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Involving Children in the Design Process of VR Games Aimed at Improving Attention in Children With ADHD

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Abstract

Attention Deficit Hyperactivity Disorder (ADHD) is a developmental disorder which affects the ability to direct attention, and mediate impulsive behaviour. Children with ADHD tend to perform worse academically than their peers due to challenges focusing within a traditional classroom. Research suggests video games aimed at training attention can improve these children's performance, and more recently, Virtual Reality (VR) applications are being studied as they allow for precise control of potentially distracting elements in such a game. This research looks at how children can be involved in the design process of such a game, through co-design.

A class of children took part in design activities to generate ideas for a VR game, which were used in conjunction with existing design recommendations for children with ADHD to create a prototype game designed to improve attention in the classroom. The game is a rhythm game, designed to train children's ability to direct and sustain their attention. The game's design and usability were evaluated on a return visit to the classroom. Overall, the design process succeeded in producing a game which the children enjoyed playing, and many were proud to see their ideas in the prototype.

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List of Abbreviations

ADHD	**A**ttention **D**eficit **H**yperactivity **D**isorder
CAI	**C**omputer **A**ided **I**nstruction
CPT	**C**ontinuous **P**erformance **T**ask
DSM	**D**iagnostic and **S**tatistical **M**anual of Mental Disorders
EF	**E**xecutive **F**unction(s)
HMD	**H**ead **M**ounted **D**isplay
MLE	**M**odern **L**earning **E**nvironment
VR	**V**irtual **R**eality

For Christopher

Chapter 1

Introduction

Attention Deficit Hyperactivity Disorder (ADHD) is a neurodevelopmental disorder with wide-ranging symptoms, typically involving problems managing attention and impulses, and a tendency to be hyperactive [1]. Typically, symptoms arise in childhood where they can often impact a child's performance in the classroom [2]. This is because traditional lessons tend to require sustained attention and an ability to moderate behaviour, skills which children with ADHD often struggle with.

While chronic, symptoms of ADHD can be managed. Approaches vary between individuals, depending on severity, and which symptoms are present [3]. Commonly, treatments are introduced in the school setting, where ADHD can cause significant learning difficulties [4]. Such interventions often involve [5]:

- Training teachers to plan lessons around the particular difficulties which children with ADHD face,
- Encouraging peers to support and tutor one another,
- Using computer-assisted tools designed to present information and goals in an engaging form for children with ADHD, or to teach children methods of self-monitoring behaviour.

It is this last intervention which this thesis explores. Specifically, the role that serious, immersive *games* can play, and how children can be involved in the design process of these games. Co-design of technologies for children is a relatively recent approach to design, and there are gaps in existing research. In particular, Virtual Reality (VR) experiences are not well studied, nor are technologies designed for children with specific learning requirements, like ADHD. The present study explores ways to approach the co-design of VR games that suit the learning needs and preferences of children with ADHD, involving children themselves in the design process.

The role of games in the treatment of children with ADHD has been a focus of study for some time, and they have been shown to be an effective tool for some children [6]. These games often take the form of cognitive training exercises, where the game is aimed at improving a skill that children with ADHD typically lack, such as sustained attention. More recently, studies of *VR* games have shown promising results [7].

The term VR has been (and still is) used to describe a wide variety of different technologies. Outside of the realm of science fiction, the first serious attempt to use computers to create a virtual environment which users can interact with is Ivan Sutherland's *Sword of Damocles* [8]. This device provided users with a stereoscopic view of a simple virtual environment rendered by a computer and displayed through two CRT screens directed at each eye [9]. It mechanically tracked the rotation and position of the user's head in space and updated the display accordingly. While hardware and software have since improved dramatically, these two aspects (stereoscopic rendering and head-tracking) remain hallmarks of modern VR Head Mounted Displays (HMDs).

Recent developments in VR technology mean that it is cheaper and significantly easier to develop for [10]. VR presents interesting opportunities for individuals with ADHD, as it provides the ability to control precisely what the user can see and hear, and also monitor where the user's attention is directed [11]. While there are numerous studies exploring the place VR technology can play in the assessment, diagnosis and rehabilitation of ADHD, there are relatively few which explore the role that VR *games* could play, and how these might be integrated into the classroom, with children involved in the design process.

This research has received ethical approval from the University of Canterbury's Human Research Ethics Committee, evidence of which can be found in Appendix A.

Chapter 2

Attention Deficit Hyperactivity Disorder

2.1 Causes

Like most mental disorders, ADHD has a variety of causes (both genetic and environmental) which are not fully understood, due to the complexity of the brain as an organ [12]. It remains an active area of research, much of which is well beyond the scope of this research [13]. However, it is important to understand the fundamentals of the disorder in order to critically examine existing technological approaches to ADHD management, and to develop something new. Being able to predict how children with ADHD will interact with common game elements and mechanics (particularly those unique to VR games) will help to determine which are likely to make a successful game.

ADHD is classified in the *Diagnostic and Statistical Manual of Mental Disorders* (DSM) as a neurodevelopmental disorder [14], a class of disorders which are caused by some kind of malformation of the brain during its development. Current research indicates that ADHD is highly heritable, and that environmental causes tend to affect individuals who are already genetically predisposed to developing ADHD at a much higher rate [12]. These environmental causes include significant brain injuries, trauma and infection.

Since 1998, MRI scans have been able to reveal physical differences in the brains of children with ADHD compared to controls [15]. A 2007 study indicates that this difference is due to a delay in the development of the cerebrum, particularly "…in prefrontal regions important for control of cognitive processes including attention and motor planning" [16, p. 1]. Some of these cognitive processes are known collectively as Executive Functions (EF).

Executive functions are a set of cognitive processes involved in activities such as behaviour-management, planning, and control of attention [17]. Broadly, they are the set of higher-level mental processes which mediate what the brain is focusing on, what information it is gathering and what it needs to retrieve, what it should do next in order to achieve its goals, and how it should manage its behaviour. Because these are the skills which are impaired most in individuals with ADHD, executive *dys*function is "...regarded by many in the field as a defining characteristic of ADHD..."[1] [17, p. 256].

2.1.1 Prevalence

Rates of ADHD in children throughout the world varies, depending on medical definitions of the disorder, access to healthcare services (in order to actually *get* a diagnosis), socioeconomic status, and rates of comorbidities [1]. The general consensus of experts in the field put the figure around 5.0%.

Even within the New Zealand context, studies with different methodologies have produced significantly different numbers for the national rate of ADHD. A 1978 study (which predates the formalisation of ADHD) put the rate of "hyperactivity" amongst New Zealand children (6 to 12-years-old) at 2.07% for boys and 1.58% for girls [19]. Then in 1987, a representative study based on DSM-III criteria [20] for ADHD diagnosis put the figure at 6.7% [21]. More recently, guidelines from the New Zealand Ministry of Health report a figure of 5% for children under 18-years-old, however it notes that this is a "rough guide" [22, p. 6].

Teacher-student ratios in New Zealand primary school range from 1:15 to 1:29 [23]. Assuming a 5% rate of ADHD among children, an average classroom can expect to include at least one or two students with ADHD. This suggests teachers should be well supported to accommodate these students, which is explored more in section 2.5.

Regardless of an ADHD diagnosis, children who pay attention in the classroom are more likely to have better learning outcomes. A 2007 study [24] found that the distractibility among adolescents increased as they spent more time on instant messaging applications. Since then, social media use has become significantly more widespread, and its effect on our attention-spans is an active area of research. A more recent study [25] indicates that problematic social media use can make ADHD symptoms worse. This could mean that children who otherwise would not get an ADHD diagnosis are meeting the criteria, because of their use of social media.

There are a number of things which can affect a child's ability to pay attention in the classroom, so while this research investigates designing technologies for children with ADHD, there is reason to believe that such interventions will be beneficial for children with only mild symptoms, or those struggling to pay attention for other reasons.

2.2 Symptoms and Impairments

Published by the American Psychological Association, the DSM-5 [14] provides "...some of the most rigorous and empirically derived criteria ever available in the history of

[1] There is controversy surrounding this claim. Critics point to studies which show while many individuals with ADHD score poorly on tests of Executive Functions, perhaps more score relatively well. Supporters of the claim would argue that existing tests of EF have not been shown to be effective at measuring impairment [18].

ADHD." [1, p. 54]. The diagnostic criteria can be found in full in Appendix B, but are summarised here.

Symptoms of ADHD generally fall under two primary symptoms, and individuals typically display aspects of either, or both, to varying degrees. They are:

- **Inattention** – A tendency to lose train of thought, become easily distracted, make mistakes, and overlook important details.
- **Hyperactivity and Impulsivity** – A tendency to fidget and move around when seated, be uncomfortable staying seated for long periods, talk loudly and excessively, and not wait their turn.

The DSM-5 lists nine symptoms under each primary symptom, with the requirement that an individual displays evidence of at least six of these, and that they persist over a six month period "...to a degree that is inconsistent with developmental level and that negatively impacts directly on social and academic/occupational activities." [14, p. 59]. Additionally, symptoms should have been present before an individual is 12-years-old, reflecting that ADHD arises during brain development. The symptoms should not be isolated to a single setting (i.e. just in the classroom) but be common throughout an individuals day-to-day activities.

These criteria clearly emphasise that ADHD is a disorder which arises in childhood, and disrupts academic and social abilities of children. While these symptoms often persist into adolescence and adulthood, it is often the knock-on effects of poor performance at school, and in social lives, that cause the greatest harm later in life [26].

The inattention dimension of ADHD is likely an effect of EF impairment causing an individual to have difficulty in *directing* their attention. While not part of the DSM-5 diagnostic criteria, some individuals also experience cases of so-called *hyperfocus*, which can be described as "...an intense state of sustained or selective attention" [27, p. 9]. The concept of hyperfocus is a relatively recent development, especially compared to ADHD research generally. There is limited experimental research into the relationship between hyperfocus and ADHD, but it is a frequently reported positive symptom [28].

Children of different genders[2] experience ADHD differently and at different rates [29]. Historically, ADHD was thought to be a disorder which only affected boys. While it is true that ADHD seems to be present more often in males than in females, the ratio was once estimated at 9:1 [30], where more recent evidence shows it is closer to 2:1 [31]. Even after the existence of ADHD in girls was established, an effort was made to show that they experienced a different set of symptoms. The evidence for

[2] "There is debate about whether differences between males and females should be termed "sex differences" (in which "sex" refers to biological males and biological females) or "gender differences" (in which "gender" refers to a broader pattern of gendered expectations and roles, over and above biological sex)." [29, p. 247]

this is not strong, as reflected in the DSM, which recommends the same diagnostic criteria for both males and females.

Boys (with or without ADHD) tend to be more at risk of externalising disorders (disorders which affect outward behaviour) than girls, which means they are referred to clinicians more often for diagnosis. Girls on the other hand are more at risk of internalising disorders (for example anxiety and depression), which is harder to observe. So while ADHD may cause the same symptoms in both girls and boys, they have different rates of comorbidities, and girls are less likely to referred for diagnosis [29].

Unfortunately, the historic under-representation of women and girls in ADHD diagnoses is mirrored in video game design. In 1999 a CEO of an educational games company revealed "…their products are designed exclusively for boys" [32, p. 12]. This is often cited as a reason that video games remain a male-dominated medium: males are more likely to design games which appeal to other males. This, paired with the gender differences in clinical settings, highlights the need to be aware of gender differences when designing games for children.

2.3 Diagnosis and Management

New Zealand health practitioners follow the DSM criteria when diagnosing children with ADHD [22]. Assessment takes the form of interviews with the child, their parent or guardian and, if the child is in formal education, their teachers. Apart from looking for evidence of the behaviours listed in the DSM, clinicians will often also look into family history, as ADHD is most often genetically caused [12]. Observations of the child in different environments may also be undertaken, if feasible.

ADHD is often comorbid with other disorders (such as mood disregulation and bipolar disorder), so clinicians will also look out for symptoms of these [33]. Indeed, many symptoms overlap with other disorders so it is important that other possibilities are considered in order to reduce the risk of misdiagnosis.

There is no cure for ADHD and the disorder is usually chronic [34]. However, there are a number of different approaches to managing the disorder, often targeted to a particular individual's symptoms.

Medications have been shown to alleviate some symptoms of ADHD in children [35]. The most commonly prescribed are stimulants, namely methylphenidate (under the brand name Ritalin) and amphetamines. Their mechanism of action is complex and beyond the scope of this research[3], but in general they are effective at reducing symptoms of inattention, impulsive behaviour and hyperactivity. Mild short-term side effects can occur but are usually manageable. These include "…insomnia, decreased appetite, weight loss, headache, stomachache, and [increased] heart rate and blood pressure" [35, p. 672].

[3]Details can be found in Connor, 2015 [35]

While stimulants have been shown to alleviate symptoms of ADHD in most cases without significant side-effects, there are a number of reasons why they may not be prescribed, even if a clinician thinks it appropriate. Stimulant medication is prone to abuse and should not be prescribed in cases where clinicians believe it likely they may be used inappropriately by friends or family of the person diagnosed with ADHD [35]. This perception of abuse, or concerns of side effects may also be reasons for a parent to deny a prescription for their child [36]. In any case, medication is never totally effective, nor appropriate for every child with ADHD, so other management techniques are almost always used in conjunction, or instead of medication [3].

A big part of many children's ADHD management is to inform their parents and families about the disorder, and to offer alternative methods of behavioural management suited to their affected child [34]. Children with ADHD often do not respond to conventional disciplinary strategies (for example time-out). This can lead to parents using harsher punitive measures on their affected children as stress levels rise (for example yelling), which in turn can lead to more misbehaviour and disobedience from the child. Evidence suggests that such behavioural parent training (adjusting home rules, commands, rewards and praise) are effective interventions [37].

There is growing research around so-called Executive Function Training in children with ADHD [38]. Described in section 2.1, ADHD is most likely caused by a dysfunction of EF, so EF training attempts to target the underlying causes of the disorder in order to manage symptoms. The evidence of the long-term benefits of EF training is not strong, but it can produce acute benefits to children at the time of treatment [39]. This suggests that benefits of such interventions are not generalisable, but may be appropriate for those situations in which the disorder presents the biggest impediments. For example, EF training could be delivered in conjunction with formal education, to improve the child's ability to concentrate on the lesson.

2.4 Technological Approaches to ADHD

In 1956 a team of psychologists developed a tool to measure the impact of brain damage on an individual's sustained attention [40]. Called the Continuous Performance Test (CPT), participants were sat in front of a device which sequentially lit up a single letter out of a series. Participants had to keep track of the last few letters they had seen, and react when the next letter matched some predetermined criteria. Experiments with subjects with ADHD show that they tended to perform worse on these tests than the general population [41], and subsequent versions of the test have been developed specifically to aid clinicians in the diagnosis of ADHD [42].

The simple nature of these tests, including the presentation of visual stimulus and interaction from participants, make computers the ideal delivery method [43]. CPT tests are almost always delivered with a computer and increasingly, more innovative technologies (such as VR) are being used [11]. These approaches are explored more in Chapter 4.

In addition to diagnosis, there are a number of technological approaches to ADHD *management*. One kind of ADHD management is called behaviour modification, and is generally designed to reinforce attentive behaviour by rewarding it in some way. A 1982 study [44] found that such interventions can induce a higher improvement in attentive behaviour than medication (in this case Ritalin). The researchers warn against generalising the results as only two children were involved in the study, and it is not clear that the intervention has lasting improvements in attentive behaviour. DuPaul et al. [45] investigated the effectiveness of a system where a teacher could reward or deduct points on an electronic device on a student's desk, based on their behaviour. These points are displayed to the child, and could be exchanged for rewards in the classroom such as free-time activities. This kind of point-scoring activity can be viewed as a kind of 'gamification' of ADHD interventions, similar to gaining points in a video game. The study found that as well as improving the subjects' attention, the intervention also improved their behavioural control, although researchers note that when participants were distracted, they were more often distracted by the device itself, than by other students in the class.

In general, a technological approach to diagnosis and behaviour modification is effective because it allows "…repeated trials, offers privacy, and organises content into smaller chunks of information" [43, p. 224-225], and can provide clear instructions, and real-time feedback. For a detailed overview, Cibrian et al. [46] describe the state of research into technologies for ADHD. They conclude that "…behavioural interventions should be co-designed with clinicians, caregivers, and individuals with ADHD." [46, p. 64]. They also emphasise the need for exploration of novel technologies like VR, and state that "More work is needed to explore how to co-design interventions using virtual reality environments…" [46, p. 64]. Chapters 3 and 4 provide and overview of co-design, and its application to designing technologies for ADHD, respectively.

As with EF training generally (described above), there is weak clinical evidence that computer-based cognitive training for children with ADHD is an effective intervention [47]. Studies note that there is room for further research into both the content and implementation of such approaches. The existing approaches are covered in detail in Chapter 4.

2.5 ADHD in the Classroom

As previously described, some of the most significant difficulties faced by individuals with ADHD are caused not by the disorder itself, but an environment unsuited to dealing with its major symptoms. For example, traditional learning environments (from primary school through to tertiary education) are designed around expectations of sustained attention and concentration, which children with ADHD find difficult. Research indicates that academic achievement in children with ADHD is significantly lower than in their peers of the same age [48]. It is worth reiterating that ADHD is not an intellectual disorder, and that this disparity in achievement is primarily due to an approach to education unsuited to the needs of affected children.

Some classroom interventions aim to improve the structure of the room and daily routine to reduce possible distractions and keep students on task [4]. These include:

- Keeping children with ADHD close to the teacher, and away from other students,
- Ensuring daily routines are predictable, with a schedule placed somewhere accessible,
- Using visual aids like posters to reinforce class rules.

These suggestions are well-suited to typical classrooms of older students where the lessons are more structured and days more predictable. New Zealand primary schools however are increasingly embracing so-called Modern Learning Environments (MLEs)[4] [49]. These classrooms tend to be larger, open-plan rooms which can support multiple classes and teachers. Children are generally not assigned desks and move about the space depending on the activity they are undertaking. The furniture as well is designed to be moved around to suit the needs of the lesson. This clearly contradicts the recommendations listed above and children with ADHD risk being overlooked in these new environments.

Apart from building design, MLEs are also designed to incorporate modern technologies into the curriculum [49]. Computer-assisted instruction (CAI) is the delivery of lessons via computers and other digital technologies in order to support children with specific learning needs, and to free up teacher time. Such technologies are often suited to children with ADHD as they can provide immediate feedback to students, clearly articulate goals and objectives, and include aspects of gamification in order to motivate the user [4]. Research indicates that children with ADHD spend more time on-task and are more likely to complete their work when it is delivered digitally [5].

[4]Such classroom designs are elsewhere called "...innovative learning environments, flexible learning spaces, physical learning space, 21st [century] learning space, modern learning environments and contemporary learning environments" [49, p. 92]. Each refers to the same, or similar concepts

Chapter 3

Co-design

While the role of video games in the treatment of ADHD is relatively well studied, the role children can play in the design of these games remains largely unexplored, particularly when it comes to VR games [46].

Originating in Europe, co-design (sometimes Participatory Design) is a design philosophy which aims to involve end-users in as much of the the design process of a product or system as is practical [50]. The extent of the involvement varies from requirements-gathering activities through (for example) surveys, up to actually having end-users on the design team contributing ideas, developing prototypes and evaluating solutions. The idea came out of a desire to give workers a voice in the way their workplace was designed, as they are experts in what they require to work efficiently [51]. While the philosophy has since been used in areas such as government policy [52] and urban design [53], it is perhaps most widely applied in software and digital technology design [50].

Within software design research, co-design falls under user-centered design, a more general philosophy which encourages designers to be constantly aware of the needs of end-users in some way during the design process [54]. Again, user involvement within user-centered design falls on a spectrum. Users may only be involved as inspiration for personas, where hypothetical end-users are constructed from interviews or observations of real users, against which design ideas are evaluated. For example, at all stages of the design process design decisions would need to be justified based on how the hypothetical users would benefit from the design, or how it helps them to meet their requirements from the software [55]. At the other end of the spectrum, users *make* the design decisions themselves, and in some cases are the lead developer of the software itself [56].

3.1 Motivations for Co-design

Co-design often incurs significant costs, in terms of both time and resources [57], and so needs to be justified by an improvement in the outcomes of the design process. A 2011 study [58] reviewed three instances of co-design undertaken by the authors, and identified the benefits it brought about, including:

- **Better ideas** – The authors claim that involving users results in ideas with "...high originality and user value" [58, p. 58].
- **Improved cooperation** – By working with non-experts, designers improved their skills working with individuals different disciplines.
- **More successful outcomes** – Co-design reduced the instances of the end-product failing.
- **Higher Cohesion** – The design-process resulted in products which more closely matched the expectations of end-users.

While co-design is becoming an increasingly recommended approach to technology design, much of the motivations for its use rely on anecdotal evidence (as above), and rarely involve formal evaluation [59].

3.2 Barriers to Co-design

While co-design can produce superior results to more traditional design methodologies, there are some instances where it may not be feasible or appropriate. For smaller projects, or projects where resources such as personnel and time are constrained, co-design could hinder its success.

Designing with children comes with its own specific considerations. As children are unable to consent to participating in research like co-design workshops, parents must be contacted and informed about the process in order to provide consent on their children's behalf. Further, most designers recommend gaining *assent* from the children themselves[1] before undertaking any design activities [60].

3.3 Co-design with children

As children are more and more the target audience for new technologies, specific co-design techniques have been developed for a younger demographic. Fails et al. [61] provides a description of a variety of such techniques, as well as how and when they can be applied. Fails also provides a motivation for co-designing with children: "...our belief is that co-design methods not only produce creative, varied, and unique technologies that would not exist without children's participation in the design process, but also that the design process empowers children" [61, p. 116]. When designing digital experiences for children disadvantaged by an ADHD diagnosis, this empowerment is even more important.

Because of a tendency for ADHD to affect competence within a classroom context, children with ADHD can have "...lower perceptions of self-worth than [do] their non-ADHD peers, specifically in the areas of scholastic competence, social acceptance, and

[1] Indeed, this is a requirement set by the University of Canterbury's Human Research Ethics Committee.

behavioural conduct." [62]. Guha [63] argues that by involving children in the design process of technology they will use for education, they can often feel proud, and want to share their work with friends. There is also evidence that treating children as design partners can boost their confidence socially and academically [64].

While co-designing digital experiences with children can lead to more suitable outcomes, it is important to look at the process through an ethical lens, and consider whether the children are benefiting from their participation in the design process, or if the are just being used to generate design ideas for researchers. Read et al. [65] suggest a tool which encourages researchers to "…critically consider the reasons for involving children in design projects"[65, p. 187], and to ensure that children are properly informed about why they are being asked to participate. Using the tool, researchers answer a set of questions with an 'excuse' and then 'honestly' about why they are looking to engage in co-design with children. The excuses reveal the 'noble' or 'worthy' intentions of the research (e.g. "we want the children to get hands on experience of the game design process", or "we think children are best placed to design solutions for children"), and the honest answers reveal the more pragmatic reasons for undertaking co-design research with children (e.g. "these children were approached because of an existing relationship with the university" or "this research is required for a Masters project"). While this tool was not used for this research, it provided a basis for critically examining ethical aspects for undertaking this kind of research.

Another study [66] considers the extent to which children find a level of enjoyment in participating in the design process. The researchers argue that children find "overcoming challenges, working towards finalised objects, experimenting, and interacting with others" [66, p. 401] fun, and incorporating these aspects into co-design sessions can ensure that the children also get something out of the experience.

Chapter 4

Related Work

This chapter reviews some of the existing research into technological interventions for children with ADHD (in particular virtual reality and video games), and approaches to co-designing these and similar experiences with children.

4.1 Interventions for Children with ADHD

4.1.1 Video Games

It has been understood for a while that children with ADHD perform differently to unaffected children when playing video games. A 1990 study by Mitchell et al. [67] measured the reaction times and frequency of errors children committed while playing a video game. The games in the study were very simple: the first was a simple test of reaction time where participants scored more points for reacting to on-screen stimulus faster. They found that children with ADHD (specifically of the hyperactive subtype) reacted slower to stimulus and were more likely to make errors during gameplay. The researchers support the view that video games can play a part in ADHD diagnosis as a screening test before a more clinical approach is taken.

Video games as computer-assisted instruction (CAI) for children with ADHD have been studied since the early '90s [68]. Ford, Poe and Cox [68] compared children's behaviour when performing computer-based learning activities in game and non-game formats. They found that participants displayed fewer instances of inattentive behaviour when doing game-based tasks rather than basic tutorials. The study did not investigate whether participants experienced improved educational outcomes from playing the games over the other tasks.

This work by Ford et al. was expanded by Ota and DuPaul in a 2002 study [69]. This study investigated whether a commercially available maths game improved the academic performance of children with ADHD. The game was designed for children aged 9 to 11, but was not targetted specifically towards children with ADHD. Video games were investigated as they are effective at meeting the needs of ADHD children, such as:

(a) allowing learners to set instructional pace;

(b) continuously prompting for a response; and

(c) providing frequent and immediate feedback about the quality of the player's performance [69, p. 243].

This study again found that participants were engaged and on-task for longer when playing the video game, than undertaking traditional "seatwork" conditions. The children also improved their academic scores. The authors remark that the results may not be particularly generalisable as the participants were enrolled in a private school specifically for children with ADHD, which had small class sizes (6 to 10). Additionally, the sample size ($n = 3$) is very small and the study is limited further by only involving boys. The authors recommend that future studies investigate performance in other academic areas, and over a longer period of time.

More recently, a study by Bul et al. [70] developed a game for treating symptoms of ADHD. The team developing the game came from a variety of disciplines (including both clinical and game design experts) to ensure it was grounded in modern theories of learning and of ADHD. This study differs from those already mentioned as rather than being used to find differences between children with and without ADHD, it is designed to treat the symptoms of ADHD by gamifying cognitive training.

The game created by researchers is called Plan-It Commander, a desktop game where players take the role of "…a space captain undertaking missions assigned by his or her mentor who guides the player …". The game consists of 10 missions and more side missions, made up of three different types of minigame aimed to achieve three distinct learning goals. The proposed learning goals were to train time management, which were set in close collaboration with healthcare professionals and a community board of parents.

Figure 4.1 shows the iterative design process used to develop Plan-It Commander. This process is clearly an example of co-design as domain experts were involved in defining learning goals and brainstorming sessions. End-users are also involved in the usability tests and pilot study, although there is room for even more involvement of end-users by having them take part in the design itself, rather than just the evaluation stage. Examples of co-designing with children are given in section 4.2.

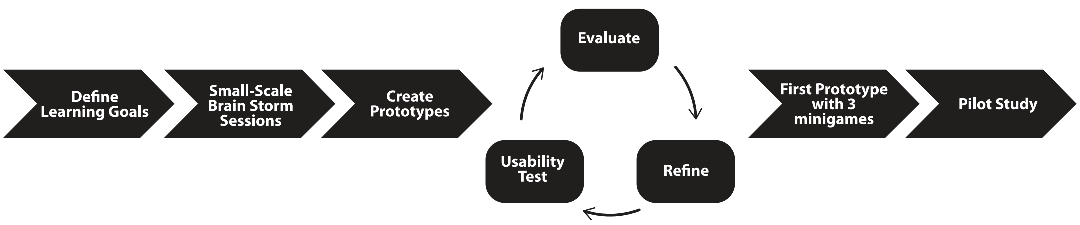


FIGURE 4.1: Design process for Plan-It Commander [70, p. 3]

Mohammadhasani et al. [71] found that including a 'pedagogical agent' in CAI improved the learning outcomes in children with ADHD. A pedagogical agent here means a character which is included within the game environment who provides instructions and helps out when players get stuck. In order to include a character that is most appropriate, the researchers presented children with different designs so they could choose the agent they were most comfortable with. Apart from improving learning outcomes, the researchers found that the presence of the pedagogical agent made them feel more comfortable, and helped maintain the children's attention.

A further study [72] found that an 'interactive avatar' within a game designed for children with ADHD is superior at improving a player's performance on a given cognitive test administered after playing the game. By interactive, they refer to an in-game character which not only instructs the player, but provides feedback on the player's progress, and how well they are paying attention within the game.

More generally, Mayer[73] suggests a facilitating pedagogical agent should use a "conversational style", "use a human voice", and use "humanlike gestures" [73, p. 63]. These suggestions are made for any computer-based learning game, not specifically targeted towards children with ADHD.

Design Guidelines

A number of studies have produced design guidelines specifically for digital interventions for children with ADHD. McKnight [74] surveyed the literature and suggests 15 recommendations for technology design. These guidelines were not specifically produced for game design. Some of the guidelines were taken from studies not making recommendations for digital technologies, and are more generally aimed at many types of ADHD intervention. McKnight however makes "…no strong claims as to their effectiveness …" [74, p. 2], however it seems likely that the strength of recommendations still apply in a digital setting. Indeed, many of the guidelines are very similar to established software usability guidelines (for example Nielson's famous 10 Usability Heuristics [75, pp. 3-4]) and some of McKnight's recommendations are made for all users. The guidelines relevant to the present research are as follows (bold indicates guidelines which are specific to those with ADHD) [74]:

1. Ensure layout is neat and uncluttered.
2. Provide a calm environment.
3. **Provide a high-reinforcement environment.**
4. Organise items in an orderly way.
5. Distinguish important information with weight, colour.
6. Use large font and a clear sans-serif typeface.
7. Keep a marker of the child's progress.
8. Use brief and clear instructions.
9. **Have an enclosed, soundproof workstation with few distractions.**
10. **Minimise surprises.**

11. **Maintain eye contact.**

As mentioned, these guidelines were not formulated with games in mind, but it is clear they can easily be applied to video games, and virtual reality experiences. McKnight also points out that some of these recommendations may conflict with each other, or with the experience being developed. For example, a high-reinforcement environment may be patronising for some children.

A further study by Silva et al. [76] sets out 11 guidelines, specifically for video games for children with ADHD. These guidelines were adapted from existing usability literature (including Nielson [75]) and strategies for teaching children with ADHD. There is some overlap with the recommendations above and again, some recommendations are appropriate for general users. The guidelines are given below [76, pp. 38-43]. Again, guidelines specific for ADHD are in bold and recommendations duplicated from above are identified.

1. Simple interactivity (see 1. above).
2. **Recurring awards and positive feedback (see 3. above).**
3. **Eliminate distracting elements.**
4. Emphasise relevant elements (see 5. above).
5. Make levels flexible.
6. **Make short levels with simple goals.**
7. Develop a multiplayer option.
8. Allow unlimited play time.
9. **Prompt for confirmation before action taken.**
10. Make graphics coherent (see 1, 10 above).
11. Present an exciting graphical story.

The researchers also point out that by taking into account design requirements for children with ADHD, a game can be made more accessible to children generally, but specifically those with other learning disorders.

These guidelines inform a large part of the design process described in Section 6.2.4, where they are critically examined against the design ideas formulated in the co-design sessions.

4.1.2 Virtual Reality

As early as 2000, VR technologies have been developed for children with ADHD. Rizzo et al. [77] created a 'Virtual classroom' designed for "…the study, assessment, and possible rehabilitation of attention disorders …" [77, p. 483]. The Virtual Classroom system is designed for a head mounted display (HMD), which the researchers suggest can simulate a real-world environment and improve on the "contrived" testing environment traditionally used for screening for disorders such as ADHD. They also state that the ability to create controlled environments and precisely manipulate distracting stimuli make HMDs well suited for for such applications. As its name suggests, the Virtual Classroom simulates a traditional classroom, in which a child can undertake a variety of tasks. The study then outlines an experimental procedure in which children are given a CPT-like test to assess for ADHD. The researchers also predict that VR technology will rapidly become cheaper and more powerful, which has certainly been the case over the last two decades [10]. The study also suggests that interventions should be designed to be programmable not only by those proficient in technology, but clinical experts and educators. This is to allow interventions to be tailored according to the needs of the child using the system. A 2004 article [78] describes a clinical trial of the system, which indicates that children with ADHD who used the system had slower reaction times, made more errors and exhibited higher levels of motor activity than undiagnosed children.

These studies establish a connection between attention problems in the real world and in VR, suggesting a use case for the assessment of ADHD. The studies use VR systems with head mounted displays and controllers which make it easy to track a person's eye and hand movement, and to precisely control both the audio and visual stimulus they receive. In the years since, a large number of further studies into the use of VR for children with ADHD have been undertaken. A 2017 review [11] examined 20 studies, including those above. Of these, seven are aimed at treating symptoms of ADHD, and 15 investigated VR's role in assessing and diagnosing the disorder[1]. Only two treatments were VR games.

4.1.3 Music Therapy

There are many interventions for ADHD considered alternative or complementary [36]. These include interventions which have not yet been clinically studied, and those which may not generalise to a wider ADHD population. One such intervention is music therapy, a term which covers a range of approaches and has been applied to a number of disorders. One such intervention for ADHD is the interactive metronome, a suite of games in which a child is prompted to react in time with music in order to progress in the game. A 2001 study [79] examined the effect of using the interactive metronome, compared to a traditional video game within a group of 56 boys with ADHD. The study found that the children who used the interactive metronome

[1] Some studies examined both treatment and assessment interventions

had significantly reduced levels of parent-reported aggressive behaviour, as well as significantly higher improvement in "...areas of attention, motor control, language processing, [and] reading" [79, p. 160] than those that received the traditional video game treatment. These findings are contradicted by a later study [80] of 12 children who used the interactive metronome over a course of 15 one-hour sessions. The study found "...no significant changes in sustained attention or inhibitory control over inappropriate motor responses after treatment.". Bader and Adesman [36] are critical of these studies for having small sample sizes, or poorly designed experiments which were unblind or partially blind.

Music therapy then is not recommended by clinicians as a treatment for ADHD because robust studies are scarce, or only weakly support it as an intervention. Like many other complementary interventions, it could be used in cases where parents are unwilling to use traditional techniques (such as medication), or where other interventions have not been successful at reducing symptoms.

While often designed for behavioural therapy, rhythm games are a genre in their own right. One of the most popular VR games, Beat Saber [81], involves slicing apart approaching music blocks in time to music. A 2021 study [82] of a training program involving Beat Saber and one other game found that participants scored better than a control group on a CPT test designed to screen individuals for ADHD. This study had a small sample size ($n = 11$) who did not report an ADHD diagnosis, and the program was not designed as an intervention for ADHD.

4.2 Co-designing Games with Children

As explored in Chapter 3, co-designing for and with children is an increasingly common approach to technology design. Khaled and Vasalou [83] present two case studies of co-designing a serious game with children. The game in question aims to teach children about conflict resolution, and effective ways of approaching it.

During the initial part of the design process, three boys aged 10 participated in a design workshop to generate mechanics and narrative for the game. The boys were introduced to the concept of conflict resolution, and asked to reflect on their own experiences of conflict, and whether they managed to effectively resolve it. The children then used storyboarding software to create characters and narratives to explore the concept further. The researchers were aided in the workshop (which lasted four hours) by a design researcher and developmental psychologist.

The researchers then analysed the "novelty and quality" of the design ideas generated using metrics described by Shah et al. [84], and O'Quinn and Besemer [85]. They found that the designs produced were not novel in the context of game design, and that some were lifted directly from the children's experience with online games. The ideas also had little to do with the core concept of the game, conflict resolution. The children were well-versed in common game mechanics (in-game currency, health bars) but failed to connect these to the theme of the game. The researchers conclude that the domain proved too high a barrier for the children to generate meaningful game-design ideas, but that the children had "…high game literacy and enthusiasm for games" [83, p. 10].

The second set of workshops occurred after the researchers had developed a prototype game for the children to show the children. These workshops involved 13 children, including some who had undergone peer-mediation training. Researchers found that having a working prototype provided a useful 'scaffolding' for the children, who came up with more appropriate and novel ideas than the participants of the first workshop did.

The researchers conclude that their approach to co=design was more effective during the intermediate design phase, when they had a working prototype to show the children. They suggest however, that a longer relationship between children and designers allows for more training to give the children expertise in being effective co-designers. They suggest that this will often incur a significant investment of resources that may not be available to many researchers. Finally, they acknowledge that children are increasingly growing up with "ubiquitous access to games" [83, p. 17], giving them significant knowledge of common game mechanics.

A 2019 study [86] explored the development of a rhythm game designed to improve attention and social skills in children with ADHD. The study briefly describes the design process as including brainstorming sessions with with experts, including psychologists, special education teachers and music teachers. The game requires children to rhythmically beat a drum in time to music, based on a visual guide on the computer screen. The researchers say that presenting children with a task that requires sustained attention, and rewarding this behaviour, may reduce symptoms of ADHD.

A pilot study [87] was carried out to investigate the usability of the developed game. Four children (two with ADHD) and two educators were involved. After playing the game, a questionnaire was given to the children asking about their initial impressions of the game, and the level of difficulty they had proceeding through the game. The educators were asked for their initial thoughts of the environment of the game before playing through it themselves. They were then asked for their view of the difficulty of the game, and what improvements might be made. The researchers conclude that the game "…keeps players engaged and bolsters collaboration". The educators were also interested in how the game could be developed further.

Dahlstrom-Hakki et al. [88] describe the co-design process for a VR science game for neurodiverse learners. They define a neurodiverse individual as an someone "…with a diagnosis of Attention Deficit Hyperactivity Disorder (ADHD), Autism Spectrum Disorder (ASD), a Learning Disability, a psychological disorder, or similar" [88, p. 1]. The design team included four researchers, and they additionally recruited three neurodiverse undergraduate students to participate equally alongside the design experts. In contrast to the previous examples, the design participants were not children. It is likely this made their design ideas more useful, and required less design training. The participants' experiences were evaluated with a questionnaire and the researchers gave recommendations for designing for and with neurodivergent individuals. These include: Build social connections, Consider novel modes of communication, Be respectful, and Ensure each member's needs are met during the design process. The researchers point out that some of their recommendations are applicable to all kinds of design activities, but are particularly important within the context of working with neurodivergent individuals.

Chapter 5

User Study: Design Phase

While co-design activities are often rewarding for children, if done during normal school hours it can disrupt the normal routine of the class. It also requires access to resources and the support of teachers. For this research a teacher known to the researcher was approached and introduced to the research, and agreed to allow it to take place within her class. Additionally, she offered her support in organising the activities.

Additionally, the school that was approached uses Modern Learning Environments as described in section 2.5. This means that the children are somewhat used to their daily routine being unpredictable and doing less traditional learning activities in the classroom. It also means that technologies like televisions, projectors and laptops would be available to be used for the design activities. The children were aged 9-11, and in either their last, or second-to-last year of primary school.

As described in previous sections, co-design is more successful when there is a high ratio of design experts and users participating. Unfortunately, in November of 2021 New Zealand was experiencing its first outbreak of the delta variant of Covid-19, which meant the school restricted the number of outside visitors it allowed to come in. This meant the activities had to be designed to be successful with only one researcher present, and in only one 90-minute session.

5.1 Design Aspects

Background research suggests that co-design with non-expert participants is generally most appropriate for gathering ideas for narrative and mechanics [83], particularly when the children aren't going to be involved for a significant portion of the design process. It seems most useful then to gather children's ideas about more general aspects of a game: where they would like to go, what they would like to do in VR. It was decided that the following aspects were most important for an initial design workshop:

1. **Environment**

   What kinds of environments do children want to go to? Do they want to experience a fantasy world like those they have seen in films and books, or do they want to experience a place in the real world? It would be interesting also to see what kinds of details they want to see like characters and structures.

2. **Helper Character/Pedagogical Agent**

   While the study by Mohammadhasani et al. [71] asked for children's input into what kind of pedagogical agent they were most comfortable with, children did not have an opportunity to provide their own ideas as to how such a character could look. As well as appearance, children will also be asked *how* the character will interact with them.

3. **Actions/Games**

   Finally, the children are asked to describe what kinds of things they want to *do* in Virtual Reality. This section is intended to be kept as open-ended as possible, as virtual reality is likely to be new to many of the children. It will be interesting to see how achievable their ideas are, given that in most cases the technology will be very new to them.

In addition to these aspects, some basic information will be gathered (whether they play video games, whether they have tried virtual reality, and what kinds of games they like to play).

5.2 Methodology

5.2.1 Set up and Introduction

Research suggests that co-design is improved if a social relationship between participants is established [61]. In order to meet some of the children before initiating the workshop, it was decided that the researcher should arrive before the beginning of class in order to talk and interact with some of the children. To help the children to view themselves as equal in the design process, they will be encouraged to refer to the researcher by their first name "...so as not to emulate a student-teacher relationship" [61, p. 123].

While VR technology is becoming more commonplace, it is not so common that all of the children in the classroom will have had experience with Virtual Reality. They may not know exactly what the technology is capable of, or even what the term means. To introduce some of these basic concepts, a demonstration of a VR activity was shown on an Oculus Quest 2 device[1], shown in Figure 5.1.

This device was chosen for portability: It is battery powered and has a system on board which provides content, rather than being driven by an external computer. It also uses technology called *inside-out tracking.* Some VR systems require external devices to track the position and rotation of the head-mounted display, where the Quest uses cameras mounted on the device itself. This made it a good choice as it required very little set up on the day.

[1]Now called the Meta Quest 2

FIGURE 5.1: Oculus Quest 2. The system is battery powered and can be used without a connection to a computer. Image by Maximilian Prandstätter on Flickr - CC BY 2.0[2]

Because of limited time, it was not feasible to allow the children to experience using the device, so it was decided to have their teacher do the demonstration activity and stream it to the classroom television, so they could see what she was seeing within the headset.

The demonstration was intended to give a very quick introduction to the kinds of environments and characters a virtual reality experience can present, as well as the kinds of interactions that are most natural. We also wanted to get the children thinking about what kinds of games they wanted to play in VR. Creating a custom VR application for this was considered, but the HMD ships with its own application which is intended for this purpose, called *First Steps* [89]. This is intended as a kind of tutorial for the user in how to use the system and its controllers, and is good at showing off the capabilities of the system.

The application begins with a table covered in different toys which the player can pick up and manipulate with the two controllers. These include blocks to throw around, a paper aeroplane, ping pong ball and bats, and a remote controlled blimp. This section is intended to get the children thinking about how interaction works in a virtual environment, and how motion tracking is different to conventional keyboard and mouse or mobile games.

The second part of the application involves the player interacting with an animated robot. The robot directs the player to move along with the music, and the robot reacts by twirling and dancing along. This is intended to show one kind of character that can be included in a VR experience, and how instructions can be delivered through them by voice and text.

The final part is a more conventional video game. This is a classic shoot-em-up where they player holds a toy laser gun in their hands and must react quickly to target geometric shapes which fly around them. This shows how traditional game mechanics (levels, scores) can work in VR, and is intended to get the children to think more about how the game they play work, and what makes them fun.

[2]https://creativecommons.org/licenses/by/2.0/

All of these activities take place in a kind of sci-fi environment, and shows how the game world can include things not seen in everyday life, or things that are not possible to see in the real world. Throughout the demonstration, the teacher is asked to describe what she sees and how she is interacting with the virtual world, and the researcher will try to ask questions to provoke thought about the design of the application and interactions, and remind the children that they will be asked to come up with their own ideas for games.

While parents are asked to consent to their children participating in the activities, the University of Canterbury's Human Ethics Committee also requires that researchers get assent from the children themselves. For this, a short form was created to ensure the children understand what is expected of them, and that their voices would be recorded.

5.2.2 Brainstorming Activities

Because of the low ratio between researchers/teachers and children, the tasks need to be designed to be as self-directed as possible. The activities should be simple enough to not need significant help from researchers, but open-ended enough to generate good design ideas that will be useful for development.

After discussions with the participating teacher, it was decided to use simple worksheets for the design activities. These are familiar to the students, and will enable them to largely self-direct their work. The classroom itself is also suited for group work, as the desks are designed to seat groups of around five students.

In a monograph on co-design with children, Fails et al. [61] describe a number of techniques which were the main inspiration for the brainstorming activities developed. However, they had to be adapted for the short time and low number of researchers participating.

One technique outlined in the monograph is "Bags of stuff", designed to elicit"…as many ideas as possible" [61, p. 132]. This involves the creation of low-fidelity prototypes using common art supplies. Designers are put in groups of around five and brainstorm together a solution to a given problem. Fails et al. suggest that the technique is most useful for creating innovative solutions, and is also suited to the beginning of a design partnership as it can act as an ice-breaker.

"Mixing Ideas" is another technique in the monograph. This involves participants sharing ideas, and combining components of other participants' designs. This tends to lead to more creative ideas and solutions as each participant is exposed to more ideas throughout the process which they can adapt and expand upon.

Loosely based on these tasks, the brainstorming worksheets[3] and activities are presented as an art exercise. As the classroom is equipped with art supplies (including pens, paper, colouring pencils) few materials apart from the worksheets need to be taken to the classroom. For each aspect described above the children are given space

[3]The worksheets are reproduced in Appendix C.

to draw their own personal ideas in as much detail as they like. There is also space for them to write about what they have drawn if they feel they need to elaborate. While each child is to come up with their own ideas first, they are encouraged to talk to each other within small groups of four or five to get inspiration, and share with others.

The first design task is for each child to come up with a place they would like to go in VR. They do this individually for 10 minutes, drawing pictures and writing a short description about their chosen environment. Afterwards, they are asked to share their ideas within their group and choose one to develop further.

For the next task, each member of the group gets one of four worksheets asking them to describe a specific aspect of the place they have chosen: what characters are there; what they can do there; how they move around; and what the place actually *looks* like. This activity is designed to allow the groups to develop their ideas more, and will show not just *where* they want to go, but what aspects of the environment (characters, landscape etc.) are most important to them. There are a number of different ways to allow movement in virtual reality, and it will be interesting to see how novel the children's ideas are. Each child works on their own sheet for five minutes, and passes it around the table after the time is up, to work on the next sheet. This allows the children to build upon the ideas of others in their team.

Next, the children are asked to present their ideas to the class as a group. Each child will explain what ideas they came up with for each of the four worksheets they worked on. This allows ideas to be shared *across* teams, so the children can see how the other teams approached the task.

The next worksheet asks the children to design a facilitating character to help them in the game world. This is done individually, but the children are encouraged to talk about the ideas with the group. After presenting their characters to the class, the last worksheet asks them to describe in general terms, what they want to do in the world they have designed.

Throughout the activities, the teacher and researcher will 'float' between groups to help children who are stuck, and initiate discussion and keep the children on task.

5.3 Results

As required by the university's Human Ethics Committee, children were required to get consent from their parents before participating in the brainstorming activities. Of the children that gave consent, 14 were present of the day of the workshop, including eight boys and six girls.

5.3.1 Introduction

When the bell rings for children to come into class in the morning, they have about 10 minutes of free time to settle themselves in and get organised. The teacher had already explained what was happening that day, and they all knew why the researcher was in the classroom. During this time, most of the children got out their school Chromebook and began playing *Minecraft Education Edition* [90], so it is clear that these students were very familiar with video games. *Minecraft* is a game in which players can explore, build, trade etc. within a block-based world. The children were eager to show off what they were building to each other and to the researcher, and many children were building together.

After the morning administration from the teacher the researcher introduced themself and the project, and explained why their ideas were needed for a VR game. With the teacher wearing the HMD the children were shown the First Steps program, showing off the features of the VR headset. It was clear that at least one student had seen the game before as they called out suggestions for what the teacher should do next.

Following the demonstration, assent forms were handed out to the children on which they were asked to indicate whether they were comfortable continuing with the activities, and having their voices recorded. Every child indicated on their worksheets that they had played video games before, and eight said they had used a VR headset before. The most commonly played games were *Five Nights at Freddy's* [91], *Among Us* [92] and *Minecraft* [90].

5.3.2 Environment

The first task was to describe an environment they would like to visit in a virtual reality game. Across the groups, there were some common themes, and many children came up with the same place. Hogwarts castle from the *Harry Potter* franchise was the most common idea, shown on the right in Figure 5.2, and also written on the left-hand drawing.

This use of existing ideas from existing media is common throughout the design ideas from the children, and reflected the findings of Khaled and Vasalou [83] described in section 4.2.

The first group wrote almost exclusively about *Harry Potter*. They were most interested in exploring the castle, interacting with the characters from the books, and their preferred way of getting around was flying on a broomstick. They also included a race track, roller coaster and castle kitchens. Additional characters included rabbits and bunnies, *Spongebob Squarepants* and *the Corpse Bride*.

Another group chose to incorporate as many of their individual designs as possible, resulting in a complex environment (shown on the left in Figure 5.2). Individually, the members of the group came up with: a game set on the Moon, the football stadium Old Trafford, a dark forest, and Hogwarts again. As a group, the children design a dragon which had the body of the Moon, on which you could explore Hogwarts and Old Trafford stadium. Their preferred method of moving around was to get shot out of a cannon.

The last group were inspired mainly by the video games *Among Us* and *Five Nights at Freddy's*. They combined aspects of both into their game world. From

Among Us, they set the game on a spaceship filled with crew members performing ‘tasks’. They also used the idea of using vents to move around. From the *Five Nights at Freddy’s* games, they had the idea of making the crew mates animatronic, and made the space ship dark to make it more scary. In particular, from *Five Nights at Freddy’s* they included a jump-scare mechanic, where much of the gameplay is driven by random appearances of intimidating figures, designed to startle the player.

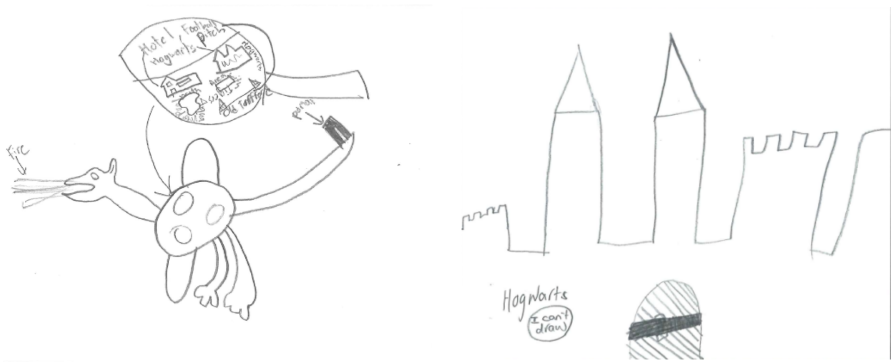


FIGURE 5.2: Designs for the game environment varied in detail, and level fantasy.

5.3.3 Facilitator

As with the game environment, many of the children’s ideas for the facilitating character came from existing media, for example *Patrick Star* from *Spongebob Squarepants* is pictured in Figure 5.3. The figure shows Patrick holding a button which the player presses for help if they get stuck in the game. Another participant came up with a similar idea for their character Bob. Bob is covered in different buttons, each one prompting him to give advice on how to play the game. Alternatively, “You can talk to Bob and Bob can talk to you!”.

Another idea was to give the player the ability to choose the gender of their facilitating character, by selecting either Bob or Susan. This character is described as a “good animatronic” who plays the game alongside you, helping you along the way. In a similar idea, another child came up with the idea of Boby, whom the player can summon by pressing a button. Rather than giving the player advice, Boby demonstrates how to do the task the player is having trouble with.

One idea that a few children came up with was to have the facilitating character have a set of tasks for you to complete. So as well as being there to assist when the player needs help, they also play the main motivating role for the player.

5.3.4 Activities

One of the most common ideas that came up, was for the ability to fly. The group that talked about going to Hogwarts in VR wanted to fly around on broomsticks, while another group wanted to be “fired out of cannons”. We briefly discussed whether they

FIGURE 5.3: There were a range of ideas for a facilitating character, some borrowed from existing media, and some invented by the participants.

might get motion-sick doing these activities, but most of the children claimed they wouldn't get sick.

Another common idea was the ability to build and explore, possibly inspired by their experience playing *Minecraft*. Other ideas included having a set number of non-specific tasks or quests to complete in order to succeed in the game.

5.4 Analysis

In general, the children were highly receptive to the activities. They were captivated by the demonstration of their teacher playing a VR game, and needed very little encouragement taking part in the activities. Whatever research outcomes and design ideas came from the co-design session, the children enjoyed the activities and had the chance to experience a little bit about what game design can be like.

As Khaled and Vasalou [83] found in their study, the children's designs often lacked novelty. Most of the ideas were lifted from existing games and media, without any original input. There *was* sometimes creativity in how they combined these ideas into a coherent design, for example one child imagined a game where the goal is to design a cure for a virus spreading through your school, completing 'tasks' and losing points if you are scared by animatronics. The child is taking ideas from games she knows (tasks from *Among Us* and animatronics from *Five Nights at Freddy's*) and combining the two with her experience of vaccinations during the Covid-19 pandemic, which was dominating New Zealand conversation at the time. There is also a clear understanding of common game mechanics here, which also featured throughout the groups.

By contrast, the group whose ideas are shown in Figure 5.2 had a less coherent mix of ideas. This is likely because when it came to discussing as a group, and combining their individual ideas, they were hesitant to discard any. Guha et al. [93] mention this is generally an issue for younger children, who may feel that their ideas are not considered valuable if they may be discarded. By contrast, this group seemed to be trying to push the boundaries with how creative they could be. Indeed, Guha et al. also remark that an absence of appropriate facilitation from adult researchers may yield "...ideas that are highly creative yet probably impractical" [93]. This certainly includes their design of a dragon who spits cheese, whose body is the Moon, on which is a football stadium and a portal. This is one of many areas where the session would have benefited from a much higher adult to child ratio, where elaboration of ideas could be done with more help from design experts focusing on single groups at a time, rather than one researcher periodically moving between groups.

While the majority of children were very happy to get on with the task themselves and knew exactly what was expected from them, there were a couple who would have befitted from more one-on-one with an adult design partner. The first understood what was expected from the design task, but seemed to lack confidence in his abilities. For a while he had only written down the name of his favourite sport. His ideas became more fully formed only after encouragement and gentle prompting: "Where is the sport happening? What things can you see?". This lead him to write specifically about a stadium filled with fans where the aim of the game is to score goals, or to act as the goalkeeper.

Another child was particularly worried that her ideas were not being considered as the group came to share and combine their ideas. She was in the group that was inspired mainly by *Harry Potter*, something she wasn't particularly interested in. Again, some one-on-one with her and the group helped to explain how everyone's ideas should be considered together, and also that there would be more time later on to work on their own individual game ideas. Again, both of these situations would have been greatly improved with a higher number of adult design partners who could act as a more constant member of each team and facilitate the elaboration of ideas more effectively.

One of the big successes of the design session was the role that the teacher played in communicating to the children what their role in the design sessions would be, and keeping them on task. Because of the time-limited session, the teacher was asked to prepare the children for the co-design activities in the days prior by explaining why they were needed for the research, and what their role would be on the day. This was a great help in reducing the time needed to get the session underway on the day, as the children already knew what was happening. Additionally, while it is unknown whether any of the children had an ADHD diagnosis, this kind of communication would prepare such children for the kind of disruption that took place, as is recommended by Pfiffner and DuPaul [4].

In the reverse, the teacher also prepared the researcher for what to expect from the children. This includes what the children expect to be doing in a school day, what materials are available to them, what kind of language they expect from written material, and the kinds of group dynamics that could be expected between the children. While there is a lot to learn about co-designing with children from the literature, this kind of specific help was invaluable when preparing the material, and the structure of the co-design sessions.

Chapter 6

Game Development

This chapter outlines the design and development process of the game, including:

- Hardware and software used,
- How the game was designed,
- How the children's ideas were used,
- How the game was designed to support the needs of children with ADHD.

6.1 Hardware and Development Environment

As mentioned in the introduction, virtual reality hardware has become much more widely available in recent years, as it became cheaper to produce more powerful devices [10]. This coincided with much more support for virtual reality development in popular game engines [94]. This section briefly describes how the development of the game was approached, from a technical perspective.

6.1.1 VR Headset

Before virtual reality systems became widely available to consumers, HMDs were relatively expensive, and often designed for narrow use cases[10]. There is now a much wider choice in device, most of which target a wide variety of VR games and applications. For the purposes of this project, there are some specific requirements that were identified for the HMD:

- The device should be relatively lightweight. As the game is designed for children, the device should be able to be used comfortably by children, and weight plays an important role in the comfort of a HMD [95].
- The device should offer standalone operation. In general, HMDs can either be used on their own (where all processing and rendering of graphics is performed on the device), or be driven by an external computer. While an external device will generally be more powerful, a standalone HMD is simpler to set up for non-expert educators, and the lack of wires removes a potential tripping hazard for children while they are in VR, and can't see the world around them.

  - Similarly, the device should support inside-out tracking. In general, VR controllers are tracked in space either by the HMD itself (inside-out tracking), or with external sensors known as lighthouses. Using a device with inside-out tracking again means fewer wires, and easier setup.

- The device should have a relatively high resolution screen(s). Because HMDs take up so much more of a user's field of vision than conventional PC monitors, much higher resolutions are required to achieve similar quality. Further, as the game will likely require the children to read text, a higher resolution will make text easier to read, especially if a child is required to remove their glasses before using the device.

- The device should have good developer support and documentation. Because of the quick turnaround between the design session and the planned evaluation, it was important that complex development processes and lack of support did not make development harder than necessary.

The Oculus Quest 2 device (Figure 5.1) was chosen as it most closely fits the requirements. At around 500 grams [96] it is not the most lightweight device available, but lighter devices tend to be less powerful, and with lower resolution screens. The Quest 2 has a per eye resolution of 1832x1920px, and offers inside-out tracking without the need for any external tracking device. It is battery powered and can be used either as a stand-alone device, or powered by an external computer.

Released in late 2020, the device is modern, but it has been around long enough that there are substantial development guides and technical support online. Additionally, because of Facebook's large market share in the VR space, it is supported by most game engines [97].

6.1.2 Game Engine

Game engines are designed to simplify the process of game development, and reduce the technical knowledge required by developers [98]. Figure 6.1 shows an overview of a typical game engine, with the dashed ellipses being the aspects handled by the engine. The Event Handler and Game Logic are written by the developer, and dictate how the game reacts to user input, and the rules of the game itself. Level Data includes things like 3D models, textures, sound effects and music, and animations. Game engines offer varying degrees of flexibility and complexity, but generally offer the following:

- **3D rendering**. Writing a rendering engine requires a high-level of technical knowledge and effort.

- **Audio**. While audio processing is simpler than 3D rendering, game engines often provide tools for playing audio. For example, as a player moves around a game world, audio should sound as if it is coming from the right place. This is particularly important in VR, which is designed to *immerse* the player in the world, and should sound, as well as look, as realistic as possible.

- **Physics**. Rather than having a developer explicitly write out rules for how objects interact and are affected by gravity, game engines usually provide these formulae, as they are unlikely to change from game to game.
- **Input**. Reading input from peripherals like computer mice, keyboards, and game controllers can vary depending on the system being used. HMDs and VR controllers from different manufacturers communicate position and rotation in space in different ways, which game engines sometimes handle for the developer.

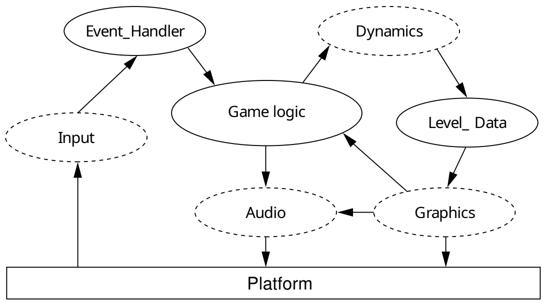


FIGURE 6.1: High-level system design of a typical game engine [98]. A game engine provides abstractions for more technical work such as rendering graphics and communicating with hardware.

By using a game engine, a developer can focus on the *content* of their own game, rather than technical specifics about hardware, operating systems, or rendering engines. Additionally, game engine publishers sometimes provide assets for game development like 3D models, audio, and animations. This can speed up development time, as designers need not create every aspect of their game content themselves. There are a number of engines available and again, a number of criteria were identified:

- The engine should offer hardware support for VR devices, in particular for the Oculus Quest 2 device.
- There should be good technical support and documentation, particularly for VR development.
- There should be a large number of assets available, and good support for different file formats.
- The game engine should support a scripting language familiar to the developer, to speed up development time.

In the end, the *Unity* [99] game engine was chosen. There are extensive guides on game development in Unity, and specific support for VR development for the Oculus Quest. There is also a large amount of assets available online from the Unity Asset

Store[1] produced by *Unity Technologies*, as well as by third parties. It also supports the C# programming language, which the developer is familiar with.

6.2 Game Design

The design process was somewhat complicated, as considerations needed to be made with regards to: ideas from the co-design session, design recommendations from existing research for children with ADHD, and concepts which will lead to an enjoyable game, and which could achieve the goal of improving children's ability to focus in the classroom. The following is a description of the game, and how these considerations lead to specific design decisions.

6.2.1 High-level Concept

The co-design sessions were designed around generating ideas for setting and characters, and what kinds of genres and activities the children prefer in video games. Because of the limited time available within the single co-design session, they were not asked specifically to come up with ideas for a game to improve concentration.

As discussed in Section 4.1.3 there is weak evidence that music therapy can be a useful intervention for children with ADHD. It is also remarked that one of the most popular VR games, *Beat Saber*, is a rhythm game, and Section 4.2 describes a recent study into a rhythm game designed for children with ADHD [87], showing it is an area actively being researched. During the VR demonstration before the co-design session, the children were highly receptive to seeing their teacher dancing in VR, with some including dancing as one of their preferred activities. Additionally, rhythm games are an area in which the researcher is both experienced and interested.

For these reasons, it was decided that the game would be a rhythm game, where the player must react rhythmically in time to music in order to succeed. As mentioned above, the game was developed using the Unity game engine, and the LEGO Microgame package. This package includes a variety 3D models, scripts, animations and audio assets to develop a LEGO-based game. There are LEGO figurines available, LEGO bricks, and completed models. The package also allows third-party models to be imported. Using these pre-prepared assets speeded up the design process, as more time could be spent focussing on the core functionality of the game, than on creating the game's assets.

For safety reasons, the game was designed to be played sitting down, so that children were not at risk of walking into things, or tripping over while wearing the HMD. To reduce the amount of guidance required to play the game, none of the buttons on the controllers are used, the only interaction comes from the player moving the controllers around.

Cybersickness is a common side-effect of virtual reality experiences [100]. Similar to motion sickness, cybersickness occurs when a player visually perceives themselves

[1] https://assetstore.unity.com

to be moving within a virtual environment, but experiences "…conflict between the visual stimuli provided and the (missing) vestibular stimuli." [100, p. 2669] In order to mitigate this effect, the entire game is designed to be played with the player sitting down, and stationary. There is no mechanism for the player to move around the game environment except by getting up and moving through space. Incongruity between visual and physical stimuli could still occur if there is latency between the player's movement and the display updating, however the game is designed to function well within the capabilities of the hardware being used.

6.2.2 Description

Setting

Many of the children described a sci-fi scenario in the co-design session with many setting their game in space. Additionally, space-themed LEGO sets and models are particularly common, providing a large range of content to select from. For these reasons, the game is set on the Moon, with the Earth rotating in a starry sky above the player. Additionally, as the Moon is a relatively featureless environment, there is less to distract the children, and making the environment realistic requires fewer 3D assets and other elements. The player is in the middle of a crater with a large white machine to their left, a chute directly in front of them, and a set of red trusses further back (see Figure 6.2a). A paddle is in each of the player's hands (Figure 6.2b), and a LEGO figurine is in front of them. As the game is designed to be played sitting down, all elements within the game are placed directly in front of the player, and there is no need for them to look behind them, nor to get up and move around.

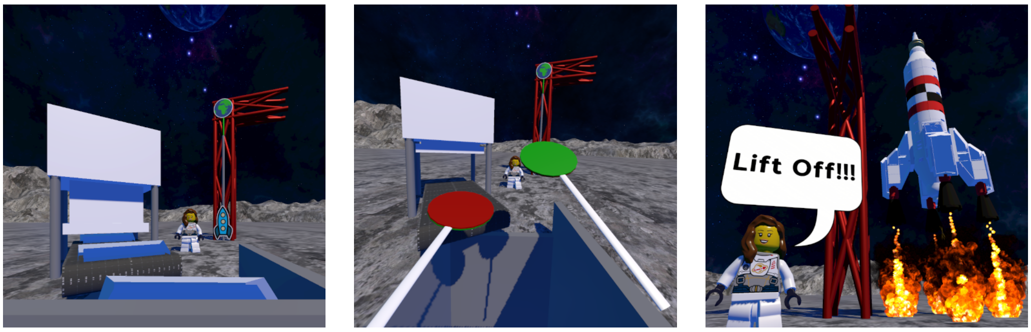
Gameplay

The game begins with the LEGO figure explaining that it is the player's job to construct a rocket ship which will fly back to the Earth. The white machine will produce LEGO bricks in time with music[2], which the player must rhythmically hit towards the trusses in order to construct the rocket.

The player is given the chance to practice the hitting motion before the real game starts. Hitting a LEGO brick at the correct time will send it flying over to the launch area in the correct position to construct the rocket (see Figure 6.2c). But if the player does not manage to hit a LEGO brick in time, it will fall down the chute in front of them. As the player builds the rocket, an icon travels up a pole on the truss, indicating how far through the game they are. The goal is to reach the green section of the pole(see Figure 6.3a).

At the end, if the player let any bricks fall down the chute, the figurine puts these pieces in the correct place for the player. The completed rocket can then be launched by the player, triggering visual and audio effects as the rocket accelerates towards Earth.

[2]Music is "Gaslamp Funworks", Kevin MacLeod (incompetech.com).



(A) This shows what a players sees when playing the game. Bricks are coming towards them in time to the music.

(B) The player must hit each brick with the green side of the paddle so it flies towards the rocket ship launch area.

(C) Once the rocket is built, it launches into space. The facilitating agent is shown in the foreground

FIGURE 6.2: The player is tasked with assembling a LEGO rocket ship by rhythmically hitting bricks towards the assembly area.

6.2.3 Co-Design Ideas

Almost all of the places which the children came up with during the co-design session were places which they would be unable to visit in real life, either because they are fictional (e.g. Hogwarts), or unreachable (e.g. the bottom of the sea). Many of the children were interested particularly in experiencing a sci-fi environment, like the spaceship found in the game *Among Us*, which was popular among the children. From a development perspective, it is also relatively straightforward to create a space-like environment: there are relatively few different objects and characters to come across, and a large amount of public domain imagery to use.

The idea for building a rocket ship is also inspired from the co-design session. Many of the children were interested in being able to build something as part of the gameplay which, as mentioned earlier, was likely inspired by their experience in the game *Minecraft*. As the children already had experiencing playing *Minecraft* in a school setting. including this kind of building mechanic would make the game familiar and accessible to them. LEGO bricks are sometimes used within the classroom as well, so including them in the game should make for a more familiar experience, which means less time explaining the mechanics of the game to the players.

While the facilitating character was initially intended as a way to help players when they became stuck or confused, a few of the children came up with the idea of the character giving the player tasks to complete, so rather than just facilitating, they are part of the motivation for the children playing the game. This is where the idea of an astronaut requesting help building a rocket comes from.

Finally, while only a couple of the children wrote about movement or dance specifically as a mechanic within their game, it was the dance part of the demonstration that seemed to captivate them most during the introduction of the co-design session. By making a rhythm game, players are free to simply hit the LEGO bricks as required, or they can incorporate some kind of dancing (bearing in mind that they will be sitting down) to keep themselves synchronised with the beat of the game.

6.2.4 ADHD Considerations

As well as taking the children's ideas into account, the design recommendations for children with ADHD also needed to be considered.

The facilitating character was based on the recommendations of Mohammad-hasani et al. as an agent to "...gain and guide attention" [71, p. 2303] within the game. As discussed, many of the children's ideas for in game characters came from existing media, which it would have been difficult to source and incorporate into the game. Many designs also conflicted with the design guidelines and research covered in section 4.1.1, specifically that in-game facilitators are most effective if they are humanoid, and provide human-like gestures and eye-contact. In particular, the *Five Nights at Freddy's* characters which appeared in a number of the children's designs are intended to be frightening and somewhat spooky, the presence of which would be counter to efforts to design a friendly, safe environment for the children.

The LEGO Microgame package provides a set of minifigures which are bundled with their own animations, sounds and behaviours. While LEGO figures were not given as a design idea during the session, all the children have experience with LEGO in their classroom, and so a LEGO figurine will likely be familiar to them. Additionally, the figures are humanoid, and the animations include a range of gestures (see Figure 6.3b) to indicate when the student reaches a goal, or makes an error.

Throughout the game, instructions and feedback appears within a speech bubble. As supported by research [74], the text is large and uses a sans-serif typeface. While research indicates spoken voice is more effective in games for children, this was infeasible in the time available. The game was designed such that future iterations of the game could include a level of text synthesis or voice acting, or a person could read the text out live. There are a set of instructions and pre-prepared feedback messages in the game, and for the purposes of the evaluation, the researcher can send custom messages to the facilitating agent at any point if the child required some specific, or more complex help[3].

A further benefit of using a LEGO figure is that they can easily be swapped out for other figures, to suit the kind of facilitator that the children would like to have within the games, within the broad range of figures in the LEGO catalogue.

Following the suggestions from Mayer [73], the agent:

- Maintains eye contact with the player.
- Speaks in a conversational style.
- Uses human-like gestures.

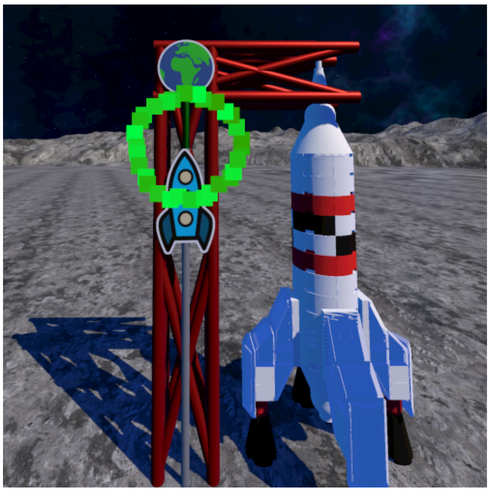
In the beginning, as the agent is describing the game, different objects with which the player is required to interact are indicating by adjusting the agent's gaze, and

[3] This kind of interaction where the child believes the messages are coming from a computer, when they actually originate from a human is know as *Wizard of Oz* testing [101]

having them gesture towards them. When the player correctly hits an object to the rhythm of the music, the agent encouragingly raises their arms in celebration. This also aligns with McKnight's guideline of creating a "high-reinforcement environment" [74, p. 2].

Figure 6.3a shows how a player's progress is tracked during the game, and the indication of when they have reached the required goal. As the player progresses, the icon of the rocket moves up the pole, towards the target of the Earth. Reaching the green section of the pole is the goal, and getting it to the top means the player has successfully hit every LEGO brick to build the model rocket. When the goal is reached, there is particle effect indicating their achievement. This reflects the guidelines for keeping a marker of the player's progress, and giving positive feedback.

More generally, the game environment is designed to include as few distracting elements as possible, without diminishing the authenticity of the scene. Apart from the facilitator and game objects, there is the floor plane, which is given a moon rock texture extending away from the player in all directions. This ends in a raised section indicating that the player is within a crater. The sky is given a starry texture and features a rotating model of the Earth, towards which the facilitator indicates when describing the game. This is not visible while the player is looking straight ahead, during the core gameplay.



(A) In order for players to be able to track their progress, a miniature rocket travels up the struts as they play the game.

(B) Research recommends the inclusion of an in-game facilitating character to guide the player through the level, and to provide help when needed.

FIGURE 6.3: Some aspects of the game which were designed specifically for children with ADHD.

Chapter 7

User Study: Evaluation

While the game was designed to improve the attention of children with ADHD in the classroom, a formal evaluation of this aspect is beyond the scope of the current study. Instead, the evaluation phase was primarily designed to explore:

- How successful the development process captured the ideas of the children,
- Whether those ideas lead to an engaging and enjoyable game and,
- If game elements designed for children with ADHD appeal to children generally,
- General usability aspects, particularly those unique to the VR environment.

The children were also encouraged to describe what they were doing and experiencing as they played the game. Throughout the play-through, the children were observed both by watching them play the game in reality, and by viewing what they could see within their headset, which was mirrored on a computer. Audio was recorded throughout the gameplay, and the interview, in order to document all comments made by the children.

7.1 Methodology

The evaluation was done on a return visit to the same classroom that participated in the co-design session. The same group of six girls and eight boys were invited (and agreed) to take part. After getting assent from the children, each child (individually) played through the game once, and then were asked about their experience immediately afterward in a semi-structured interview. The questions covered:

- Whether they enjoyed the experience.
- What specific aspects they liked, or didn't like.
- Whether they found the game too easy, or too hard.
- If they recognised their own influence in the game's design.

While the children were playing through the game, observations about where there attention was directed, what they appeared to struggle with, and how quickly they grasped the mechanics were made.

While one of the reasons the Oculus Quest headset was chosen for the game was its ability to be used without being connected to a computer, for the purposes of this experiment, the game was broadcast to the device by an external laptop. This allowed the researcher to observe live approximately what the children could see within the device, and to see more clearly how they interacted with the game world. It also meant that dialogue could be sent to the facilitating agent in the event that a child became stuck and needed specific assistance.

7.1.1 Risks

As described in Section 6.2.1, the children played the game sitting down, in order to minimise the risk of injury or damage to the device. The room was unoccupied apart from the child, their teacher and the researcher. A wide area of about two metres around the player was cleared of obstacles to minimise the risk of collision even in the event that a child did get up out of their chair.

Given that cybersickness is common in virtual experiences [100], the children were closely monitored and asked whether they felt well enough to continue, as motion (or simulation) sickness is not uncommon in VR experiences. For additional safety, and to ensure the children were as comfortable as possible playing the game, their teacher was present and observing at all times.

7.2 Results

7.2.1 Design Ideas

As described in the previous chapter, many of the ideas generated by the children would have been infeasible to implement, or not conducive to creating a safe and calm environment recommended by the research for children with ADHD. This meant that much of the specific designs from the children were not included in the game. Setting the game in space, which was one of the most common environments described in the design process, meant that many children saw at least an *aspect* of their ideas in the game. However while all the children said they enjoyed playing, many were disappointed they couldn't see their specific ideas in the game.

There were of course other ideas selected from the the co-design session. Extending the role of the facilitator into more of a motivating force within the game, came from the children's ideas. This meant that instead of having to click through a traditional tutorial and reading instructions as is often the case for educational games, the facilitator was part of the narrative of the game, and the instruction is given through the speech of the agent, through speech bubbles. This was successful as none of the children required additional instruction outside of what the facilitator provided within the environment. From a design perspective, integrating the facilitator with the environment is particularly suited to a VR game. In a traditional desktop interface, elements like buttons and input fields are not part of the game world, which means that a facilitating agent sits in between, describing elements of the user interface, while also interacting with the game world. Because VR allows for more natural interaction, where (for example), pressing a button is done by literally moving your hand towards a button rather than simply clicking a mouse, the facilitator only needs to interact with elements that are a part of the game world.

Another mechanic from the design session was the idea of building something in the game. This appeared in a few of the children's ideas, with ideas that seemed to be inspired by their experience with *Minecraft*. While the aim of the game is to construct a LEGO rocket ship, the children did not literally put the LEGO bricks together as this was done automatically. None of the children recognised this as being their idea, as it is perhaps the case that the children's designs refer more to the freedom to build what they like, and not be constrained by the game putting the pieces into position for them.

These game mechanics, which were taken from the co-design session, were not recognised by the children as being their own ideas. This suggests that children are likely to recognise their ideas only if they remain relatively unchanged through the development process. This could effect could be reduced in cases where children are able to be involved more often through the design process, rather than just once as is the case in this research.

7.2.2 ADHD Design Guidelines

The focus on designing for children with ADHD did not seem to have an significant impact on the children's experience of the game. Indeed, they were each able to follow the instructions of the facilitating agent, one of the suggestions from existing research [71]. The children did not talk about the progress indicator, or win animation (Figure 6.3a) in their interview, suggesting that they may not have noticed it, or did not consider it to be important. This may be because the game includes no penalty for failure, reducing the need for the children to monitor their progress through the game. The children also did not comment on a lack of detail in the game environment, suggesting that limiting game elements to avoid distractions does not necessarily make a game significantly less enjoyable, or immersive. This is perhaps helped by setting the game on the Moon, which is naturally featureless and free from distraction.

7.2.3 Device

It is difficult to design VR hardware that accommodates different head shapes, eye-separation (or interpupillary distance), prescription, and even hair-styles. For clarity, the device must sit precisely on the user's face, or the image can appear blurry, or the stereoscopic effect can be misaligned. As an observer, it can be difficult to work out why a user might be having trouble with the device, as you cannot directly see what the player sees.

It is promising then, that the majority of children did not have trouble reading the text in the speech bubbles attached to the facilitating agent. This was clear as each child was able to read aloud the words of the agent, and follow her instructions. Only one child needed the font size to be increased and the instructions were read out for him. This did not seem to impact his ability to succeed at playing the game.

With only one exception, all the children remained seated on the chair and completed the game without incident. One participant, transfixed by a LEGO brick he had missed which was rolling around some distance away, got up and went to investigate at the very end of the game. As designed, there were no objects in the way and the headset was removed before a collision occurred. As shown in the screenshots (Figure 6.2), all of the important game elements are placed in front of the player, and relatively closely. It was only when a fault in the game caused something to roll away from the player that any of the children tried to move within the virtual environment. This suggests that children may be tempted to interact with distant objects by getting up and moving around, but that this can be avoided by ensuring no interesting elements are placed away from the player. For example, this could be done by setting the game in a relatively small space, like a room, or by setting the game in a naturally featureless environment, like the Moon.

The children were asked for ideas about how to move within the game environment in the co-design session, however most of their ideas were some form of flight. As mentioned previously, movement like this can cause cyber-sickness within VR [102], and so is not generally an effective way of moving around. The idea was not discarded entirely however, as the idea for flight is integrated into the rocket taking off at the end of the game. Again, the idea was too abstracted for any of the children to be able to point to it as an example of their ideas being used in the game.

7.2.4 Game

Not only could the children read the instructions given to them, they all followed and understood them. The researcher did not have to intervene with specific dialogue to the facilitator when a child became stuck or required extra help than what the facilitator provided. The children had no problems using the controllers, and generally could hit the LEGO bricks as they moved towards them. One player managed to hit all the bricks and build the entire rocket, something that even the game designer found difficult to accomplish. Some children did not seem to follow along with the music, merely reacting to the bricks as they approached them. This would frustrate them as while they seemed to be hitting the bricks in the game, because it wasn't in time to the music, they would not fly over to the rocket as expected.

Even with the minimal environmental cues, each child was able to recognise that the game was set on the moon. The children were able to focus on the game for its duration, with few exceptions. Even when the room filled with excited children after the school bell rang for the end of class during one subject's experience, they managed to continue playing the game without distraction or interruption. The only exceptions occurred when a bug in the game caused something unexpected or inexplicable to happen. For example sometimes objects appeared to bounce off each other without ever actually colliding. The children tended to fixate on this when it happened, eagerly pointing it out to the researcher. Two children also discovered they could 'cheat' in the game by rapidly moving the controllers back and forth, easily hitting all of the bricks.

The final part of the game – where the children launch the rocket – includes visual and audio cues, as well as a countdown from the facilitator, yet did not seem to draw the children's attention. Many did not even notice the rocket launching into the air and were instead looking in other directions. It was expected that their attention would be drawn by the bright flames (see Figure 6.2c) and spatialised audio. This is a unique problem in VR games, where it is impossible to view the entire environment at once. Compare this to a traditional desktop game, where it is simple to contain game elements within the screen, which it is safe to assume will usually be in front of the player, unobstructed.

As mentioned above, the children were able to read and follow the instructions of the facilitating agent. One player remarked they thought the LEGO figurine was "bossy", but in general the children agreed that she was helpful at explaining the game to them.

Chapter 8

Discussion

8.1 Co-Design

Overall, the co-design session was useful for gaining an understanding of the children's experience and understanding of what VR is, and also their literacy in video games. The success of the session was constrained largely by the limited time allocated, and the restriction of having only one researcher able to attend, due to Covid-19 restrictions.

The biggest challenge was the children's reuse of existing ideas and characters from existing media. This reflects research by Khaled and Vasalou [83], and Mouws and Bleumers [103]. Where Khaled and Vasalou view this negatively, Mouws and Bleumers suggest such ideas "…can be a stepping-stone" [103, p. 39] to teaching concepts of proper attribution of ideas. Neither study suggests how to guide children away from just lifting copyrighted material from existing media.

What these kinds of ideas *are* useful for is in discovering types and categories of character that children like to see in games. Many of the characters described in the session were protagonists from existing media, who were intended to work alongside the player to achieve the goal. However many other designs were for *frightening* characters that get angry with the player when they don't succeed within the game. From a design perspective, choosing a friendlier, more cooperative character will appeal to a wider audience, however the success of games like *Five Nights at Freddy's* and *Among Us*, and their popularity among the participating schoolchildren reveals that some children may prefer a less welcoming environment in their games. Whether such designs would be compatible with an educational game would require further study.

Because the co-design session took place at the earliest possible stage of the design process, the children had very little context, or constraints under which to formulate their designs. The only decisions that had already been made, were that we were designing a VR game for children with ADHD. Every other aspect was up in the air, including the specific goals such a game should have. This may have contributed to the less intelligible ideas from some of the children, who tried to combine as many of their individual designs as possible. Guha et al. [93] suggest this can be remedied with more help from researchers and facilitators during the session. Likely, some of this help could be described as added context, and the ability to keep the children on task.

While many aspects of the game's design were taken from, or were inspired by the co-design session, children had difficulty identifying these unless they were directly lifted from their ideas. Children were excited and felt a sense of pride when they saw their ideas reflected in the game, but were disappointed if they could not see them. This is one of the limitations of a short, one-off design session with a relatively large number of children. If it were possible to involve children in more of the design activities that went into making the game, they could have provided more specific ideas, in relation to a more developed prototype of the game. For example, when designing the facilitating agents, the design sessions produced a wide variety of characters, most of which were unusable for reasons of copyright. If the children were involved *again*, after the decision was made to use the LEGO microgame package, they could have been asked to choose or design specific LEGO figurines. These designs would be much more likely to make it into the final prototype, as the LEGO figures had already been identified as being appropriate for a game for children with ADHD, where a friendly, recognisable character is recommended [71].

In the end, a balance has to be reached between what the design experts and existing research suggests will be most effective at achieving the stated aims of the game, and the ideas that children come up with during design sessions. Again, the co-design session described in this research took place very early in the design process, so the children were asked for *very* high-level ideas. In a longer project, it would make sense to give the children more context about the goals of the game, and some of the constraints they should try to stay within as they come up with ideas. If the children understand the goals of the design process clearly, it should improve the suitability of the ideas, and reduce the need to discard designs which are infeasible or misaligned with the game's stated aims.

A surprising outcome of the session was the level of game literacy the children had with respect to game design. They were able to come up with some of the most common games elements (points, achievements, resource management, lives and health bars), without prompting from researchers. While these ideas weren't novel, the show that the children were able to think abstractly about game elements, and apply them to entirely new scenarios.

Additionally, some children were quick to discover bugs and flaws in the game design. This seemed to occur midway through the game, as they become more confident within the game world and started experimenting with other techniques of hitting the LEGO bricks. When the children saw something go wrong within the game, they were quick to point this out to the researcher. The bugs were relatively minor, mostly to do with objects' appearing to bounce of one another without ever colliding, but were still picked up by the children. This may be due to the nature of a VR experience being more immersive than a traditional desktop game, which makes discrepancies between what is expected and what actually occurs, more noticeable.

8.2 ADHD design considerations

Many of the children's designs would not be compatible with the some of the design recommendations from previous research. As already mentioned, many of the children wanted elements of surprise and fear in their games, which goes against the predictable, calm and not distracting environments recommended by both McKnight [74] and Silva et al. [76].

In general, where there was a clear conflict between the children's design ideas and what the literature suggests when designing for ADHD, the literature recommendations were prioritised. For example, where most of the children's designs were dynamic, with many elements, Silva et al. [76] recommends *minimising* distracting elements. In this case, it is clear that the children's ideas are likely to be inappropriate for a game designed for children with ADHD who, as described in Chapter 2, have difficulties sustaining and directing their attention.

In other cases, the children's ideas were adapted to the design recommendations, or were used in conjunction with them. Where Mohammadhasani et al. [71] recommend a facilitating agent who helps the player out, most of the characters designed by the children played more of a directing role, setting goals for the player, and directing them throughout the game. The LEGO figure in the prototype draws on both of these concepts. She is there to help out if the player gets stuck, but she *also* directs and motivates the player throughout the game.

The nature of rhythm games are naturally counter to some design recommendations for children with ADHD. Again, Chapter 2 describes how ADHD can affect reaction times, leading to a slower response to stimulus. This is reflected in VR design recommendations, for example Belter and Lukosch recommend "…no imposition of time limits should be used …with no time impositions" [104]. In this case, however, the game's purpose is to *train* this aspect of attention control, by rewarding children when they successfully react to visual and audio stimuli. It seems it would be impossible to train this skill with a game that doesn't actually require its use. On the other hand, it is not clear to what extent executive functions like attention controls *can* be trained. If the penalties for slower or mis-timed reactions are too high, children may be discouraged from playing as they fail to progress. The prototype described in this research does not have any penalty for failure, as the facilitating agent will complete the rocket ship at the end of the game for the player. This seemed to suit the children during the evaluation, as none of them reported feeling discouraged, or that they had failed. But reflecting on some of the children's design ideas, where they *wanted* in game characters to get angry with the player if they were not performing well, there may be space for further research into the role harsher penalties for failure can play for some children. Again, the literature [74][76][104] clearly recommends against such designs for children in general, but it may be a suitable design decision for some very specific circumstances.

8.3 Recommendations

A higher researcher to child ratio is more important than a large number of participants.

As discussed, the children were largely self-directed throughout the design workshop, due to the low ratio of researchers to children (1:14). The researcher moved from group to group in order to ensure the children understood the activities, and remained on task. This one-on-one time with the children produced the most valuable design ideas as the researcher was able to build upon, and invite elaboration on the ideas produced by the children. This elaboration was constrained by the need to move between groups, and a higher ratio between researchers and children, even if that means a smaller group of children participating, would produce more complete, and valuable, design ideas.

Children's game literacy should not be underestimated.

Even though it was raised in the background research [83], the level of game literacy among the children was surprising. The design activities were designed to be as general as possible, inviting children to think about places they would like to visit, characters they would like to interact with, activities they would like to do, without necessarily discussing concrete game elements. This was an attempt to be as inclusive as possible, the assumption being that not all children would have significant experience with video games.

In fact, all children were familiar with video game concepts, not least because video games were sometimes incorporated into their learning at school. This recommendation is specific to the context in which the design workshop was undertaken. The participating school is in a relatively well-off area in a developed nation, the children of which will have greater access to digital technologies than could be found in other parts of the world.

It is important to establish, or leverage existing relationships with the participating institution.

For this study, the classroom used for the co-design workshop was taught by a teacher known to the researcher. This reduced the barriers required to get a school on-board with the research and agree to participate. Because the teacher was already familiar with the research, and often met casually with the researcher, it made the process of explaining what would be required from her and her pupils much simpler. Research such as this is disruptive to the children's routine, and can be administratively difficult as consent forms needs to be delivered to, and returned from parents.

Chapter 9

Conclusions

While fairly established on the consumer market, Virtual Reality remains a dynamic field of research in both the diagnosis, rehabilitation and management of ADHD. There is strong evidence for computer games as an effective intervention, and this study describes how children can be brought into the design process for an immersive virtual reality game.

The developed game drew from ideas from the children, design guidelines developed specifically for children with ADHD, and from expert knowledge in developing digital experiences for children. The game is in the rhythm-game genre, which is popular amongst VR experiences, and shows promising results for children with ADHD.

Undertaken during a period of Covid-19 restrictions, this study shows that co-design sessions can produce results even with a low ratio of researchers to children, and valuable insights can be made. In particular, this study has discussed that the children tended to draw their ideas from existing media without significant novelty and originality. Additionally, the children tended to have higher levels of video game literacy than expected, and were able to talk about their favourite games abstractly, in terms of game elements.

Additionally, the children were able to come up with a large number of ideas, and combine these between themselves. This mixing of ideas often became incoherent, or resulted in one child being disappointed that their design would not be followed through with.

In general, the children's designs included elements that would be incompatible with what the existing research suggests is appropriate for making a calm and distraction-free environment for children with ADHD. In particular, the children were keen to experience the kind of jump-scares they had experience in the game *Five Nights and Freddy's*, which is contradictory to established design guidelines for establishing a welcoming environment with minimal surprises.

The children enjoyed playing through the prototype, and were satisfied when they recognised their own designs in the game. Those children whose designs did not make it in, did not feel as strong a connection to the game. Many of the ideas used in the final game, while taken from the co-design session, were abstracted to the point that the children could not recognise that they were ideas that they had come up with.

9.1 Future Work

The small evaluation of the prototype was designed to appraise the co-design process, and whether it was able to produce an enjoyable game. Further evaluation would need to be undertaken to determine whether it fulfils its stated aim of improving attention in children both with and without ADHD. This could be done by having a child routinely play through the game, periodically administering a Continuous Performance Test (described in Section 2.4) measure any increase in their ability to focus. Having children with ADHD play through the game and evaluate their experience could verify how effective the design guidelines outlined in Section 4.1.1 are.

Now that there is a basic prototype, a further co-design session could be run, asking children to design a LEGO facilitator. As discussed, some of the children's design ideas seemed to be held back by a lack of constraint in the design activities presented. Now that there is significant structure to the game, it may lead to children developing more feasible design ideas. Similarly, the construction task could be adapted to something else the children would like to do in VR. During the co-design session, it had not been decided that the game would be a rhythm game, so it would be interesting to see what kinds of design ideas children could come up with, given this added context.

Appendix A

Ethical Approval

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

HUMAN ETHICS COMMITTEE

Secretary, Rebecca Robinson
Telephone: +64 03 369 4588, Extn 94588
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2021/144

29 October 2021

James MacKay
HIT Lab NZ
UNIVERSITY OF CANTERBURY

Dear James

The Human Ethics Committee advises that your research proposal "Co-Designing VR Games for Children with ADHD to Improve Attention in the Classroom" has been considered and approved.

Please note that this approval is subject to the incorporation of the amendments you have provided in your emails of 26th and 29th October 2021.

Best wishes for your project.

Yours sincerely

Dr Dean Sutherland
Chair
University of Canterbury Human Ethics Committee

University of Canterbury Private Bag 4800, Christchurch 8140, New Zealand. **www.canterbury.ac.nz**

F E S

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

HUMAN ETHICS COMMITTEE

Secretary, Rebecca Robinson
Telephone: +64 03 369 4588, Extn 94588
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Ref: HEC 2021/144

6 December 2021

James MacKay
HIT Lab NZ
UNIVERSITY OF CANTERBURY

Dear James

Thank you for your request for an amendment to your research proposal "Co-Designing VR Games for Children with ADHD to Improve Attention in the Classroom" as outlined in your email dated 1st December 2021.

I am pleased to advise that this request has been considered and approved by the Human Ethics Committee.

Yours sincerely

Dr Dean Sutherland
Chair, Human Ethics Committee

University of Canterbury Private Bag 4800, Christchurch 8140, New Zealand. **www.canterbury.ac.nz**

F E S

Appendix B

DSM-5 Diagnostic Criteria for ADHD

The following are the diagnostic criteria for ADHD taken from the DSM-5 [14].

A. A persistent pattern of inattention and/or hyperactivity-impulsivity that interferes with functioning or development, as characterized by (1) and/or (2):

   1. **Inattention:** Six (or more) of the following symptoms have persisted for at least 6 months to a degree that is inconsistent with developmental level and that negatively impacts directly on social and academic/occupational activities:

      Note: The symptoms are not solely a manifestation of oppositional behavior, defiance, hostility, or failure to understand tasks or instructions. For older adolescents and adults (age 17 and older), at least five symptoms are required.

      a. 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, work is inaccurate).
      b. Often has difficulty sustaining attention in tasks or play activities (e.g., has difficulty remaining focused during lectures, conversations, or lengthy reading).
      c. Often does not seem to listen when spoken to directly (e.g., mind seems elsewhere, even in the absence of any obvious distraction).
      d. 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).
      e. Often has difficulty organizing tasks and activities (e.g., difficulty managing sequential tasks; difficulty keeping materials and belongings in order; messy, disorganized work; has poor time management; fails to meet deadlines).

f. 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, reviewing lengthy papers).
g. Often loses things necessary for tasks or activities (e.g., school materials, pencils, books, tools, wallets, keys, paperwork, eyeglasses, mobile telephones).
h. Is often easily distracted by extraneous stimuli (for older adolescents and adults, may include unrelated thoughts).
i. Is often forgetful in daily activities (e.g., doing chores, running errands; for older adolescents and adults, returning calls, paying bills, keeping appointments).

2. **Hyperactivity and impulsivity:** Six (or more) of the following symptoms have persisted for at least 6 months to a degree that is inconsistent with developmental level and that negatively impacts directly on social and academic/occupational activities:

   Note: The symptoms are not solely a manifestation of oppositional behavior, defiance, hostility, or a failure to understand tasks or instructions. For older adolescents and adults (age 17 and older), at least five symptoms are required.

   a. Often fidgets with or taps hands or feet or squirms in seat.
   b. 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).
   c. Often runs about or climbs in situations where it is inappropriate. (**Note:** In adolescents or adults, may be limited to feeling restless.)
   d. Often unable to play or engage in leisure activities quietly.
   e. 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, meetings; may be experienced by others as being restless or difficult to keep up with).
   f. Often talks excessively.
   g. Often blurts out an answer before a question has been completed (e.g., completes people's sentences; cannot wait for turn in conversation).
   h. Often has difficulty waiting his or her turn (e.g., while waiting in line).

i. Often interrupts or intrudes on others (e.g., butts into conversations, games, or activities; 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).

B. Several inattentive or hyperactive-impulsive symptoms were present prior to age 12 years.

C. Several inattentive or hyperactive-impulsive symptoms are present in two or more settings (e.g., at home, school, or work; with friends or relatives; in other activities).

D. There is clear evidence that the symptoms interfere with, or reduce the quality of, social, academic, or occupational functioning.

E. 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, substance intoxication or withdrawal).

Appendix C

Brainstorming Materials

Name: ______________________ Age: ____

Do you play video games?

☐ Yes ☐ No

What are your favourite games? Think about video games, card games, board games or sports.

____

____

____

____

____

____

Have you ever used virtual reality like in the picture?

☐ Yes ☐ No

1

Draw a place you would like to visit in virtual reality.

It could be a real place like your house or the school, or somewhere you wish you could go like outer-space or the bottom of the sea.

Write a little bit about your place:

(You can write on the back of the page if you run out of room)

Draw a friendly character to help you.

You might need help playing a game in virtual reality, and you can't see or hear your teacher.

Write a little bit about your character:

____

____

____

____

____

(You can write on the back of the page if you run out of room)

Think about the places we have talked about. What kind of game or activity do you want to play there?

Write about your activity:

(You can write on the back of the page if you run out of room)

Place: ______________________________

What kinds of people, animals or characters are at this place? Write about or draw as many as you can think of below:

(You can write/draw on the back of the page if you run out of room)

Place: ______________________________

What things can you see and hear? (For example, buildings, trees, the ocean). Write about or draw as many as you can think of below:

(You can write/draw on the back of the page if you run out of room)

Place: ______________________________

How do you move around and explore this place? Do you walk, drive, fly, even teleport? Be creative, see how many you can come up with:

(You can write/draw on the back of the page if you run out of room)

Place: ________________________________

What can you do here? Can you talk to people? Can you build something? Are there toys to play with? Write or draw as many as you can think of below:

(You can write/draw on the back of the page if you run out of room)

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