online. The integrated development environment used Visual Studio 2015 (update 3) and Notepad ++. The Microsoft.Net Framework 4.6 was used as the web installer. The code was implemented using the following programming languages: C#, HTML, CSS, jQuery, and JavaScript. Our database platform was MongoDB (v. 3.4). For real-time client-server communications, we used Node.js 6.11.2 and Socket.io 1.4.5. The hosting infrastructure was the AWS EC2 Instance Windows Server 2012 R2 Standard. As for the tool of research, we used the same iPads used in our first experiment. The iPad specifications are found in Chapter 4.

5.3. Ethical and Legal Authorisations

This study has been approved by the Research Integrity and Governance Office (RIGO) in the University of Surrey. The school head and Special Educational Needs (SEN) head have approved preforming the investigation in the school with the students, and information sheets and consent forms were signed by the parents of the participants as well (see the Appendix).

5.4. Experiment Design and Methodology

One of the issues was the inability to develop a chatting feature within ACTIVATE itself due to a limitation from the developing company. Therefore, we decided to build an add-on application (see the limitation section). The idea was running ACTIVATE games synchronously with the Chit-Chat application to make the students feel that they were using a single application.

Relying on our research objectives, we designed a qualitative and quantitative experimental study. The independent variable was the chatting tool (the Chit-Chat application), and the dependent variables were all the following behaviours, which were measured and assessed in the experiment: Motivation to complete tasks, socialising, knowledge, and experience.

The experiment included three mini interventions. A pilot study was done three weeks prior to the actual experiment to test the study design to understand the time needed for each session and to test the wording of the tasks. A usability test was done during the intervention to study the interface design and discover more usability issues. Usability test tasks and the fixed issues are listed in a separate section.

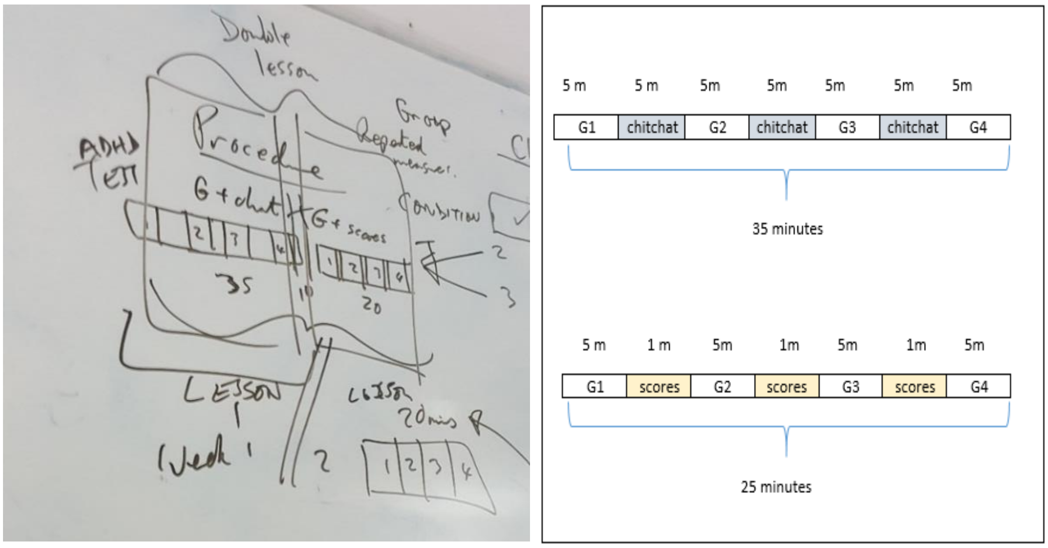

Figure 5.4. Intervention design draft: four mini games followed by Chit-Chat sessions.

Before we started the intervention experiment, a baseline session was prepared to allow participants play with ACTIVATE alone for 20 minutes. Then, the intervention sessions were held on three days for 35 minutes each in total: 20 minutes for ACTIVATE and 15 minutes for the Chit-Chat application (Figure 5.4).

As described earlier, ACTIVATE contains four mini games per session. Each game takes only five minutes to complete. Thus, our idea was to slot in the Chit-Chat application for a certain amount of time after each ACTIVATE mini game. There will be three sub-sessions of Chit-Chat in a single intervention.

Before the intervention, the children were reminded that all the chats will be recorded, they must not use any bad words or negative comments. A psychologist attended all the interventions to help the researcher interpret some behaviours and actions and to help maintain organisation.

In the first intervention, the participants played the first game in ACTIVATE for five minutes (Figure 5.5) using an iPad. The game automatically shuts itself down after the time is done. After each game, the teacher revealed the Chit-Chat panel and unlocked the chatting feature for the children. In the first chatting sub-session, participants were asked to do certain usability tasks. After approximately five minutes or after they finished all the tasks, the teacher locked the chat and asked the participants to play the second ACTIVATE mini game. Again, after the mini game, the teacher unlocked the second chatting sub-session and started to participate in the chat. The teacher initiated the chat by introducing himself and asked the participants to do so and to talk about themselves a little bit. Using this activity, the researcher studied the effect of a chatting activity on the children's socialisation. In the third chatting sub-session, after playing the third ACTIVATE mini game, the teacher chatted with them, but this time the teacher asked about the ACTIVATE games. The teacher asked: What is the best game? How can one get a higher score? What are some secret hints to share with other participants? We wanted to know to what extent the chatting activities encourage children to exchange their knowledge and experience about given tasks. At the end of this intervention, they played the last min-game in ACTIVATE.

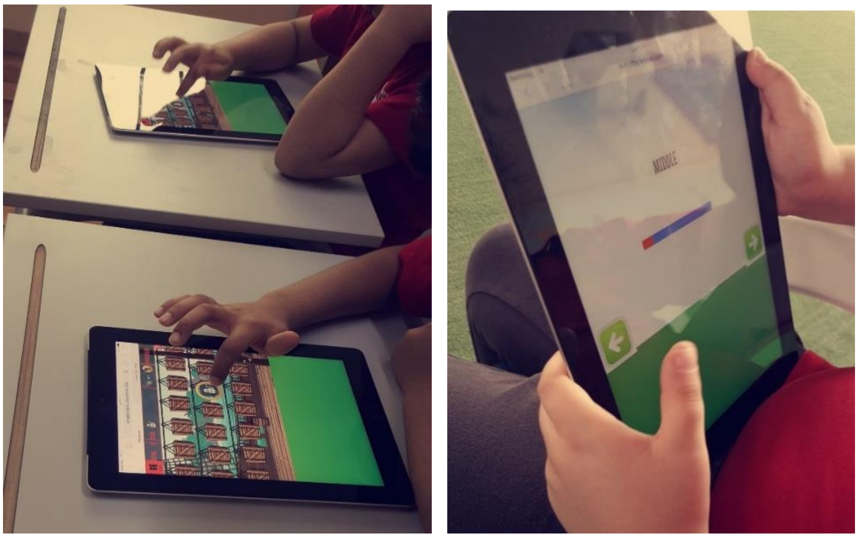

Figure 5.5. Participants are playing the mini games run by ACTIVATE.

In the second intervention, the children played all the mini games as usual, but after each game, the teacher revealed the game scores for all the participants on the chatting panel. The chatting remained locked, and the children were given the chance to see their scores and their friends' scores for about one minute. Then, they returned to the ACTIVATE games. We wanted to investigate the effect of seeing their peers' scores regarding whether it would motivate them to do better or worse in the next tasks.

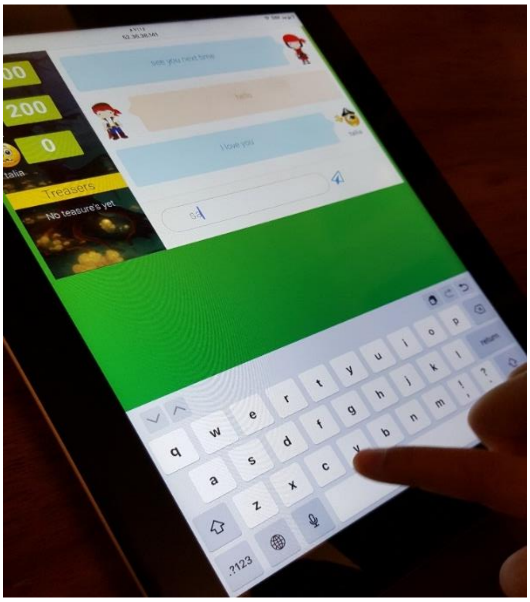

Figure 5.6. Participants using Chit-Chat chatting tool.

In our last intervention, the researcher used the same experimental design for the first intervention. The only difference was that the teacher did not interfere in all three sub-session chats (Figure 5.6). We wanted to investigate whether the teacher's presence and participation affected this chatting activity positively or negatively (i.e. is the teacher considered a supporter or inhibitor in such an activity?).

5.5. Participants

Seven children, all diagnosed with ADHD (three females and four males), were recruited and used the diagnostic model. The students were from Grades 1, 2, and 3 from Al-Nojood International Private School. Pre-intervention demographic questionnaire and Conner rating were used to identify the type of ADHD, level of severity, and social skills for the participants, which were filled in by parents (Table 5.1). They were all familiar with the iPad and used it regularly in playing online games and viewing YouTube clips. However, the students had never used any chatting applications before.

Table 5.1. Participant demographic data, ADHD type, and sociability.

Participants	Age (years)	ADHD Type	Academic Level	On Treatment?	Sociability?
Bader	7	Combined	Medium	NO	Limited friends
Firas	6	Combined	Low	NO	Social
Galia	6	Hyperactive	Medium	Yes (medication)	Shy–no friends
Obaid	7	Inattentive	Medium	NO	Social
Sarah	7	Inattentive	Low	NO	Shy-few friends
Suhaib	8	Combined	Low	NO	Shy–few friends
Talia	8	Inattentive	Medium	NO	Limited friends

5.6. Data Collection and Analysis

There were two types of data collected: quantitative and qualitative. The quantitative part was gathered when participants did the National Institutes of Health (NIH) test provided by ACTIVATE as an online testing tool before the intervention to measure their executive functions, such as the level of attention, working memory, and processing speed. In addition, the ACTIVATE system measures each participant's overall progress in mini games against their peers. Their progress results were posted on the teacher portal. We intended to do the NIH test again after the intervention to determine whether there was any cognitive improvement that could be detected by comparing the before and after results. However, unfortunately, the second test is set automatically by the system after 500 minutes of playing ACTIVATE. Because of that, we were unable to use the NIH test results. Instead, we used the baseline and the post-intervention progress measures for each participant to check their performance before and after the intervention. To statistically analyse their progress points, we used the paired t-test to evaluate the significance by calculating the *p*-value.

For the qualitative part, some of the participants' behavioural responses were recorded (written) by the researcher while interacting with the application, such as body and hand movements and interacting with each other. Video recording was prohibited due to school policy, but we had approval from the head of the school to take pictures without showing their faces. Moreover, we managed to get approval to record audio tracks of post-intervention interviews with the participants to capture their experience with the chatting tool.

Thematic analysis (Clarke & Braun, 2014) was applied to the qualitative data gathered from participants' chat history, observational notes, and audio recordings of post-intervention open questions. This process allowed us to interpret the gathered raw data and present it in a more intensive construction of themes. The following sections discuss the levels at which the thematic analysis was conducted, and the results are reported and discussed in the next section.

To test usability and satisfaction, a usability test was done in the first session of the intervention. For the user experience, an open-ended interview was used. These feedback items were included in the thematic analysis as part of our gathered data.

First Level: Data Familiarisation

The first level of the thematic analysis required writing down each of the digitally recorded open questions and printing the chat history log and observational notes. Then, the researcher read and re-read the texts to become familiar with and absorb the data.

Second Level: Producing Initial Codes

In this phase, the researcher re-read the texts and assigned codes to any word, phrase, or paragraph that was believed to be noteworthy and related to the study objectives. The initial codes are familiarity, dislikes/likes, interact, physical-activity time breaks, excitement, controlled hyperactivity, boredom, tired, writing, reading, listening, concentration, creativity, thinking, communication, support, engagement, activity, frustration, enthusiasm, competition, score comparing, time, cooperation, positive feedback, opinions, hints, concerns, instructions, feelings, criticise, satisfaction, efficiency, error rate, memorable, and ease of use.

Third Level: Searching for Themes

After producing the codes from the texts, the researcher grouped related codes in categories of more general themes. Clarke and Braun (2014) recommended using visual models to sort codes into general themes and to show potential relations between them. By this stage, the researcher was able to build the thematic network shown in Figure 6.7, which organised the analysis data into groups of themes and related codes.

Fourth Level: Reviewing Themes

At this point, the researcher checked the proposed themes versus the written text to determine whether they articulated a conclusive story of the data and related to the research questions. Consequently, the researcher noticed that some codes correlate with more than one theme and that pointed out a bond between those themes. The thematic network was modified due to these detected links.

To support the credibility and dependability of the analysis and eliminate any researcher bias, electronic copies of chat history, written observational notes, and answers to open-ended questions were sent to the psychology specialist who attended the intervention sessions to review them. A copy of the thematic network was also sent to be checked. A confirmation was sent back from the specialist to assert the credibility and dependability of the outcomes.

Fifth Level: Defining Themes

In this stage, the researcher analytically reviewed each theme to make certain that the proposed themes comprehend all the data and the relationship between them, whether mentioned or inspired by participants' behaviour, directly or indirectly. The definitive naming of each theme was finalised in which the themes deliver a clear interpretation of the logic and relevance to the study framework. We managed to group six main themes, which were hypothesised to be essential to develop an online chatting tool for children with ADHD: motivation, knowledge and information exchange, socialisation, behavioural reaction, skills development, and usability.

Sixth Level: Producing the Report

As a final step, the researcher constructed an explanatory closure that involved linking the analytical outcome with some quotes from participants and compared this analysis with the related work. The selected phrases were the most expressive and exemplify the research objectives. By applying a thematic analysis, we were able to construct a relation between participants' experience and the similar existing literature.

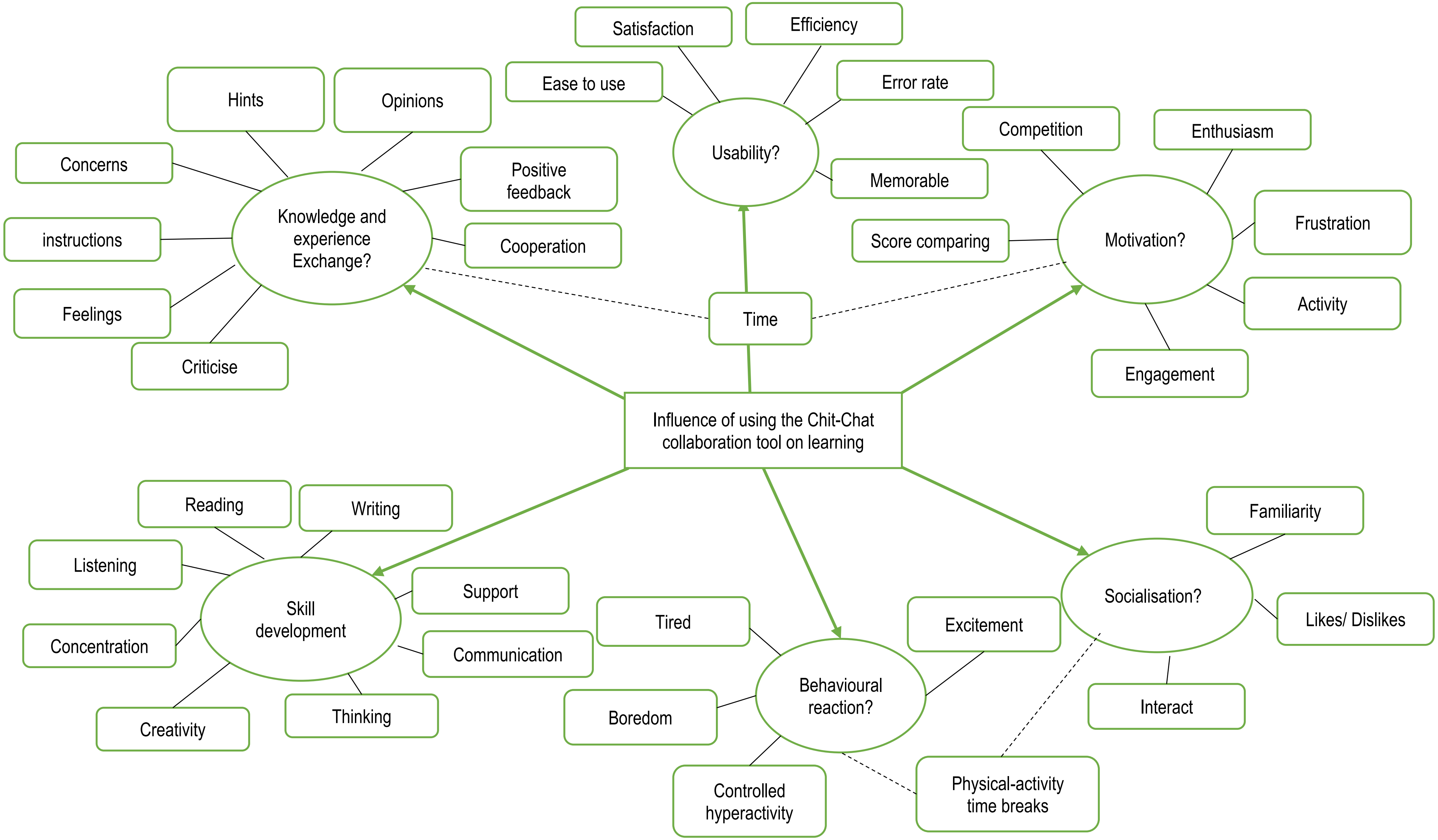

Figure 5.7. Thematic network showing the influence of using the Chit-Chat chatting tool on children with ADHD.

5.7. Usability Test and Fixed Issues

In designing the Chit-Chat interface, we used some of the guidelines suggested from literature for children with ADHD and applied usability guidelines (McKnight, 2010). The main idea was to keep it as simple and easy as possible and less distracting. Therefore, we asked the participants and a teacher to do the usability tasks on the Chit-Chat portal. As Nielsen (2000) stated, a usability test carried out by only five participants will disclose 85% of the usability issues.

We asked the students to do the following tasks:

1. Chat (write) any phrase to your friends
2. Send any emoji or picture to your friends
3. Try to hear what your friend or teacher has written and write back to them.
4. Change your avatar/character
5. Report the score of a student by the name ‘Rahman’.
6. Report the status of chatting whether it is enabled or not
7. Report your score (which is the student that this account belongs to) and how many treasure trunks you got
8. Log out from the account

We asked the teacher to do the following:

1. Enable the chatting feature for the children
2. Chat (post) the phrase “Hello everybody!!”
3. Send any emoji
4. Print the chat history
5. Print the progress report

6. Change your avatar/character
7. Disable the chatting feature for children
8. Clear the chat
9. Log out from the account

Fixed usability issues:

The teacher completed all the tasks with no difficulties. However, some students raised issues, and we dealt with them as follows:

- The term 'log out' was not familiar to most of the participants (*n* = 5); therefore, we replaced it with an easier symbol, which is a door icon. After this change, they all understood its meaning.
- It was obvious that the settings icon, the famous metal gear, was not related to the avatars from the students' point of view. Only a few participants (*n* = 3) were able to change their avatar character. Thus, it was changed to a plain avatar character icon. The participants directly recognised the icon and its use.
- Some of the participants (*n* = 3) were confused by the triangular icon near the text box (submit icon ➢); thus, we changed it to a flying message icon, so they could relate it to its action.
- We thought they would have a problem with the scroll bar if the chat accumulated, but they used their fingers to scroll down and up by dragging the middle of the chatting space up and down.
- We provided them with a limited emoji selection, but unpredictably, they used the iPad keyboard to insert more emojis and pictures already installed in the iPad system.

5.8. Findings and Discussion

5.8.1. Effectiveness of the chatting tool

For our quantitative data, we measured the effectiveness of our tool by comparing the participants' performance before and after the intervention. The statistical significance was determined by a paired t-test using GraphPad PRISM (v. 5.0, GraphPad Software, Inc.). A *p*-value of less than 0.05 was considered significant. As our research hypothesis stated, utilising the independent variable (the chatting tool) by children with ADHD will positively affect their performance in the educational mini games (ACTIVATE). Thus, the null hypothesise was that utilising the independent variable (the chatting tool) will negatively affect participants' performance in the educational mini games (ACTIVATE) or have no effect at all.

Table 5.2. Progress points by participants before and after the intervention.

Participants	Progress points per session				Percentage of improvement
	Baseline	Post-intervention			
Bader	17	18	37	58	12%
Firas	12	11	26	47	25%
Galia	14	20	42	63	57%
Obaid	16	14	33	55	19%
Sarah	14	15	31	51	14%
Suhaib	18	18	42	64	41%
Talia	18	20	41	65	17%

Table 5.2 shows the progress points scored by each participant before and after the intervention. Each progress point is a measure of the levels completed and the speed within ACTIVATE. The distribution of the progress points differences was fairly normal (Figure 5.8). As our baseline measures, the pre-intervention mean was $M = 15.57$, with a standard deviation $SD = 2.30$. After intervention, they were $M = 21.57$, and $SD = 1.27$.

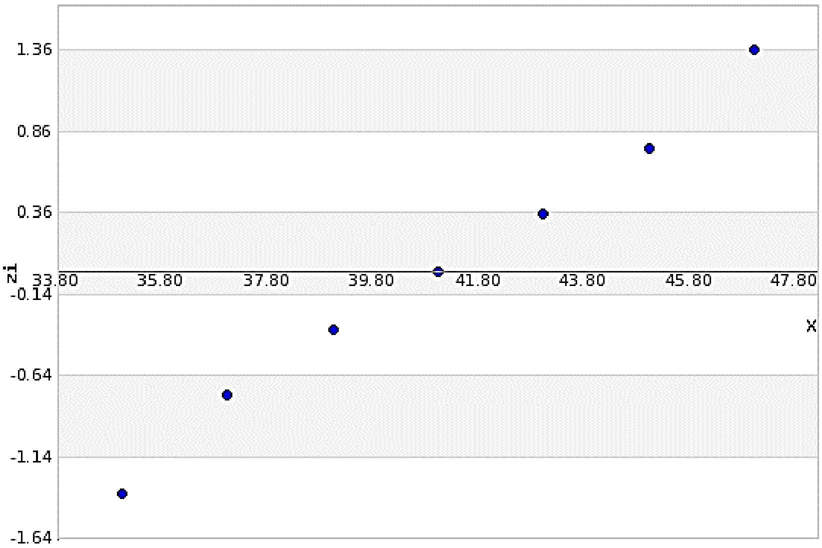

Figure 5.8. Normal Probability Plot of the differences.

The one-tailed *p*-value was less than 0.00005 ($p \leq 0.05$); thus, we rejected the null hypothesis. By conventional criteria, this difference was statistically significant. The mean of the baseline minus the post-intervention is -6.00 (95% confidence interval (CI) [-7.60, -4.40]). As a conclusion, participants' performance in ACTIVATE was positively affected by applying the online chatting tool (Chit-Chat; t(6) = 9.165, $p \leq 0.05$).

In Figure 5.9, there is some stability in the performance between the baseline and the first intervention session; participants have earned nearly the same amount of points. However, in the second session, we spotted a progressive increase in performance. By computing the difference in performance between the first and second sessions of intervention, we found an improvement in performance at an average of 26%.

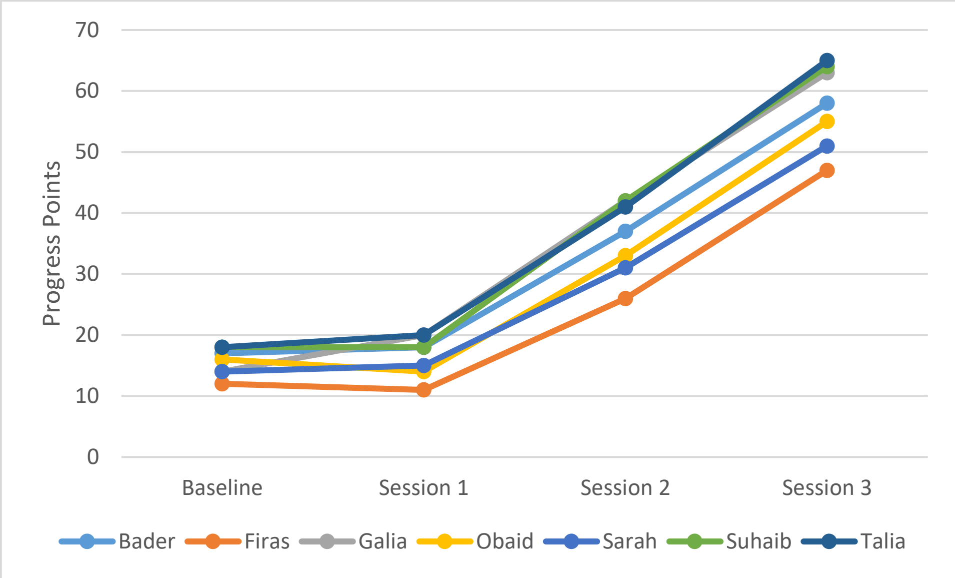

Figure 5.9. Participants' performance in baseline and during intervention.

Theoretically, one of the reasons was due to motivating them by displaying participants' scores for all of them on the collaboration tool. Regarding the literature, many studies encourage posting scores for all students, so that each student can be positively motivated by others' scores (Klingberg et al., 2005; Ali & Puthusserypady, 2015). Another reason is that participants in the first session exchanged some of the playing techniques and hints that helped them personally increase their scores, such as speed, concentrating on the monkey with fingers close to the screen, easy games versus hard games, and making fewer mistakes the higher the mouse goes up. By the second session, some of them were actually applying these techniques while they were playing. The observational notes and chat history demonstrate the positive effects of exchanging knowledge and experience on improving performance. This was in line with the findings of a study (Fiers, 2017) that utilised peer tutoring and information exchange among students with emotional and behavioural disorders. It showed growth in cognitive skills and gains in problem-solving proficiency. As motivation and knowledge exchange were dependant variables in our study, more details and qualitative results are reviewed in the next section.

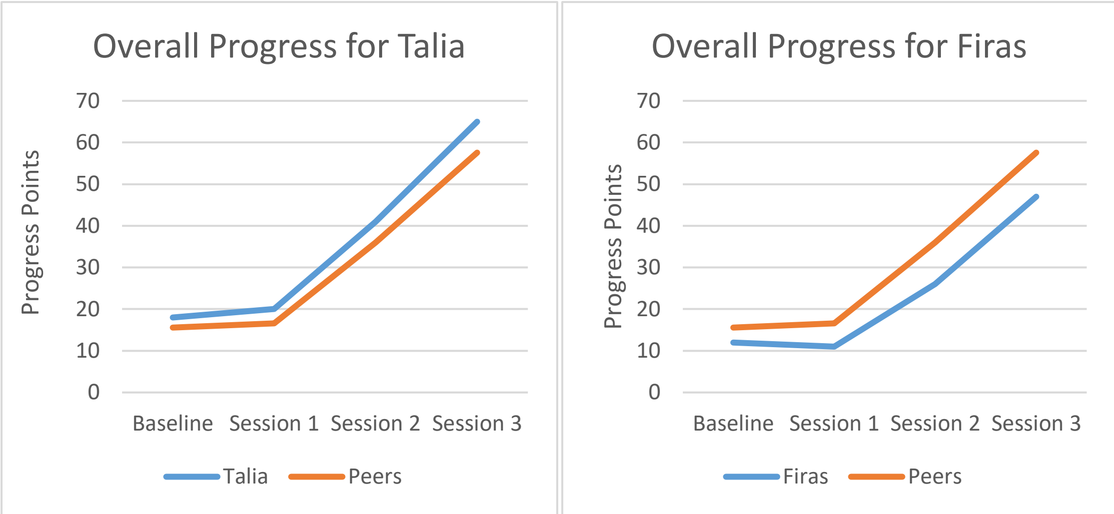

Figure 5.10. Talia's and Firas's overall progress in baseline and during intervention.

On the individual level, Firas had the least progress points (Figure 5.10), a total of 47. However, remarkably, he was one of the top three who benefitted the most from this intervention with a 25% improvement in performance. He was diagnosed with severe ADHD (inattentive and hyperactive combined type) and was the youngest participant. Yet, this experience has affected his performance positively. In contrast, Talia, who was the oldest participant in the group, had the most progress points (Figure 5.10), a total of 65. Her performance improved by 17%. She has non-severe ADHD with a medium academic level.

After discussing these findings, we were unable to state with certainty if the improvements in progress points were based on a certain factor or caused by a specific dependant variable. All we can assume that according to these positive quantitative findings, the chatting tool has positively affected their performance while playing with ACTIVATE.

5.8.2. Thematic analysis results

In the second part, our qualitative results were built upon the thematic analysis discussed earlier. All the transcribed information was translated from Arabic to simple English, considering the same simple expression level. We will discuss the most important and prominent codes with some of the quotations from the texts.

5.8.2.1. Knowledge and Experience Exchange

In the first intervention, the researcher asked the participants about ‘how the mouse goes up’ as an attempt to bolster the talk among participants. This indicates the mastery level of the player in the game. At the opening five minutes, participants (*n* = 3) were very shy to contribute in the chat, they told the researcher that they do not know how to spell the words correctly. The researcher expressed to them that there was no need to worry about perfectly spelled words; just write it in any way and try your best. Participants were encouraged one by one to give their perception about the asked question (*n* = 4). Sarah, for example, tried to explain that the mouse will rise up only if she gets ten correct answers in a row, while a wrong answer will let the mouse fall down (Quote 1). Other participants started to inquire about some of the difficulties they encountered while playing. Firas, for example, called out for a challenging obstacle; he was having a problem with clicking the monkey that appears and disappears very quickly. This was a game for improving processing speed and attention. Obaid replied with a very good playing technique; he explained that the closer the position of the fingers, the quicker he will be in clicking the monkey and releasing him out of the box before he disappears. It was clear that the participants were able to use the chatting panel in exchanging what they knew and learned. It is worth mentioning that the term ‘time’ (**الوقت**) has been mentioned twice in the chat. It was apparent that both participants knew that time matters to win. However, we do not think that there was a direct influence on their time awareness, but it was definitely one of the important hints exchanged, and it motivated them to perform better.

Quote 1 – Hints and playing instructions
:
Researcher: How the mouse goes up [?]
Sarah: 10 correct, if one wrong the mouse fall
:
Firas: monkey go quickly
Obaid: put your hand near the screen
Bader: Time

Our findings were in contrast with an earlier study that found negative effects of an online collaborative experience on children with behavioural disorders (Lipponen et al., 2003). One of their results indicated that students with disorders tend to post negatively in online discussions and avoid meaningful and reasoning conversations. Our findings showed positive conversations, socialisation, and information exchange. Another study explained that low progress students struggle to ask for help (Kroesbergen et al., 2004). Again, in our study, a good number of help requests were raised from some of the low progress participants.

Yet, many studies were in line with our findings (Rief, 2016). It has been shown that the peer-tutoring approach has promising effects on children with learning and behavioural disorders (DuPaul & Stoner, 2014). Another finding confirmed exchanging information stimulates students' abilities (Tsuei, 2014). Online interactions facilitate high progress students to aid low progress students (Tsuei, 2017). Moreover, Vasalou et al. (2017) evaluated the experience of students with learning difficulties in exchanging knowledge, which resulted in improvements on their academic achievements.

Returning to our second finding, we noticed another interesting aspect; participants were giving positive feedback to each other (*n* = 4). Some of them admired the avatar selection of others (Quote 2). Galia, for instance, complimented Sarah's girl pirate with the pink dress. The later, she expressed her astonishment regarding Talia's high score by posting an ‘impressed’ emoji (a smiley face character). These kinds of reactions would increase their self-esteem and confidence and encourage others to improve their performance (Van Popta et al., 2017). A different form of feedback was observed – a sort of a light and respectful criticism was introduced. Suhaib was pointing to his dilemma that he could not manage to get his ducks to fly; ducks fly only if a correct answer is given. Bader tried to simply criticise the way Suhaib was doing it by stating that he was choosing answers with no concentration. He suggested straightforward playing instructions to overcome Suhaib’s difficulty.

Quote 2 – Positive feedback

Galia: I like your avatar

:

Suhaib: my duck don’t fly

Bader: you click quick, think (indicating that he is selecting answers without thinking)

Bader: same colour or same shape

:

Sarah: 😍 Talia got higher score

Our outcome was in line with a study that specified that children with ADHD are affected by positive feedback yet are less considerate of negative feedback (Bul et al., 2015). Another study found that written peer-interaction with supportive talk increases learning and improves social skills (Genlott & Grönlund, 2016). Van Popta et al. (2017) also found that positive feedback among students with ADHD supports the creation of numerous possible learning gains.

5.8.2.2. Motivational Influence

This theme was mainly detected by the observed behaviour and reactions of the participants. The second intervention was designed specifically to post game scores attained by all participants. Participants were able to see their scores and their peers' scores. Few studies have emphasised exposing group scores to reinforce motivation and to improve performance (Klingberg et al., 2005; Ali & Puthusserypady, 2015). Participants (*n* = 6) showed excitement by moving their hands quickly up and down, jumping, and saying ‘yes’ or ‘yay!!’

Galia was the only participant who showed frustration due to her low score in the first part of the second intervention. She pushed the iPad away and folded her arms as a sign of discontent. The researcher suggested a time out to relax, but after two minutes she came back and asked to resume playing. Galia showed a remarkable increase of scores in the second and third interventions (table 5.2). Another sign of motivation was noticed by the researcher; after score posting, some participants (*n* = 3) were taking a bit more time thinking about the task, concentrating, and progressing well. In addition, two participants (*n* = 2) shared how many reward stars they received. Even Firas, who had less progress points (table 5.2), was open about his achievements and happy and confident (Quote 3).

Quote 3 – Achieved scores
Bader: I got 5 gold stars
Firas: I have one 😄 (happy emoji face)

Another factor that helped the researcher validate motivation was the level of engagement and activity in the chatting tool. To motivate the children’s engagement in any game with others, factors such as challenge, competition, and interaction must be applied (Yee, 2006). For example, on the third intervention, Suhaib and Bader set their own competition by agreeing on the next mini game they would play. After completing the game, and returning back to the chat panel, the first thing they did was check on each other's scores. Another important aspect was the participants' engagement frequency in the chat. Firas and Galia were the youngest participants in the group; they were less confident and less engaged in the beginning. They were not participating in the first session, they started to post emojis and wrote a few words that were not correctly spelled but were fairly understood. By the third session, they were engaging actively with their peers with a range of three words and more in the sentence (Quote 4).

To my knowledge, there was no study found on the relation of the engagement level with the motivation for children with ADHD while using collaboration tools. Yet, we found one study (Ronimus et al., 2014) that showed that there is no significant effect on children's engagement by challenge level or reward system. From our point of view, the factors of peer interaction and competition were not presented in their work.

Quote 4 – Engagement and activity level

Firas: Year 1

:

Galia: ☺

:

Firas: Monkey go quickly?

:

Galia: I like your Avatar

5.8.2.3. Socialisation

One of the main symptoms of children with ADHD is having some difficulties in their social skills and interaction with peers (Wilkes-Gillan et al., 2017). Our objective in this study was to help them develop these skills by engaging them in a close online community. This assisted in reducing the fear of confrontation and encouraged them to release their feelings and opinions about certain games. In the first intervention, the researcher introduced himself and asked the participants to introduce themselves as well. In the first session, a few participants (*n* = 3) talked about their classes, favourite subjects, and things they like to eat (Quote 5). Others (*n* = 2) were too shy to write anything. They were observers rather than participators. In fact, they were only posting emojis as a way of interacting, but they were eventually encouraged by feedback from their peers who commented and interacted with their input. By the third intervention, some participants (*n* = 2) were sharing short jokes, and others (*n* = 2) were planning to play in the playground after the intervention (Quote 5). From the observation, we found that this experience has reflected positively on their prosocial relation outside the playing sessions. Galia, for instance, was very shy, and she surprisingly asked Obaid to let her play football with him during the break between sessions. The concepts of indirect learning, emotional feedback, and facilitating mastery of given tasks, which are the fundamental elements of behaviour development in the social cognitive theory (Bandura, 1986), were executed in the intervention design.

Quote 5 – Enhancing social interaction

Sarah: I am in year 2, where is your class?

Talia: I am in year 3

Suhaib: year 3

:

Obaid: I like watermelon

Suhaib: I like 🍉 (an emoji of watermelon) but we call it ‘Juh’ (an Arabic name for watermelon)

:

Galia: I like the playground

Firas: I like football

A study done by McHale (2010) revealed that children with ADHD normally encounter difficulties in public online social communities owing to lack of safety and differences in reaction speed, cognitive abilities, and social skills. Children with this disorder usually are segregated and downgraded in social life; therefore, providing them a safe monitored online community will positively support them. Another study that was in line with our findings investigated an online communication system designed for children with ADHD. They found that children are more confident, open to self-identity, and seek support if needed from their peers more easily online than in real-life situations (Raskind et al., 2006).

5.8.2.4. Behavioural Reaction

This theme was mostly detected by observing the participants. We discuss the most obvious behaviours worth mentioning, with the aim of highlighting them to ease the development and design of any future electronic intervention for children with ADHD.

One of the common symptoms among children with ADHD is boredom from doing a single task for a long time (Diamond, 2005). Consequently, it is recommended to diminish the activity time or apply moderate switching between physical and stable activities (Wexler, 2013). Most of the participants (n = 6) were getting bored after the second chat session; they get up from their seats and walk around the classroom, or simply say they want to go outside to play. As our experiment design maintained five minutes for each session, it was convenient to give them a break half-way through the intervention to play outside. Other participants (n = 3) were sneaking to other game applications on the iPad; therefore, the researcher had to lock all the applications on the iPad except ACTIVATE and Chit-Chat.

Another behaviour was addressed. One of the participants initiated a negative chat input. He posted an emoji that resembles human excrement. He was not abusing anyone, but from his point of view, he thought it was funny. The researcher did alert them before the intervention about not posting any unpleasant text or image. However, he had to remove the post immediately; otherwise, if no action was done, other participants would be encouraged to do the same thing, thinking this behaviour is acceptable.

Despite the researcher's attempts to introduce extra break time to play outside and to diversify the activities to avoid boredom, two participants (*n* = 2) demanded to stop and do something different. The researcher tried to incentivise them (i.e. tangible rewards for the top three who earned a golden trunk due to high scores), and it was enough to bring them back to play the games.

5.8.2.5. Skill Development

The text-to-audio feature helped younger participants (*n* = 2) and promoted them to interact with others. In the first few sessions, there was an increase in the use of the feature, but in the last intervention, no one was using it. No clear evidence about its effect on the children's skills was found. More evaluation with a longer duration of use is needed. Additionally, no studies were found, to my knowledge, about the effect of text-to-audio/text-to-speech features on improving any skills for children with ADHD.

Their writing skills were enhanced by 62%, and they were posting an average of 80 words/emojis in the first session. By the last session, the average increased to 130 words/emojis per session, and their writing speed increased as well. They were not posting correctly spelled words, but it was acceptable since it was readable and understandable. In fact, their reading ability was enhanced, as they were reading incomplete and wrongly spelled words, yet they interacted and responded.

This improvement, in my opinion, will encourage others who are interested in the field to explore the benefits of online texting to children with ADHD. I agree with the study, (Zebroff, 2018) that acknowledged that the effectiveness of online texting remains unclear. More research should be done with larger sample sizes and longer durations. Similar to ours, another study found that online texting promotes children's reading and spelling achievements, since it provides them with a rehearsing platform to practice what they learned (Wood & Johnson, 2018).

Quote 7 – Creativity and thinking
Obaid: My favourite game is 🐵 (emoji of a monkey)
Shuaib: ♡🐥 (refers to Suhaib likes the duck game)
Obaid: 👮👫🚗🏢, tell me what that is?
Shuaib: I know, the police catch bad guy and put in jail.
Obaid: ✅
Suhaib: 👍🐵👎😎🙌

A kind of emotion symbolism using emojis was used by participants. It is a pictorial character that aids the process of merging emotions while texting using different messaging applications (Pohl et al., 2017).

> *Emoji not just allow for expression of many emotional states (e.g. 😥, 😓), but also enable users to decorate messages (e.g. 💥, 🎊, 🎶). Using a visual icon instead of a word enables users to introduce ambiguity and playfulness where they see fit. (Pohl et al., 2017, p.2, l.12)*

Generally, emojis are used in text chats by children or adults to reply to each other, share their favourite preferences, or express their emotions by means of substituting one or two words with an emoji. However, in our case study, it was remarkable to see participants (*n* = 2) used full sentences of emoji to create a story or a riddle without the use of words. This interesting technique showed their creativity and thinking skills. Obaid, for example, created a small riddle to let Suhaib think about what story he is trying to tell (Quote 7). Suhaib solved it correctly. In his turn, he came up with a different emoji riddle as an exchange; he disclosed that he liked the monkey game, but he does not like feeding the pirates game. They were extremely happy and excited while using this method of communication. They believed it was their cryptic language or a code nobody would understand except them. In addition, we noticed an increase in attention and concentration from both; they were attracted to this act for about the whole chat session. This result was in line with a study that recommended the use of emojis to influence attention for some subjects (Willoughby & Liu, 2018).

5.8.3. Chit-Chat usability and satisfaction

One of our essential goals in this study was to evaluate the Chit-Chat interface in terms of usability and satisfaction. As we stated earlier, a usability test was done on the first session of the intervention with the same group of participants (*n* = 7). They were given certain tasks to perform, and they were encouraged to talk aloud during the test. Detected usability issues were fixed on the same day, and a post-intervention open-ended interview was done to assess their experience with the tool.

Nielsen (1994) identified usability using five quality components that must be applied, to any system in which humans might interact. Thus, any system interface would be considered usable if it was efficient, learnable, memorable, and satisfactory and has a small error rate.

The quantitative results showed that Chit-Chat is an effective chatting tool for children with ADHD. We found fairly significant improvement in the participants' performance after comparing their achievements in ACTIVATE before and after using the tool. From these findings, the Chit-Chat chatting tool is efficient.

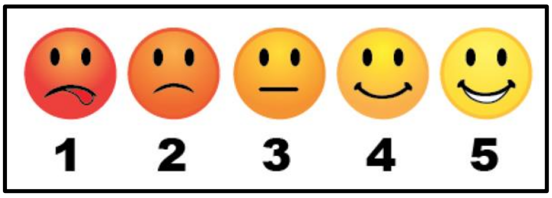

Figure 5.11. Five smileys (ranged from strongly agree to strongly disagree) to assist answering interview questions.

The remaining quality components were measured by seeking the participants' feedback and experience with the tool, combined with our observational notes while they were using the application. A post-intervention interview was conducted with each participant individually. We did not use the questionnaire type due to their young age and probable struggle of reading, comprehending, and writing well-constructed and explanatory sentences. Therefore, we used interview-like questions with the aid of five printed smileys (Figure 5.11) that ranged from strongly agree to strongly disagree to help them show their emotions about a specific question, and then talk about the 'why?' afterwards.

Table 5.3. Post-intervention interview questions.

Usability Quality Component	**Interview Question**
Learnable	Was it easy to use the Chit-Chat application the first time you encountered the design? Was it easy to know if the chat was activated or not? Was it easy to know your score and your friends' scores? Was it easy to hear audio from the written text? Was it easy to post text? Or emojis? Was it easy to change your avatar?
Memorable	On the next day of intervention, did you remember how and from where you could: Change your avatar? Post a text or emoji? Check your score and your friends' scores? Hear a text in audio form? Can tell if chat is activated or not?
Error rate	How many errors did you make when using Chit-Chat? What were they?
Satisfactory	How pleasant was using the Chit-Chat tool? Did you like the pirate theme design and colours? Did you like the avatar pirate characters?

The interview took approximately ten minutes with each participant. They were asked multiple questions shown in Table 5.3 that relate to each quality component.

All participants (n = 4) strongly agreed and (n = 3) agreed that the system was simple and easy to use from the first time they interacted with the interface. Two participants (n = 2) found that the chat deactivation feature was confusing in the beginning, but in less than a minute they noticed the statement ‘the chat is locked by the teacher’ and immediately understood and waited until the teacher unlocked the chat. Regarding the avatar icon, and after changing it from a gear () that resembles settings to a small human character (), they easily knew how to change their avatar character. The participants did not face any problems with converting text to audio. Most of them (*n* = 5) tapped the text directly when we asked them to hear what they wrote on usability test and recognised the left-hand side when they were asked about scores. From these user experiences with the tool, Chit-Chat is learnable.

On the third intervention, all the participants (*n* = 7) remembered how to reach all the features within the Chit-Chat interface. They were using the tool with confidence and skill. The features were few, easy to reach, and all on the same page; therefore, the Chit-Chat interface is memorable.

As expected, due to its nature as a chat-only tool, the error rate was nearly none. There was no wrong way of doing something. All the participants completed the tasks they were asked to do correctly and chatted through the panel without mistakes. They knew the use of each icon, and no multi-steps nor multi-levelled tasks were required. For that reason, the Chit-Chat interface has no error rate.

The design was kept simple and easy with less distraction. All participants (*n* = 7) strongly agreed that they liked the theme, colours, and icons in the interface. A few of them (*n* = 2) suggested that they want to customise the pirates and dress them up, and one (*n* = 1) asked about whether they could have more control of the text in terms of changing the colour, font, and size. All these suggestions will be taken in consideration when modifying the tool in the future for another evaluation. Therefore, the participants agreed that Chit-Chat was subjectively pleasing, and they were satisfied with the overall interface design.

From these previous findings and feedback, Chit-Chat is efficient, learnable, memorable, and satisfactory with no error rate. Thus, the Chit-Chat collaboration tool is considered usable and satisfactory.

5.8.4. Collaborative experience within ACTIVATE

Collaboration in learning is a commonly used technique to enhance cognition and social skills among students (Fawcett & Garton, 2005). It comprises students performing a single, synchronous activity that they contribute together through different inputs to solve a certain problem as a group.

As we showed earlier, ACTIVATE is an individual-account system. Therefore, in our intervention, we tried to develop a link to bond players together while using ACTIVATE, and to create an effective online experience. The results were promising (see previous section).

As adifferent attempt to create and evaluate collaboration within ACTIVATE, we allowed a number of participants to share a single tablet and play four mini games in 20 minutes. The seven participants were divided into two groups: A and B. Each group intentionally had almost equal performance and skill levels to ensure an accurate and fair comparison. Group A included Obaid, Galia, Bader, and Taliah. Group B included Firas, Suhaib, and Sarah.

For Group A, we logged in using Obaid's account. From the moment we gave them the iPad to start playing, all participants knew that this account belonged to Obaid. Thus, Obaid took the lead and put himself in charge and experienced a feeling of possession over the game. In the beginning in the first mini game, he showed a defensive behaviour towards his friends, trying to save the scores he gained so far. When others tried to tap on the screen he said things like: 'no, you are making me lose', 'no, this is not right'. Galia rapidly lost interest in such a playing attitude and walked away to do something else. Talia and Bader were sharing game techniques and answers, such as 'pick the yellow triangle', 'quickly, quickly'. In the second mini game, the teacher interfered to let the other group members share and play. Bader started to play, while Talia was giving supportive feedback: ‘the mouse is almost on the top, come on come on’. Galia was encouraged by hearing positive cheering in her group and was drawn back to observe closely, yet with no interaction. Bader did not mind others tapping on the screen. When it was Galia’s turn, she did not seem comfortable or self-assured as she was in the individual intervention. Obaid was giving her some negative comments, such as ‘please do not make us lose’, ‘you are slow’. She felt the pressure at the start that led to a few mistakes. More negative talk occurred, such as ‘Nooooo, I told you!’. There were a few attempts from Obaid to gain control, but other members were vindicating her turn and encouraging her by: ‘it’s her turn, let her concentrate’, ‘she can do it’. With the help of her friends, she managed to progress and bring the mouse to the top again.

In the other group, we witnessed some similar behaviours. Firas was the first player, and all participants realised that it was Suhaib’s account. Firas encountered some difficulties with the working memory game (the hungry pirates). He was feeding the wrong series of hungry pirates. Suhaib showed frustration by covering his eyes and saying: ‘oh no, Firas, you did not get it right’. At the same time, Sarah was trying to visually memorise the sequence by pointing her hand over the first and last pirate. In the third attempt, Firas was following Sara’s instructions, and they got it right this time. They unintentionally worked it out by group work. Suhaib jumped for joy.

On the second mini game, Suhaib took control. He was playing very well, maintained good progress, and was showing pride and independence. Firas and Sara were happy with his progress, and they were giving him positive encouragement and helping with the answers. However, it seemed they did not have the courage to tap on the screen, as they were probably worried about Suhaib’s disapproving reaction. It is worth mentioning that, when Suhaib selected a wrong answer, Firas said as a payback: ‘look, you have lose too, not only me’. Unexpectedly, they laughed together. Sarah did not come across any issues; all were sharing answers and tapping the screen, which she did not mind at all.

As a conclusion, from our point of view, this approach was not considered successful for a few reasons. First, ACTIVATE was not designed as a collaborative game portal. A main player should always be assigned, and the rest of them only share by giving answers or instructions. Another issue we noticed was that active participants with good progress and performance in the games took a role as tutor and received all the credit for high scores, while the less active participants with low progress and performance were constantly instructed with playing strategies and subjected to constant blame. The inequality of progressing in the game without preserving this progression was unsatisfying for some of the participants. A third issue we acknowledged was that every participant has a different processing speed and attention level. Some of them worked well when given their own space and pace.

As a challenge in our future work, we suggest adjusting ACTIVE to make it suitable for multi-players to accept multi-taps and adjust the scoring system, which would address the balance of different abilities. Another option would be to undertake this experience with a different electronic game that supports a collaborative approach, such as puzzles and whiteboards. Another important recommendation that we will consider is the duration of this new trial. Our current experience was for one session with 20 minutes in total. Because of that, we cannot validate the output. More reliable findings would be gained with a longer duration and perhaps a bigger sample size.

5.9. Conclusion

The outcomes of the current study fit into the forthcoming projects of online activities interventions for children with ADHD. We have stated the results of an intervention in which we investigated the influence of connecting ACTIVATE players together through an add-on online chatting tool using iPads as the tool of study. ACTIVATE, which was found effective and usable for children with ADHD in our early work, offers mini games to stimulate executive functions in the brain. The online tool Chit-Chat was designed and developed to support the ‘e-collaboration’ concept through providing a chatting panel to engage participants.

The intervention took place in an international primary school in Jeddah, Saudi Arabia. Seven students with ADHD aged between 6 and 8 years participated in the study after their parents’ approval. A pilot test was done before the intervention, and a usability test was done during the intervention. The intervention involved three mini interventions, each with four ACTIVATE mini games, and a chatting session after each game. Children showed fairly significant improvements in their performance while playing ACTIVATE. Chit-Chat, the online chatting tool, was found to positively influence children’s knowledge and experience exchange, motivation, and social skills. In addition, the Chit-Chat tool was effective, usable, and subjectively pleasing.

Furthermore, this study yielded quantitative and qualitative findings. For our quantitative part, we measured the effectiveness of our tool by comparing the participants’ performance before and after the intervention. The One-tailed p-value was less than 0.00005 ($p \leq 0.05$). By conventional criteria, this difference was statistically significant. Thus, the participants’ performance within ACTIVATE was positively affected by the online chatting tool (Chit-Chat; $t(6) = 9.165$, $p \leq 0.05$).

Moreover, thematic analysis (Clarke & Braun, 2014) was applied to the qualitative data gathered from the participants’ chat history, observational notes, and audio recordings of post-intervention open questions. This process allowed us to interpret gathered raw data and present it in a more intensive construction of themes that supported our outcomes. After going through all the transcripts, we found promising outcome and strong evidence of improvements in the following participants’ skills:

1. Participants utilised the chatting panel to successfully exchange playing instructions, techniques, hints, feelings, concerns, and positive feedback.
2. Evidence of motivational reinforcement by score comparison and increments in competition, engagement, and activity levels.
3. Participants demonstrated an improvement in social interaction in real life outside the classroom.
4. Unexpectedly, we discovered that other skills have been enriched. This experience has positively affected their reading, writing, creativity, and thinking skills.

The results did not reveal improvements in the following participants' cognitive abilities: attention, processing speed, and working memory. This could be clarified by the fact that the developed chatting tool did not aim to target these types of abilities by itself. It was developed to be integrated with another system, ACTIVATE, that works on improving those abilities. Another clarification might be that, to measure cognitive improvements using the NIH built-in tool box within ACTIVATE, the player should have completed 500 minutes of play time to be able to detect reliable measures (Wexler, 2013). This was unachievable due to our short-term evaluation duration. Second, there was no clear evidence about the effect of text-to-audio/text-to-speech feature on children's skills. Additionally, no studies were found, to my knowledge, that investigated the effect of text-to-audio/text-to-speech features on improving any skills for children with ADHD. More evaluation with a longer duration of use is recommended.

As a summary to answer some of our research questions, we found strong evidence that utilising an online chatting tool by children with ADHD positively affects their motivation, knowledge, experience, and social behaviour. Chit-Chat, the chatting tool, was found to be usable and subjectively pleasing by children with ADHD. However, we did not find any differences in outcomes regarding whether the teacher contributes in the chatting activity or not. No direct nor noticeable effects on the children's behaviour were found. In my opinion, the reason for this was that the teacher physically was present in the test settings even if the teacher did not participate in the chatting activity, which gave the participants the impression of being monitored. More tests should be done regarding this concern.

5.10. Limitations

Some of the limitations, which disturbed the investigation of this study, need to be addressed. We intended to implement a long-term evaluation with a larger sample size to study the effects of adding a chatting panel to a learning tool, on the students' cognition, abilities, and skills. Unfortunately, despite great efforts to reach a large number of primary schools with SEN in Surrey and London in the United Kingdom, no approvals for evaluation within their schools were permitted. We contacted the Surrey council – Schools and Education Department and presented our evaluation plan. They were supportive and promised to help direct us to interested schools. However, no school accepted the idea of committing for three months to three sessions a week, each requiring 20 minutes of time. Providing a place, time, and a specialist were their main concerns. We reached families with children with ADHD though Facebook groups; yet, only one parent replied but was unwilling to commit for a long time. After four months of searching, we decided to change the plan and do a short-term evaluation. As a result, we were able to evaluate the tool with a small sample size. A future long-term evaluation with a larger sample size and the use of neuropsychological/cognitive tests is strongly recommended to investigate the effects on children's cognitive abilities and behavioural skills.

Another limitation was the inability to develop a chatting feature within ACTIVATE itself due to a limitation from the developing company.

In addition, our first intention in this work was to explore e-collaboration, which is one of the recommended components in our recommended list of guidelines. Therefore, we developed a chatting tool, Chit-Chat, as an add-on for user engagement that enable teachers to submit tasks for students to work it through together. But due to time limitations, one week only approved by the school, we did not have the chance to evaluate a collaborative work. Instead, we evaluated the chatting act and investigated its impact on children’s skills.

Chapter 6

Conclusion and Future Work

Throughout this thesis, we were able to achieve the key research aim. A list of recommended guidelines was produced, which proposed automated strategies (features) as components. It would assist interface designers and developers create effective learning systems for children with attention deficit hyperactivity disorder (ADHD) and to improve their abilities and skills. It could be used by teachers or parents as a guide to help them distinguish good applications from others. As our findings stated, applying these strategies on any system targeting children with ADHD will result in better academic achievements, improvement in cognition and behaviour, and reinforcing socialisation. We have fulfilled this aim by implementing three objectives.

We initiated our work by performing a grounded meta-analysis with 49 empirical studies on enhancing skills and abilities for children with ADHD using technological interventions with game elements. Five units of analysis were conducted separately, which targeted five attributes of abilities and skills: attention, working memory, processing speed, behaviour, and social skills. This analysis highlighted the significant and effective game elements (features) explored from the included studies. As a conclusion, a list of recommended guidelines to develop effective systems for children with ADHD was proposed. No studies were found, to my knowledge, on the effect of ‘e-collaboration’ on young children with ADHD, as this was our fourteenth component.

In the second phase, an e-game, ACTIVATE, was selected upon certain criteria, which apply e-learning strategies that closely fit our proposed guidelines. The game consisted of six different brain training games, each triggering one or two cognitive capacities. It was evaluated by 17 students, from two international schools in Saudi Arabia, who had clear signs and symptoms of ADHD. The iPad was used as the tool of the study. Testing took place in school settings in class sessions. Students played with the game for four months, at three sessions a week for 20 minutes each session. The National Institutes of Health (NIH) tests were done pre- and post-intervention to measure improvements. The results show significant improvements in cognition, behaviour, and social skills, quantitatively and qualitatively. The participants’ academic performance enhanced and evolved as well. The game interface was easy to use and pleasant, adaptable, and accessible.

Finally, we developed and evaluated the effectiveness and usability of a chatting online tool (chit-chat) for children with ADHD. Seven Saudi children with ADHD aged from 6 to 8 years were assigned to the chatting intervention using iPads. They played ACTIVATE, then chatted using our developed chatting online tool for three days for 35 minutes each. Progress points were measured and quantitively analysed before and after the intervention. A thematic analysis was applied on the qualitative data: chat history, observational notes, and vocal recordings of post-intervention interviews. Participants showed improvements in overall performance. Online chatting was found to be effective for children with ADHD and positively influenced their knowledge, experience, motivation, and social skills. Promising outcome and strong evidence were found of improvements in competition and engagement level, social communication, and unexpected enhancements in other skills: writing, reading, creativity, and thinking skills.

The profound benefit of this work was drawing out a list of recommended e-strategies, outlined from multiple empirical studies, that could be used to build effective and reliable learning systems for children with ADHD. This list not only proposed implementable strategies, it also suggested effective game elements/features (proven by empirical studies) that would have more effects on the development of abilities and skills than any other game elements/features.

Different amendments, experiments, and ideas were left to the future because of the lack of time and other limitations. From our point of view, if considered, they will complement and reinforce the ultimate goal of providing a better learning experience for children with ADHD. The following ideas could be tested:

- Study the effects of using the Holy Qur'an audio clips on the behaviour of children with ADHD, while interacting with a brain training game interface. The Qur'an is known for its therapeutic effects, psychologically and physically. Some studies encouraged playing sound clips as a background during a given task to children with special educational needs. Other studies have found that this approach will add extra distraction for these children.

- In our first draft of the guidelines, we proposed 'linking to social media' as a resource of knowledge and communication, and we proposed that it would be beneficial for students with ADHD to be offered a link to access YouTube, Facebook, Twitter, etc. However, by exploring relevant studies that targeted ADHD, which were few, we sensed a general agreement on the incompatibility and inappropriateness of this intervention for adolescents with ADHD, and subsequently for young children as well. Most issues were related to addiction to social media and its relation to self-esteem, health-related problems, hijacking, verbal abuse, and more (Veil et al., 2015; Uzun et al., 2016; Mérelle et al., 2017). One study was found on the positive effects of multimedia (Facebook) on university students with difficulties in social relation management and school environment adaptation (Fovet, 2009). Social media, as it is now, is considered an exposed unsecured community. Because of that and because there was no study found about the effects of social media on younger children with ADHD, we had to exclude this notion from the guidelines' list. We suggest, for the future, developing a mechanism to apply restrictions and customise what these children can access based on their age, cognition abilities, type of disorder, and other executive function specifications that could be assessed by a system. Further investigation should be done in this area.

- Another future work that could be suggested is repeating the experiment of evaluating the chatting tool tools by children with ADHD, but with a larger sample size and longer duration. Participants without ADHD could be included to explore how social diversity affects their interaction with the tool.
- Regarding the socialization tool 'Chit-Chat', we focused on implementing and evaluating certain features that relate to our objectives. More improvements could be done to the tool by adding features such as teacher-student private chat, voice messaging, free-style hand writing, and collaborative challenges. This could open new investigation opportunities for interested researchers.

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Appendix

[Letter to Parents of Pupils at Primary School]

Feb 2018

Dear Parents/Caregivers

Re: Research study on effects of an online collaborative experience on the performance of children with Attention Deficit Hyperactivity Disorder while playing educational games

I am Mrs Doaa Sinnari, a PhD student in Surrey University in computer science Dept., under Professor Paul Krause supervision. My research mainly targets ADHD children in the age range of 7-11 years. I am intending to evaluate the experience of an iPad e-game with a chat feature. The e-game, ACTIVATE, was developed under the supervision of Prof Bruce Wexler, Neuroscientist at Yale School of Medicine, United States. It was evaluated by children with ADHD in many countries. I did evaluate the game myself, in another country, in an earlier stage and had significant positive effects. For detailed results and findings of the prior ACTIVATE evaluation please contact the researcher by email address: ds00215@surrey.ac.uk. The game basically contains 4-6 mini games, a mix of sorting, categorising, remembering, shapes and colour recognition and collaboration games. The goal of these mini games is to develop the cognition skills, improve math and reading achievement, enhance attention and social skills. Each user/player has a unique account, in ACTIVATE, that could be accessed by appointed passcodes. For more information about ACTIVATE games you can visit https://www.c8sciences.com/how-it-works . Permission to conduct this evaluation has been granted by the head teacher of the school attended by your child.

ACTIVATE is a paid application, but as a researcher I will take care of all the fees for creating accounts for participants to be used for evaluation. It will be a new experience for the children. iPads and ear pieces, provided by the researcher, will be the only tools used. Children will be informed that this experience will help them concentrate better and explore interacting with other friends through chat.

The enclosed information sheet explains more fully what is involved. If you are willing to allow your child to participate, you need to sign the attached consent and return it back to [school email] or hand it in to school secretary. However, if you do not wish your child to take part, you don't need to take any action.

If you would like further information, please do not hesitate to contact me (the researcher) at: ds00215@surrey.ac.uk

Many thanks and kind regards,
Yours sincerely
Doaa Sinnari
PhD computer science student

Information Sheet for Parents/ Caregivers

Study on the effects of an online collaborative experience on the performance of children with Attention Deficit Hyperactivity Disorder while playing educational games

Introduction: My name is Mrs Doaa Sinnari. I am a PhD student at the University of Surrey. I invite your child to take part in my project. This sheet tells you why the research is being done and what it will involve. Please read the information carefully and discuss it with others if you wish. If anything is not clear, you can contact me for more information. Take time to decide whether you wish your child to take part or not. This study has been given a favourable ethical opinion by the University Ethics Committee.

What is the purpose of the study? The purpose is to find out about whether using a chat feature along with an educational e-game, ACTIVATE, will help children with Attention Deficit and Hyperactivity Disorder to be more collaborative, motivated to perform better and whether it could enhance their social skills.

Why has my child been invited to take part in the study? Your child has been asked to take part because he/she is a pupil in a primary school, between the age 7-11, diagnosed with ADHD only. I would like to know what he/she thinks about online collaborative experience.

Does my child have to take part? No, he/she do not have to participate in the study. It is up to you and your child to decide whether to attend the games sessions or not. Commonly, this will take place in a classroom after the school day, the school psychology specialist, with the researcher, will attend all evaluation sessions. If you do decide to let him/her take part in the study, you will be asked to sign a consent form. Participation is voluntary. You should read this information sheet and if you have any questions you could contact the researcher.

What is my child going to do? If you approved your child to be part of this evaluation, you will be given a questionnaire to fill in about your child name, age, Type of ADHD, whether is he/she on medication, and how is his/her sociability with others. After that, Your child will be asked to attend four sessions only, 35 minutes each, after school. All the participating children will be in the same class undertaking the task. He/she will be given an iPad and ear piece. Basically, he/she will be playing an educational mini game, ACTIVATE, for five minutes, then access a chatting panel to enable all the participants to chat with each other for about five minutes. Because of that, it is critical to group the participants together at the same time to implement this chatting activity. The session will be involving 4 mini games and three chatting sub-session. The chatting panel will be a private closed- community designed for children with ADHD, the participating children will be the only member in the chat. All chats (text) written by your child will be saved to be used later in the data analysis and results phase. Any written personal names will be obliterated for anonymity reasons. Researcher will be writing observational notes about your child's behaviour while interacting with the application.

ACTIVATE games are brain-training exercises for children with ADHD assumed to enhance and develop their learning skills in classroom settings. These games train the student's ability to move between different tasks, remember sequences, classify items, and reinforce thinking strategies. The games' theme is about being in an island that been discovered by Captain Blue feather and his crew, the student must help them complete levels and collect scores. The Captain introduces each game and gives audio instructions, to help students to understand their tasks. These tasks range from feeding the crew, categorizing items, helping animals and more. For more details about ACTIVATE please visit https://www.c8sciences.com/how-it-works.

After completing four sessions, he/she will be interviewed by researcher with the presence of the school psychology specialist, individually, about whether they like chatting with friends using the chatting application or not, and their overall opinion on the chat application. The interview will be registered (written) for research purposes, and pictures of the children whilst interacting with the tool will be taken without showing their faces, all project data will be held for at least 6 years and all research data for at least 10 years in accordance with University policy and that your child personal data is held and processed in the strictest confidence, and in accordance with the current UK data protection regulations. The children will be subject to existing school behavioural and safeguarding policies at all times.

What are the good things about taking part? In addition of your child may find the experience exceptional and exciting, your child responses will be a valuable addition to research.

What if I don't feel comfortable about my child taking part? If you feel uncomfortable about letting your child attend these sessions at any point, you can contact the researcher to solve the issue, or withdraw from the study at any time. His/her anonymous data, already collected will still be used in the study.

What happens at the end of the research? A report about your child contribution in this project will be handed to parents; it will include a summary of your child's behaviour and performance, during the four sessions, while interacting with the tool. Results will be written up to contribute towards my research and may be published and/or presented at a conference. Your child name will be coded to be anonymise and nobody will know that he/she were part of this study.

What if there is a problem? For any complaint or concern about any aspect during the study please contact your Head teacher of school: [*Head of school email*]. For more information you can contact the research team through email address. Researcher: Mrs Doaa Sinnari ds00215@surrey.ac.uk , Supervisor of the project: Prof Paul Krause p.krause@surrey.ac.uk

Thank you for reading this.

Participant Information Sheet for Pupils

Study on the effects of an online text messaging on the performance of children while playing educational games

*This sheet will be read out to participants in the first session before starting the evaluation

My name is Doaa Sinnari. I am a student at the University of Surrey. Thank you for attending this special activity class. You have been asked to take part because you are a pupil in a primary school, and between 7-11, and I would like to know what you think about our games and chat application. We want you to test a game called ACTIVATE that may help you concentrate better. As well as testing text messaging with your friends in this group, that may help you learn new things. You will be given an iPad and an ear piece to use in our sessions. You need to attend one session after school, for four days only. Your teacher [*psychology specialist name*] will be attending with us in all sessions in case you need help. After completing sessions, you will be asked about whether you like chatting with friends using the chatting application or not, and your opinion on the chat application. If you have any questions at any stage, or if you need a break or wish to stop what you're doing, or you want to leave this session, you can just put a hand up. Reports about your scores, how well you play and text will be handed to your parents. Results will be written up in my research and may be published and/or presented at a conference. Your name will be coded, and nobody will now that you were part of this study.

Thank you for your attention.

Consent Form for Parents

[Study on the effects of an online collaborative experience on the performance of children with Attention Deficit Hyperactivity Disorder while playing educational games**]**

Please initial each box

- I have read and understood the Information Sheet provided (version 4, 17 April 2018). I have been given a full explanation by the investigators of the nature, purpose, location and likely duration of the study, and of what my child will be expected to do. ☐
- I have been given the opportunity to ask questions on all aspects of the study and have understood the advice and information given as a result. ☐
- I agree for my child's chat history to be used for this study and future research that will have received all relevant legal, professional and ethical approvals. ☐
- I agree for my child's performance scores to be used for this study and future research that will have received all relevant legal, professional and ethical approvals. ☐
- I give consent to the post-intervention anonymised interview with my child to be registered (written) and used in the study. ☐
- I give consent to the observational notes that will be taken by the researcher on my child's behaviour and interaction with the game. ☐
- I understand that all project data will be held for at least 6 years and all research data for at least 10 years in accordance with University policy and that my child personal data is held and processed in the strictest confidence, and in accordance with the current UK data protection regulations. ☐
- I agree for the researchers to contact me through school to provide me with a report about my child's contribution. ☐
- I understand that my child is free to withdraw from the study at any time without needing to justify his/her decision, without prejudice and without his/her legal rights and studies being affected. ☐
- I understand that personal data will be destroyed, but even if my child withdraw, I allow the researchers to use anonymous data already collected as outlined in the participant information sheet and this consent form ☐
- I confirm that I have read and understood the above and freely consent my child to participating in this study. I have been given adequate time to consider his/her participation. ☐

Name of participant	....
Signed	....
Date	....

Name of researcher/	MRS DOAA SINNARI
Signed	
Date	

Pre-Project Questionnaire
(For Parents/Caregivers)

Thank you for agreeing for your child to take part in this study. I would like to ask you some questions about your child's condition, behaviour, performance in social life. It will be good to know a little background about those aspects, so it will be easier for the researcher to analyse any kind of response during the project. Please omit any question you do not wish to answer.

A) Please tick the option which best describe your child behaviour

1) Excessive activity and movement
☐Often ☐Always ☐Few ☐No

2) Fast enthusiasm and excitement, impulsive and reckless
☐Often ☐Always ☐Few ☐No

3) Disturb other children
☐Often ☐Always ☐Few ☐No

4) Is not able to complete what had begun (lesson or play)
☐Often ☐Always ☐Few ☐No

5) Can't sit down a reasonable period, a lot of fidgeting
☐Often ☐Always ☐Few ☐No

6) No attention and very little focusing
☐Often ☐Always ☐Few ☐No

7) Must perform his/her demands at once (No patience)
☐Often ☐Always ☐Few ☐No

8) Cry quickly and easily without a real reason
☐Often ☐Always ☐Few ☐No

9) Quick change in the mood radically, quick anger and frustration
☐Often ☐Always ☐Few ☐No

10) Quickly explode and unexpected behaviour
☐Often ☐Always ☐Few ☐No

B) Was the child clinically diagnosed with Attention deficit and hyperactivity disorder (ADHD)

☐Yes ☐No ☐I prefer not to declare

C) Was the child on any kind of treatment / medication related to his ADHD condition?

☐Yes ☐No ☐I prefer not to declare

If you choose **yes,** please give some details about the treatment/medication given

Is the child still on treatment/medication?
☐Yes ☐No

Why?

D) I believe that my child's academic performance related to others in his/her age is:

☐Low ☐Good ☐high ☐I prefer not to declare

E) I believe that my child's social skills are considered:

☐Very low (Isolated) ☐Low (shy) ☐Good (social) ☐Very good (very friendly)

Thank you for completing this questionnaire

Post- Interview (short talks)

(For participants)

There will be only one interview with each participant after the intervention. Simple language will be used with those young children. It will be more like a short chat than an interview. Researcher will ask them about their interaction with the chatting application (table1), then write down their responses. The phycology specialist will be present in the interview. Our purpose is to evaluate the usability of the tool and children satisfaction.

Table 1. Participants post-intervention interview questions

Usability Quality component	**Interview Question**
Learnable	Was it easy to use Chit-Chat application in the first time you encounter the design? Was it easy to know if the chat is activated or not? Was it easy to know your score, and your friends' scores? Was it easy to post text? Or Emoji? Was it easy to change your avatar?
Memorable	The next day of intervention, did you remember how and from where you could: Change your avatar? Post a text or emoji? Check your score? And your friends score? Can tell if chat is activated or not?
Error rate	How many errors did you make when using Chit-Chat? What were they?
Satisfactory	How pleasant was using Chit-Chat tool? Did you like the pirate theme design and colours? Did you like the avatar pirates characters?

Information Sheet for Psychology Specialist
(school staff member)

Study on the effects of an online collaborative experience on the performance of children with Attention Deficit Hyperactivity Disorder while playing educational games

Introduction: My name is Mrs Doaa Sinnari. I am a PhD student at the University of Surrey. I invite you to take part in my project. This sheet tells you why the research is being done and what it will involve. Please read the information carefully and discuss it with others if you wish. If anything is not clear, you can contact me for more information. Take time to decide whether you wish to take part or not. This study has been given a favourable ethical opinion by the University Ethics Committee.

What is the purpose of the study? The purpose is to find out about whether using a chat feature along with an educational e-game, ACTIVATE, will help children with Attention Deficit and Hyperactivity Disorder to be more collaborative, motivated to perform better and whether it could enhance their social skills.

Why have I been invited to take part in the study? Children with ADHD, from your school, is taking part of this study. We need you to help maintain organization among them and help with interpreting some observed behaviour during the intervention sessions.

Do I have to take part? No, you do not have to participate in the study. It is up to you to decide whether to participate or not. Commonly, this will take place in a classroom after the school day, will attend all evaluation sessions as well as the researcher. If you do decide to take part in the study, you will be asked to sign a consent form. Participation is voluntary. You should read this information sheet and if you have any questions you could contact the researcher.

What is I am going to do? If you approved to be part of this evaluation, you will be asked to attend four sessions only (from Mon 16th April until Thurs 19th April), 35 minutes each, after a school day. children will be given an iPad and ear piece. Basically, they will be playing an educational mini game, ACTIVATE, for five minutes, then access a chatting panel to chat with the participating children in the evaluation for about five minutes. The session will be involving 4 mini games and three chatting sub-session. The chatting panel will be a private closed- community designed for children with ADHD, the participating children will be the only member in the chat. Researcher will be writing observational notes about children behaviour while interacting with the application, she may ask for interpretation of some children behaviour. You can help maintaining their organization, and respond to any behaviour impulsiveness.

ACTIVATE games are brain-training exercises for children with ADHD assumed to enhance and develop their learning skills in classroom settings. These games train

the student's ability to move between different tasks, remember sequences, classify items, and reinforce thinking strategies. The games' theme is about being in an island that been discovered by Captain Blue feather and his crew, the student must help them complete levels and collect scores. The Captain introduces each game and gives audio instructions, to help students to understand their tasks. These tasks range from feeding the crew, categorizing items, helping animals and more. For more details about ACTIVATE please visit https://www.c8sciences.com/how-it-works.
After completing four sessions, children will be interviewed by the researcher, individually, about whether they like chatting with friends using the chatting application or not, and their overall opinion on the chat application. You will be asked to attend the interview, children will be more comfortable and honest if they see one of their teachers. The interview will be registered (written) for research purposes, all project data will be held for at least 6 years and all research data for at least 10 years in accordance with University policy and that your child personal data is held and processed in the strictest confidence, and in accordance with the current UK data protection regulations. The children will be subject to existing school behavioural and safeguarding policies at all times.

What are the good things about taking part? You will have experience about the effect of some existing educational and engaging tools on children with ADHD. In addition, we will be benefiting from your valuable experience and input in this study.

What if I don't feel comfortable about taking part? If you feel uncomfortable about attend these sessions at any point, you can contact the researcher to solve the issue, or withdraw from the study at any time.

What happens at the end of the research? Results will be written up to contribute towards my research and may be published and/or presented at a conference. Your contribution in this study will be acknowledge in the research.

What if there is a problem? For any complaint or concern about any aspect during the study please contact your Head teacher of school: [*Head of school email*]. For more information you can contact the research team through email address. Researcher: Mrs Doaa Sinnari ds00215@surrey.ac.uk , Supervisor of the project: Prof Paul Krause p.krause@surrey.ac.uk

Thank you for reading this.

Consent Form for Psychology specialist

[Study on the effects of an online collaborative experience on the performance of children with Attention Deficit Hyperactivity Disorder while playing educational games**]**

Please initial each box

- I have read and understood the Information Sheet provided (version 4, 17 April 2018). I have been given a full explanation by the investigators of the nature, purpose, location and likely duration of the study, and of what I will be expected to do. ☐
- I have been given the opportunity to ask questions on all aspects of the study and have understood the advice and information given as a result. ☐
- I agree for my interpretation and explanations of children behaviour to be used for this study / future research that will have received all relevant legal, professional and ethical approvals. ☐
- I will keep confidentiality about data, information, participants I came across in this study, and I will not disclose any related information about them. ☐
- I agree for the researchers to contact me through school, after intervention, to inquiry about certain event or behaviour happened during intervention. ☐
- I understand that I am free to withdraw from the study at any time without needing to justify my decision, without prejudice and without my legal rights and job position being affected. ☐
- I confirm that I have read and understood the above and freely consent myself to participate in this study. I have been given adequate time to consider my participation. ☐

Name of participant ....

Signed ....

Date ....

Name of researcher/ MRS DOAA SINNARI
Signed
Date