A Serious Game for Children with Autism Spectrum Disorder

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Abstract

In this thesis, we propose a Serious Game (SG) for children with the Autism Spectrum Disorder (ASD) that builds on the concept of LEGO®-Based Therapy that is aimed at improving social and cognitive skills. The proposed SG is composed of building blocks augmented with electronic modules that connect to a computing device that provides visual feedback. We investigate the effects of using the proposed computer SG by comparing it to a non-computer block-game during two empirical studies, one following an unstructured play approach and a second one with structured play by assigning roles to the players.

For the first study, the proposed system showed an improvement in social interaction, collaborative play and exercise performance, as well as a decrease in solitary play. For the second study, the proposed system showed an improvement in social interaction, positive vocalizations and exploratory behavior. There was also a marked preference towards the proposed game. Furthermore, we perceived a decrease on the assistance needed when using the proposed system during both studies. Our results suggest that the proposed system can be a useful play therapy tool aimed for young children with ASD.

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List of Acronyms

ADC: Analog-to-Digital Converter

ASD: Autism Spectrum Disorder

CCPT: Child-Centered Play Therapy

CDC: Centers for Disease Control and Prevention

GUI: Graphical User Interface

HCI: Human-Computer Interaction

HFA: High-Functioning Autism

NUI: Natural User Interface

PD: Participatory Design

PECS: Picture Exchange Communication System

PRT: Pivotal Response Treatment

SEN: Special Educational Needs

SG: Serious Game

TUI: Tangible User Interface

Chapter 1. Introduction

1.1. Background

Autism Spectrum Disorder (ASD) is defined as a developmental condition characterized by a marked impairment in social interaction and communication skills [1]. Findings of the CDC's (Centers for Disease Control and Prevention) Autism and Developmental Disabilities Monitoring Network show that about 1 in 68 children in the United States were identified with ASD [2]. Some of the most common signs of ASD include differences in the way a person communicates, learns, interacts, and behaves [1]. These signs usually appear during early childhood. The sooner the individual receives an intervention, the more likely he/she can live an independent life as an adult [3].

Because of the differences associated with this condition, people with ASD present limitations in adaptive behaviour and therefore have Special Educational Needs (SEN) [4]. Some of these SEN are addressed during therapy. *Play therapy* (or theraplay) is a type of occupational therapy commonly used with children with developmental conditions such as ASD and other SEN. Since playing is one of the main methods of communication for children [5], this technique allows them to improve their interactive and social skills while engaging in an entertaining activity. Some of the most commonly suggested toys to use during play therapy are: dolls, blocks, LEGO®, paint supplies, drawing supplies, board games, animals and cars [5]. In this thesis, we focused mainly on building blocks (such as LEGO® and MEGA BLOKS®). We will follow up on the concept of *LEGO®-Based Therapy* that was proposed by LeGoff in 1994 [6] as it showed optimistic results when tested with children with ASD.

Chapter 1: Introduction

The term Serious Game (SG) was first introduced by Abt in 1970 [7]. He devised games to improve education inside and outside the classroom. Since then, serious gaming has been redefined to encompass any game that presents a utilitarian purpose in education, health care, work training, military, among many others [8]. More recent definitions of serious gaming refer exclusively to computer games (i.e. video games) that have additional goal beyond mere entertainment [9]. For this work, we use the latter definition, since we are solely interested in computer games.

The use of games and toys during early education has been a common practice for several years [10], and educational games dominate the field of serious games [1]. Proving the effectiveness of video games for educational purposes is not an easy task, mainly due the difficulty in defining “educational effectiveness”. Even though several research studies have attempted to prove the effectiveness of video games for educational purpose, very few actually compare a video game with a traditional teaching method [9]. So, the question of whether educational video games provide a better approach to learning compared to traditional methods has not been conclusively answered [9]. However, most studies agreed that video games are more engaging and motivating than conventional teaching methods [10][11][12][13]. Note that there are many similar terms used to refer to educational games, such as e-learning, edutainment, game-based learning, etc. However, we will refer to such games as SGs in this thesis since it is the dominant term in the field and encompasses a wide range of applications beyond education.

Nowadays, with the growing popularity of mobile devices such as smartphones and tablets, video games are becoming even more prominent tools for education [11][14][15]. Even though most of the research involving SGs has been directed to the Typically Developed (TD) community, during the past few years, researchers have reported positive results for the use of SGs in special education [10][11][16]. This thesis contributes to this ongoing effort of catering to special needs individuals, in particular, children with ASD.

Tangible User Interfaces (TUIs) are devices that embed digital technology within graspable objects to realize Human-Computer Interaction (HCI). The TUI, as a gaming interaction style, has proven to be engaging and motivating for children [17]. TUIs take advantage of the human ability to manipulate physical objects and allow users to create a connection between the physical and the virtual world. Hence, children tend to find it easier to interact with a TUI as opposed to a Graphical User Interface (GUI) [17]. While most SGs are digital, TUIs offer an interesting way of coupling the physical and virtual worlds. Sitdhisanguan et al. demonstrated through their experiments that a TUI-based system offers improved ease of use compared to mouse-based systems. In terms of learning efficacy, TUI-based systems can produce superior results over touch-based systems [18]. Moreover, previous researchers have proven that children with ASD enjoy using TUIs to play games [18][19][20]. Henceforth, we will integrate an intuitive TUI into the proposed play therapy system this thesis introduces.

1.2. Motivation and problem Statement

In Section 1.1, we alluded to the fact that SGs can be engaging and motivating. Moreover, SGs have shown promising benefits for individuals with ASD such as an increase in social interaction [12][21] and an increase in cognitive skills [13][22]. Also, we pointed out that TUI-based systems often result in an ease of use that can be helpful for children with ASD [18]. Such systems also offer a richer multimodal interface that can increase the exploratory learning skills of children with ASD [18]. Moreover, the work presented in

[6][23][24] show that non-computer SGs such as building blocks (e.g. LEGO®) can be used during play therapy to improve the social skills of children with ASD. However, to the best of our knowledge, there are no existing solutions that integrate SGs, TUIs, and play therapy techniques within a single tool intended for improving social and cognitive skills of children with ASD. We hypothesize that such tool can aggregate some of the advantages of these techniques while resulting in a highly engaging system.

In this Thesis, we propose a SG as a tool for play therapy, targeting two basic skills: conceptual and social by building on the concept of LEGO®-Based Therapy [25]. We use MEGA BLOKS® (i.e. building blocks) as a TUI integrated electrically with a 3D graphics application running on a computer to create a cognitively stimulating and interactive game. We probe the following research questions:

1. Does the combination of a tangible and a graphical interface lead to an effective educational tool that enhances the basic skills of children with ASD (i.e. conceptual and social)?
2. Is the SG more appealing to children with ASD compared to the non-computer games used for play therapy?
3. Does the SG increase the level of social interaction between children with ASD compared to the conventional non-computer approaches?

1.3. Contributions

In this Thesis, we propose and evaluate a serious game for children with ASD. The suggested system is intended to be used as a tool during play therapy to improve the social and cognitive skills of children.

The main contributions of this Thesis are:

- The design and development of a TUI for children with ASD from 5 to 9 years old. The TUI uses building blocks following the concept of "LEGO®-Based Therapy"[25].
- A computer SG that communicates with the TUI. The SG displays a virtual representation of the TUI with target models to build and provides visual real-time feedback. The main objective of the game is to improve two basic skills: conceptual and social.
- The empirical evaluation of the proposed system through a usability study. The evaluation includes a comparison between the proposed system and an existing conventional clinical method of similar characteristics. The metrics measured for the empirical evaluation correspond to the targeted skills (i.e. conceptual and social).

1.4. Scholarly Achievements

1st place in the Computer Science category of the Faculty of Engineering's Graduate poster competition with the poster "A Serious Game for Children with Autism Spectrum Disorder as a Tool for Play Therapy".

During the process of completing this work, the following paper has been published:

A. Ornelas Barajas, H. Al Osman, and S. Shirmohammadi, "A Serious Game for Children with Autism Spectrum Disorder as a Tool for Play Therapy", *5th IEEE Conference on Serious Games and Applications for Health (SeGAH)*, Perth, Australia, 2017.

1.5. Thesis Organization

The succeeding chapters of this thesis are organized as follows:

Chapter 2 presents a literature review of the related work and the background on Serious Games and Play therapy that are relevant for this thesis. At the end of this chapter we also provide a gap analysis exposing the areas of opportunity that we identified in the state of the art of this field.

Chapter 3 introduces the characteristics of the proposed system along with the technical details of the implementation. This chapter includes the particulars of both the hardware and software modules that compose our system.

Chapter 4 describes the evaluation methods. We report on our empirical evaluation that compared the proposed system to a related conventional tool. This section also details the main challenges and difficulties faced during the evaluation.

Chapter 5 summarizes the conclusions of this thesis and includes ideas for potential future work.

Chapter 2. Background and Related Work

In this chapter, we will discuss the notion of SGs, their applications, and relevant existing work. Hence, first, we will present a general description of SGs. Second, we will discuss educational SGs, especially those intended for children with special needs. Third, we will talk about the concept of play therapy, which forms the basis of this work. Fourth, we will describe the use of TUIs as a mechanism for interacting with similar applications. Finally, we will present a summary and highlight a gap in the existing work.

2.1. Serious Games

As we mentioned in section 1.1, SGs have a primary purpose that goes beyond entertainment. In this sense, SGs use the ‘gaming’ element as a medium to provide an experience, teach a lesson or deliver a message [26]. Serious gaming applications target areas include education, healthcare, energy, government, defence, retail, corporations, research, among others [8]. Due to the popularity of video games, the serious gaming market has grown significantly in recent years and according to a market research report by *MarketsandMarkets*, it is estimated to reach $5,448.82 Million by 2020 [8]. There are major international companies involved in this market, including IBM, Microsoft, Cisco and Nintendo [8].

2.1.1. Serious Games for Education

There are important gaps between the conventional teaching methods used in schools and how knowledge is absorbed by students. According to David Michael and Sande Chen in their book "Serious Games: Games That Educate, Train, and Inform" [26], this leads to a decrease in motivation and engagement among students. The motivation problem becomes more significant as children progress through the school years [7]. According to a CBS news segment in 2005, a typical student loses interest after 15 minutes in the classroom, whereas they can be playing a video game for 2 to 4 hours [26]. Hence, the entertainment element of SGs has the potential to significantly increase student motivation and engagement [27]. The benefits rendered by SGs have promoted their use inside the classroom and during behavioral therapy [11].

All games, regardless of genre, require the player to learn something. At the very least, players have to learn the rules. According to Raph Koster [26], there are certain things that the majority of video games teach, such as:

- Motor skills through hand-eye coordination
- Spatial relationship between 2D and 3D objects
- Curiosity as players learn to seek information and test everything

Clark Abt introduced for the first time the concept of SG in his book "Serious Games" [7]. He described the game *Grand Strategy*, an educational SG that simulates some of the events of World War I. This game was used with junior high school students during a History class to teach them about the Great War [26]. Since then, SGs have been widely used in the classroom to teach different subjects such as: mathematics, physics, literature, science, history and more [28][29]. We discuss two representative examples of such SGs below:

- *SuperCharged!* Is a game intended to teach complex physics concepts, including electromagnetism; Squire et al. examined the effects of *SuperCharged* in an 8th grade classroom and compared it with the traditional methods (i.e. interactive lectures, experiments, and observations). During the study they found statistically significant differences between the group that used the SG and the control group, suggesting that the SG can be effective tools in helping students understand complex physics concepts [30].

- *LearnMem1* is a SG aimed to help students learn concepts about to computer memory. Papastergiou conducted a study to evaluate the impact of *LearnMem1* on educational effectiveness and student motivation. She compared the SG (i.e. *LearnMem1*) with a non-gaming application (i.e. educational website on computer memory). The results of the study showed that the SG was more effective in terms of promoting knowledge and more motivating for students [31] .

In the following section (2.1.2), we will discuss the use of educational SGs for children with ASD and other SEN.

2.1.2. Applications of Serious Games for Special Educational Needs

Most of the research involving SGs is targeted towards Typically Developed (TD) individuals. However, previous work has shown positive results for the use of technology for children with SEN [11][13][22]. Since one of the main characteristics of ASD is the marked impairment in social interaction and communication skills, most of the research is focused on improving these skills [3][14][15]. Below we present a short survey of these applications including details relevant to our work.

Many researchers proposed the use of mobile gaming applications to encourage social interaction for children with ASD. For instance, Hourcade et al. [3] developed the software system "*Open Autism Software*" designed to naturally encourage positive social interactions. This system consists of four applications: (1) *Drawing*, (2) *Music*, (3) *Untangle* (i.e. visual puzzle), and (4) *Photogoo* (image manipulation for emotion modeling). The applications were used during an afterschool program with a group of children with high functioning autism (HFA). The researchers organized collaborative activities such as: storytelling (using the drawing application) and music composition (using the music application). Ribeiro and Raposo [32] introduced *ComFiM,* an interactive communication game that uses a TV screen to display the main GUI and a tablet to allow the user to interact with the game using a Picture Exchange Communication System (PECS). *ComFiM* consists of three levels: for the first level, the player performs an individual message exchange with a virtual tutor using the PECS, and for the second and third levels two players exchange messages using the PECS and the virtual tutor acts as a mediator. Additionally, Fletcher-Watson et al. [33] collaborated closely with pre-school children with ASD to design an iPad application dedicated to rehearse key social communication skills. This application consists of two different modes: (1) the first mode requires the player to find a human character in a scene that contains various distractors; (2) for the second mode, the player has to follow social cues presented by a virtual character; target objects appear in different locations in the scene and the player has to select the object pointed to by the character's social cue (head-turning, eye-gazing direction and pointing). For all three studies, researchers found that the mobile applications contributed to increasing social interaction between children. Furthermore, they found that children were more socially and physically engaged with the application-based activities compared to similar activities that do not use the applications.

Didactic games that involve human-computer interaction can effectively be used to increase the cognitive and academic skills of children with ASD [16]. Gonzalez et al. designed *Sc@ut DS* to help children with special needs associate letters, words or sentences to concepts; *Sc@ut DS* uses Nintendo DS™ and a Wiimote as a user interaction style [16]. Bossavit and Parsons mediated a collaboration between teachers and adolescents with High-Functioning Autism (HFA) aimed at designing a SG to improve the academic skills of the latter in Geography [13]. They adopted a Participatory Design (PD) approach using Kinect as a Natural User Interface (NUI) and body movements to interact with the game; the resulting SG is a question-based game that allows players to "win" countries based on their knowledge of Geography. Through their work, they showed that it is possible to get teachers and teenagers with HFA to collaborate in the design process of a SG.

In Section 1.1, we discussed some of the typical characteristics of ASD. As part of their behavioral struggles during social interactions, children with ASD often suffer from a lack of understanding when it comes to recognizing emotions from facial expressions [34]. Therefore, some SGs such as *LIFEisGAME* [35] and *GameBook* [36] are aimed to help children recognize and express emotion through facial expressions. The goal of *LIFEisGAME* is for the player to associate six different facial expressions on an avatar to the corresponding emotions: happiness, sadness, fear, disgust, surprise, and anger; a further development of the game includes a virtual character synthesis based on the player's facial features. The resultant virtual character is a 3D rendering of the player. This way, the child can identify better with the avatar [35]. Similarly, *GameBook* [36] is an interactive storyteller mobile application that assists children with emotion recognition while promoting motivation and imagination. *GameBook* describes five scenarios with real world situations;

a virtual storyteller describes an emotion evoking situation and the player has to select the appropriate facial expression that best fits the story's emotional content.

2.2. Play Therapy

The Greek philosopher Plato once said, "You can discover more about the person in an hour of play than in a year of conversation" . The first documented case of play therapy was that of "*Little Hans*" as reported by Sigmund Freud in 1909. *Little Hans* was the case of a 5-year-old boy with a phobia of horses. Through correspondence, Freud recommended among other treatment ideas, that Hans and his father engage in role playing games where the father pretends to be a horse as a method of exposure to the feared animal [37]. In 1921, Hermione Hug-Hellmuth was the first therapist to provide play materials during child therapy, as a medium to express themselves [37]. For children, play is a natural medium of communication [37]. They can express themselves better with spontaneous play than with words [37]. According to Landreth in [37] there are eight things that a child can learn from play therapy:

1. Respecting themselves.
2. Realizing that their feelings are acceptable.
3. Expressing their feelings responsibly.
4. Assuming responsibility for themselves.
5. Being creative and resourceful in confronting problems.
6. Exercising self-control and self-direction.
7. Accepting themselves.
8. Making their choices and accept the responsibilities for them.

Some of the most typical objects used during play therapy are: (1) blocks of different materials, sizes, shapes and colours (2) dolls and puppets (3) art supplies such as crayons, markers, paint, paintbrushes and paper of different colors (4) animal figures (5) marbles (6) balls of different sizes (7) puzzles [5].

Since it is commonly said that children with ASD do not play in the same way as TD children do, play therapy for this population has become a common research topic [5]. The term *AutPlay Therapy* has been used specifically for play therapy applied to children and adolescents with ASD [38]. The psychologist Morgenthal documented a case study based on Child-Centered Play Therapy (CCPT) for children with autism in [5]. During her 2-year study she found an increase of communication skills with her patient as well as an increase in spontaneous symbolic play behaviour.

2.2.1. LEGO Therapy

Building blocks such as LEGO® are a popular tool used for play therapy. Several studies have shown the advantages of these toys in improving social skills. For example, LeGoff used LEGO® play, in both group and individual therapy, to improve the social competences of children with ASD [6]. The structure of the therapy includes three roles: the engineer, the builder and the supplier. The roles are distributed among the players and rotated so that every child has the opportunity to assume each one of the different roles. LeGoff also demonstrated the long term benefits of this technique through a 3-year study that showed that "the LEGO® groups made twice the gains demonstrated by the control group on the VABS–SD (Vineland Adaptive Behavior Scales–Socialization Domain)"[24]. And more recently, LeGoff et al. [25] released a book on LEGO®-Based Therapy where they provide an evidence-based manual for professionals working with children with ASD and related conditions. The manual provides a detailed guide for setting up *LEGO®-Therapy* groups.

Following LeGoff's work, MacCormack et al. [23] suggested a community-based LEGO® social-skills program for youth with ASD. The idea was to apply a clinical intervention method in a non-clinical environment and see if the results held. They used the main of the aspects from LEGO® Therapy such as the rotation of three roles and the use of structured play versus unstructured play. During the study they found a congruity of play skills and social skills.

2.2.2. Other Therapeutic Serious Games for Autism and other Special Needs

In Section 2.1.2 we talked about SGs for SEN, we mentioned some of the existing systems that have been studied. And even though some of those games could be used during play therapy, they were mainly thought to be used in a non-clinical environment for recreation or for educational purposes. In this section we will mention some SGs that are aimed to be used for therapeutic purposes.

For children with ASD, emotion recognition exercises are often an important component of therapy [39]. For this purpose, Carter et al. documented the interaction between children and avatars [40]. During their study, they analyzed if the interaction between children with ASD and avatars is affected by the appearance of the avatar; they compared the participants' reaction to cartoon avatars, realistically rendered 3D avatars, and a video showing human subjects. Their results showed an improvement in nonverbal social behaviors when avatars with exaggerated facial expressions are used. Christinaki et al. [39] designed a SG using Kinect as a NUI where simple hand gestures are used to select the correct answers to questions presented on the screen. The game has three levels: (1) in the first level, the player has to label the emotional content of images, (2) in the second level, the player has to recognize an emotion given by a description and associate it with a facial expression, (3) and in the third level, the player has to identify the causes for emotions in a given situation. Similarly, *emot-iCan* is an application that can be used for emotion recognition assessment. It allows an administrator (e.g. parent, teacher or therapist), to design a custom simulated scenario that result in a character displaying particular facial expressions. The application prompts the child to match the requested expression; the application allows the administrator to choose between cartoon faces or real photos [41].

Pivotal Response Treatment (PRT) is a behavioral intervention for ASD that therapist employ in order to address key (pivotal) skills [14]. One of these pivotal skills is *multiple cue responding* which allows people to make a decision based on two pieces of information [42]. *Go Go Games* is a suite of SGs that targets this skill using PRT as a therapeutic approach. This applications consists of three games, ("*Build-a-Train*", "*Wheels and Roads*", and "*Out of this World*". For each one of the games, players have different options and they have to select the correct choice based on the information that is given [14].

2.3. Tangible User Interfaces

The coupling between the physical and the digital worlds has been a common concern of researchers for some time [17]. Such coupling can be achieved through the use of TUIs [43]. TUIs are graspable objects embedded with digital technology [19]. Below are some of the benefits that can be reaped through the adoption of TUI as an interaction style:

- They can be easier to use compared to other UI interaction styles; such as WIMP (windows, icons, menus, pointer) [44] and mouse or touchpad [17].

- They can be more accessible than other UI interaction styles [18].
- They may promote collocated cooperative work [45].
- They can offer a rich multimodal interface [18].
- They can increase task engagement and exploratory learning [18].
- They offer a coupling between the physical and digital world [17].
- They can be shared and passed between multiple users [19].
- They may exhibit positive effects on learning [46].

2.3.1. Using TUIs for Children with Autism Spectrum Disorder

Block-based toys have been used as TUI tools in education and play therapy targeting different types of skills as discussed in section 2.2.1. Farr et al. studied the effects of using *Topobo*, a construction toy with programmable movement using plastic blocks similar to LEGO®, as a tool to improve the social skills of children with ASD [19]; during their study, they compared conventional blocks (i.e. LEGO®) versus technology-embedded blocks (i.e. *Topobo*). Their results showed an improvement in collaborative play and reduction in solitary play associated with *Topobo* compared to conventional blocks; their findings suggest that toys with embedded digital technology may lead to an increase in social interaction. Other examples of TUIs include the use of tabletops and smart objects. Piper et al. introduced *SIDES*, a puzzle-style game with a tabletop TUI that aims to improve the social and cognitive skills of adolescents with ASD. Their findings suggest that the use of TUIs can be conducive to an engaging experience in a cooperative gaming setup [21]. Escobedo et al. [20] introduced *Things that think (3T)*, a system composed of smart object that allows teachers to provide object discrimination training for children with ASD; this type of training consists of repetitive trials to help children identify objects.

2.4. Summary and Gap Analysis

Table 1 presents a comparison between the related works described in this chapter that focuses on four important aspects:

1) Age range (of children that benefit from the system)
2) Skills targeted (for improvement through the proposed system)
3) Platform (i.e. type of device used to run the system)
4) User Interaction Style (i.e. GUI, NUI, TUI or a combination of several styles)

Table 1: Related works comparison

System	Age range	Skills targeted	Platform	User Interaction Style
ComFiM [32]	5-11	Social	TV screen and tablets	GUI
Open Autism Software [3]	10-14	Emotion recognition, motor and collaborative skills	Tablet	GUI
GameBook [36]	Not mentioned	Emotion recognition	Tablet, smartphone or laptop	GUI
LIFEisGAME [35]	4-11	Emotion recognition	Computer	GUI
Fletcher-Watson et al. [33]	Under 6	Social	Tablet	GUI
Sc@ut DS [16]	Not mentioned	Cognitive and social	Nintendo DS and Wiimote	GUI
Bossavit and Parsons [13]	11-15	Academic	Screen and Kinect	GUI + NUI
LEGOTherapy [6]	6-16	Social	LEGO	-
Carter et al. [40]	6-10	Social	Computer	GUI
eMot-iCan [41]	Not mentioned	Emotion recognition	Tablet or smartphone	GUI
Christinaki et al. [39]	2-6	Emotion recognition	Screen and Kinect	GUI + NUI
Go Go Games [14]	Not mentioned	Multiple cue responding	Tablet or smartphone	GUI
Topobo [19]	8-11	Gross motor and social	Blocks with embedded system	TUI
SIDES [21]	11-14	Social and cognitive	Tabletop	TUI
Things that think [20]	3-8	Discrimination training	Smart objects	TUI
Our The proposed system	5-9	Social and cognitive	Computer Screen and building blocks	GUI + TUI

Gap Analysis:

There is no doubt that serious gaming has proven to be a motivating educational method [10][16][14]. But, purely GUI based videogames lack the interaction with physical objects, while TUIs have shown to be engaging and have improved collaborative play in previous cases [17][19].

One of the biggest challenges when developing a SG for children with ASD, is to address social interaction and communication problems. There are different known strategies used to improve communication skills in children with ASD. Some children with ASD respond better to visual instructions, rather than verbal ones. Also, one of the most successful strategies to improve social interaction is to use visual support [47].

Hence, we identify two gaps in existing systems:

- Purely GUI based videogames for children with ASD lack the interactive quality that TUIs provide.
- Conventional therapy techniques that use tangible objects (e.g. LEGO® Therapy) lack the visual feedback that children with ASD often respond to.

We propose to add a GUI to the conventional non-computer LEGO®-Based Therapy as a form of visual feedback; we will examine whether the resulting game becomes more appealing and engaging. We will also evaluate whether the proposed game encourages more social interaction during group play.

Chapter 3. Proposed System

In this Chapter we will discuss the proposed system. Hence, we will present a general overview of the SG and provide design and implementation details of each of its modules.

3.1. System Requirements

Based on the gap analysis presented in Chapter 2, we identify few important features that our system must support:

- **Targeting social and cognitive skills:** The main challenges associated with ASD are related to the development of social and cognitive skills [1]. Therefore, our system will target the improvement of these skills using effective strategies such as LEGO® Therapy [6], tangible interfaces [19][46][18] and computer-based serious games [40][36][48].
- **Integrating interactive multimedia visual support:** Interactive multimedia using visual support has been used for therapy and special education [49]. Multimedia solutions appear to be more engaging and entertaining than non-technological approaches [3][19][47]. Thus, we will strive to realize an engaging and motivating system through the integration of such feature.
- **Highlighting positive feedback:** Children with ASD tend to get frustrated or discouraged when they receive strong negative feedback [18]. Furthermore, in some cases, a child with ASD (especially with low functioning autism) might develop a preference towards the negative feedback, causing a repetition of incorrect behavior [18]. Conversely, a reward system can encourage children to continue playing and

helps them stay focused on the game [50]. Hence, the proposed SG will minimize negative and emphasise positive feedback.

- **Using graspable objects:** Tangible objects offer several advantages including a low learning curve and an increase in task engagement and exploratory learning [18]. TUIs have shown a great potential for children with ASD [18][19][20], and we think that the adoption of a TUI will render the proposed SG more engaging.

3.2. System Overview

We adopt an approach in serious gaming that combines a TUI and a GUI. We take advantage of these two user interaction styles to bridge the gap between the physical and the digital world. Hence, we build on top of an existing mental model the children possess about the real world to enable them to interact intuitively with the SG. Our choice of TUI is building blocks due to the proven popularity and social benefits of the toy. Moreover, it is one of the suggested toys for play therapy [5]. Specifically, we use the MEGA BLOKS® maxi, with the dimensions of $3 \times 3 \times 6$ cm^3 to build our TUI. We use large blocks since some children with ASD have difficulties with fine motor skills [6]. Therefore, the large blocks are easier to manipulate. The proposed GUI displays a 3D graphics simulation whose state is changed through the interaction with the TUI.

Through the proposed interactive SG, we intend to provide a tool that stimulates the basic skills of children with ASD and improves their adaptive behaviour. To play the game, children interact with the system using the TUI (i.e. physical building blocks). At the start of the game, the GUI displays a virtual representation of the TUI and a target model; the player has to replicate this model onto the TUI using the physical blocks (See Figure 1). With each block the player places on the TUI, the GUI provides real-time feedback (positive or negative) until the constructed model and the target model match at which point the level is considered to be completed. In the following subsections we describe the design and implementation details of the proposed system; Section 3.4.1 provides details about the TUI and Section 3.4.2 about the GUI.

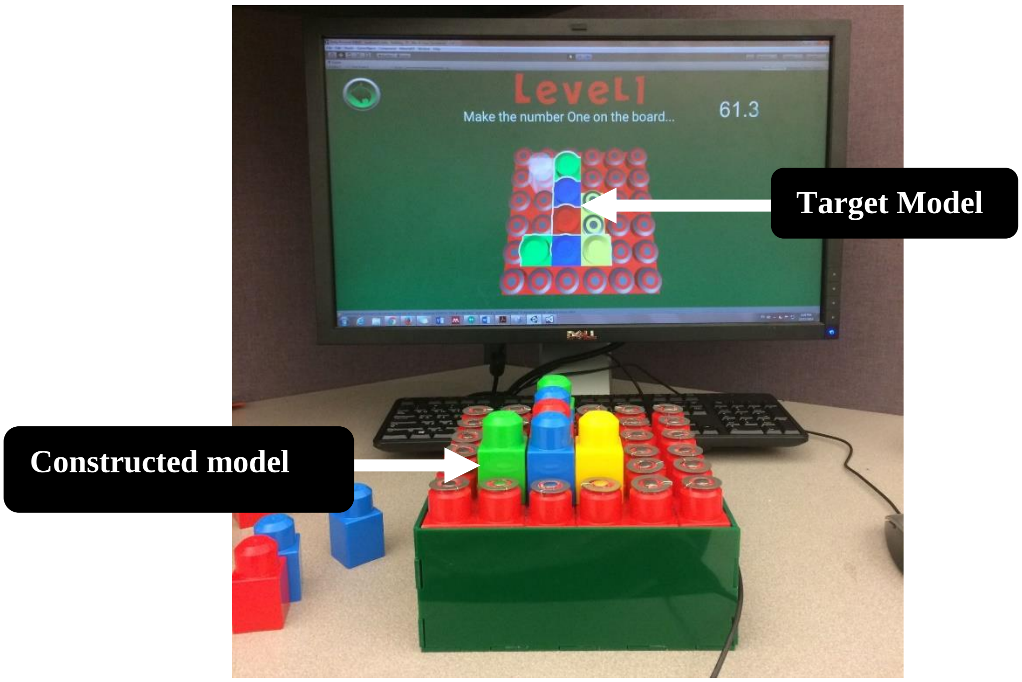

Figure 1: Proposed SG

3.3. System Architecture

The system is divided in two main parts, the board interface (i.e. TUI) and the computer interface (i.e. GUI). The board interface is composed of four modules: block detection, codification, data transfer, and data collection. The computer interface has three modules: mapping, game management, and multimedia output. Figure 2 shows a diagram of the system architecture and below we describe the details of each module.

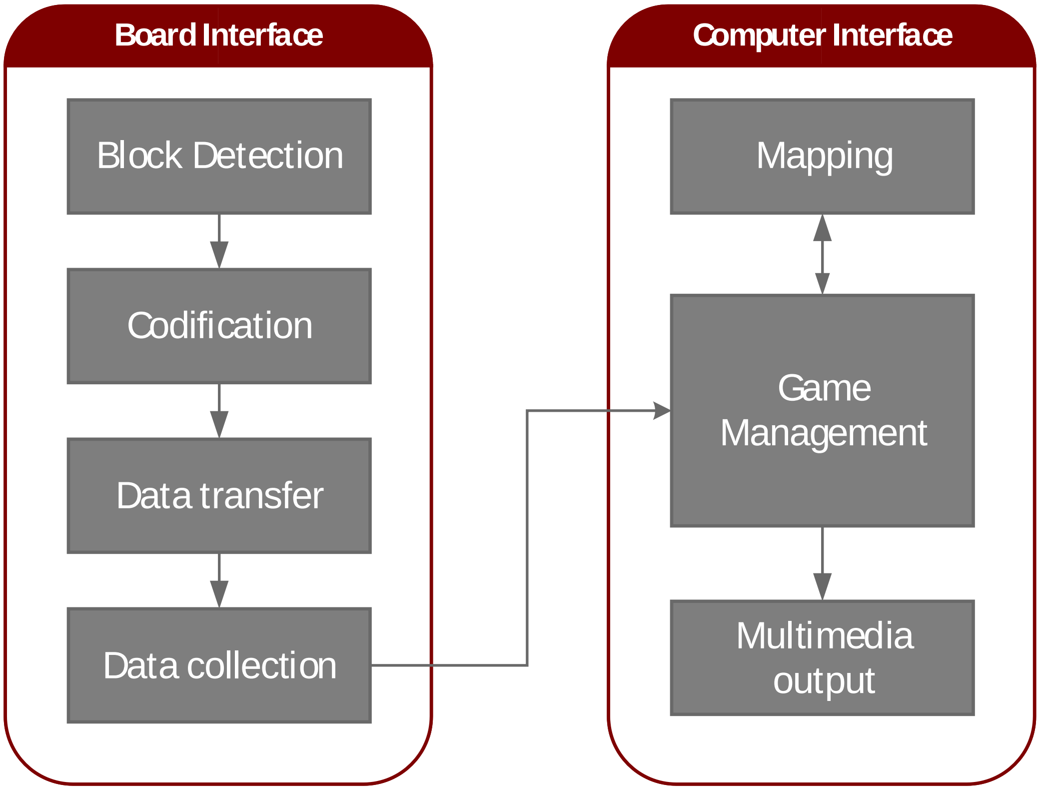

Figure 2: System Architecture diagram

a) **Block detection:** This module is in charge of detecting when a block gets connected/remove to/from the cluster. Each block has an internal resistor that gets connected to the board circuit when the block is placed on the board. The value of the resistor represents the colour of the block (ColourID). The block detection module has to detect all connected blocks. This module recognizes the resistor value of a connected block through a voltage divider circuit whose output is connected to an Analog-to-Digital-Converter (ADC) port on one of the board's microcontrollers (see section 3.4.1 for more information about the hardware structure of the board). This module also tests whether the value outputted by the ADC is valid (i.e. block connected/removed) or invalid (i.e. noise). Hence, it compares the value retrieved from the analog to digital converter to a threshold. Any value below that threshold is judged to be noise and ignored. The threshold was identified after careful testing of all blocks.

b) **Codification:** The identification module is responsible for assigning a code to a newly connected block. The code stores three pieces of information about the block into three bytes: the first byte describes the colour of the block (ColourID), the second byte details position of the block on the board (PositionID), and the third byte indicates whether the block is connected or removed from the cluster (StateFlag).

c) **Data Transfer:** Once the block is assigned a code, the data transfer module makes sure that the code is sent to the data collection module through a communication bus.

d) **Data Collection:** The data collection module receives the code through the communication bus and relays it to the game manager module in the computer interface.

e) **Game management:** This module is responsible for executing the game logic. It performs three main tasks: 1) receive the code sent by the data collection module of the board interface and convey it to the mapping module, 2) compare the information from the constructed model with the target model (See Figure 1), and 3) make a decision regarding the type of feedback (i.e. positive or negative) based on the comparison (if there is a match, positive feedback should be displayed, and if there is a mismatch, negative feedback should be presented). This decision is sent to the multimedia output module.

f) **Mapping:** This module is in charge of transforming the constructed model to its virtual representation. For this purpose, the mapping module receives the code and retrieves the information it encapsulates (i.e. PositionID, ColourID and StateFlag). It also sends the necessary updates the virtual model depending on the StateFlag. If the StateFlag indicates that a block was added to the cluster, the mapping module sends the information of the new block (i.e. ColourID and PositionID) so that the virtual model gets updated. Conversely, if the StateFlag indicates that a block was removed, the mapping module removes the block from that PositionID from the virtual model.

g) **Multimedia output:** Displays a virtual representation of the TUI including both the target model and the constructed model. Note that the target model represents the model that the player must construct while the constructed model is a digital rendering of the model the player has constructed so far using the TUI. The target model is represented with transparent colored blocks and the virtual constructed model is represented with opaque colored blocks. This module also displays visual and auditory feedback based on the decision made by the game management module. The positive feedback consists of a glowing effect and a colour change (i.e. from transparent to opaque), and the negative feedback displays a message with instructions to move the block.

3.4. System Design and Implementation

In this section we describe the implementation details of the system's components.

3.4.1. The TUI

As mentioned previously, the proposed SG uses building blocks as a TUI (MEGA BLOKS® maxi). We use large blocks to accommodate ASD children with fine motor skills' impairments. Also, the large blocks offer more space for the integration of electrical elements.

The Blocks:

The blocks are all of the same size, with four different colours: red, blue, green and yellow (see Figure 3). Internally, each one of the blocks has a spring with one end attached to the top and the other to a circuit; the spring allows the circuit board to move vertically inside the block (see Figure 4). The circuit board consists of a resistor connected to two terminals. The terminals are concentric circles. The value of the resistance determines the ColourID of the block (see Table 2).

Figure 3: Blocks

Table 2: Resistor Values

Block Colour	Resistance (Ω)
Red	0
Blue	2.2k
Green	3.3k
Yellow	4.7k

The board:

As shown in Figure 4, the board is a square constructed using 36 individual blocks (6 by 6 matrix). It consists of red blocks, except for the 4 middle blocks which are yellow, to serve as a reference point for the child so that she/he can more clearly compare the target model shown on the screen to the physical one being built (i.e. constructed model). Inside the board there are four microcontrollers, one master and three slaves communicating using the Inter-Integrated Circuit (I2C) protocol. Figure 7 shows the electrical diagram of the board. Each stud (i.e. block head) on the board has two concentric terminals, resembling the ones from the circuit board inside the blocks (see Figure 4). All internal terminals are connected to the VCC power supply and each external terminal is connected to an ADC channel on one of the microcontrollers. The microcontrollers map the ADC channels to a position on the board. The position is indicated by a character assigned to each stud (i.e. A-Z and 0-9, See Figure 5).

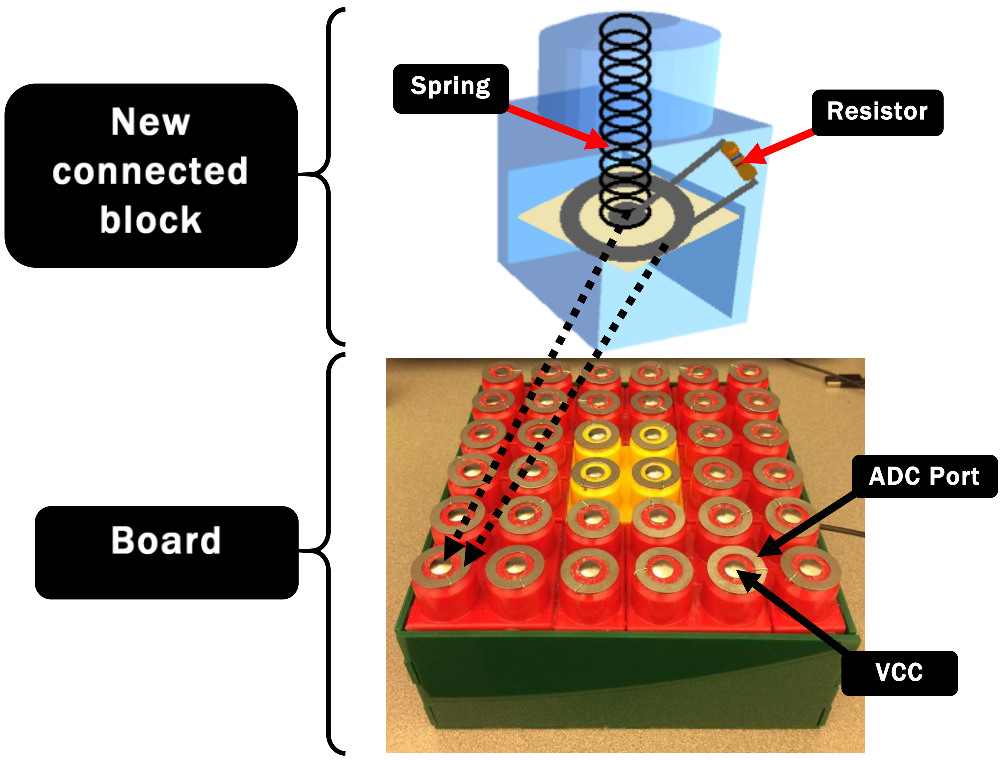

Figure 4: Tangible User Interface

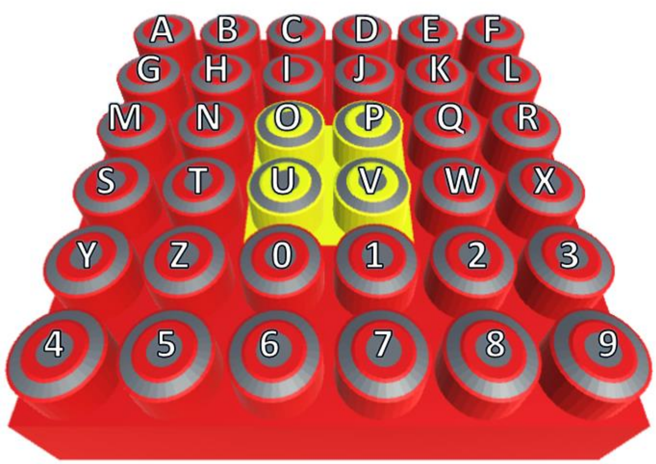

Figure 5: Board PositionID

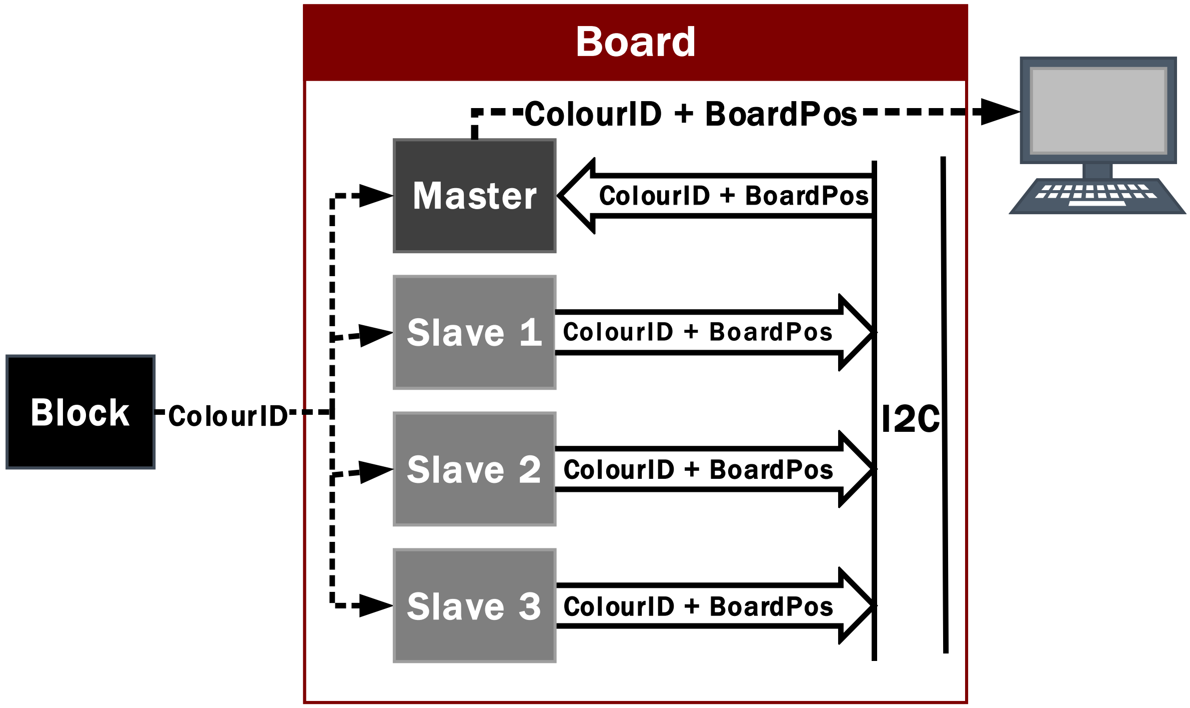

Figure* 6*: System communication diagram

Functionality:

When a block is placed on the board, the resistor gets connected to the ADC port of one of the microcontrollers (see Figure 4 and Figure 7). Then, the microcontroller receives the block ColourID obtained from the resistance. The slave microcontrollers map the ADC channel to a position on the board and send the information to the master through the I2C bus (see Figure 6). The master microcontroller reads the position and the ColourID, generates the block's code (See Table 3), and forwards it to the computer via a serial communication link (i.e. UART). Similarly, when a block is removed from the board, the code is passed to the computer. When the game manager module executing on the computer receives the latter information from the TUI, it updates the graphical representation. Figure 8 shows the details of the process running on the microcontrollers using a UML state machine. The SG software (i.e. the game management module) records the performance of the user which is assessed by comparing the constructed model (i.e. the model physically built on the TUI) to the one the target model.

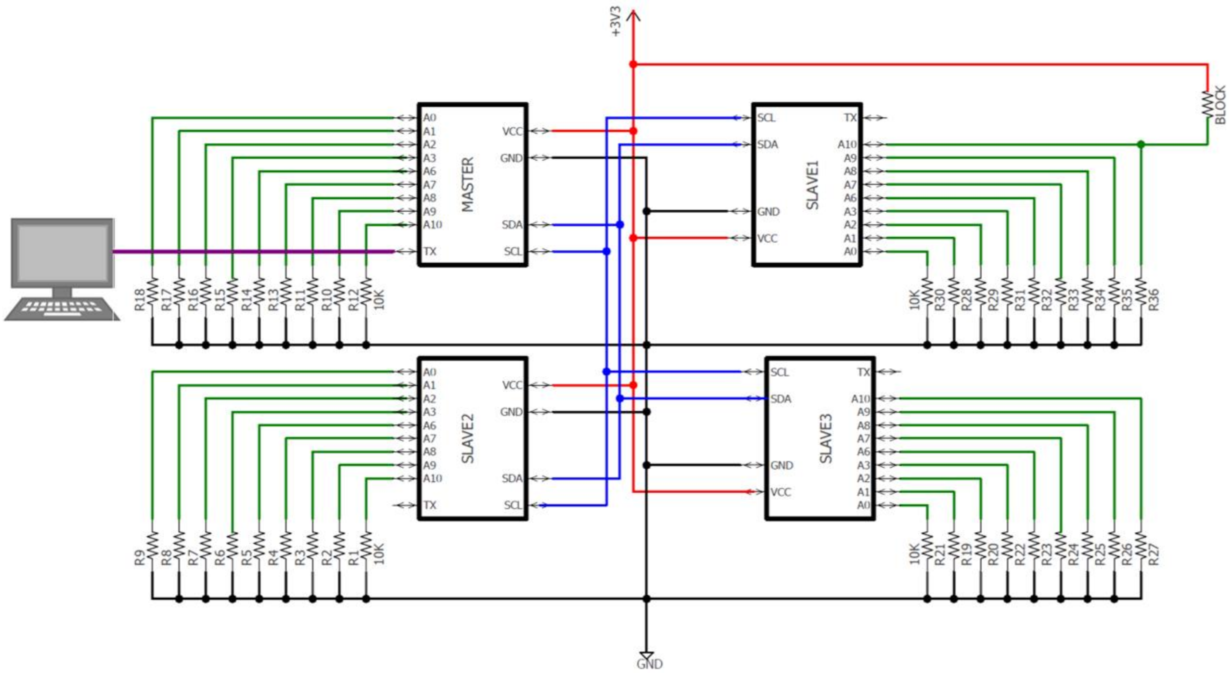

Figure 7: Electrical Diagram

Table 3: Code example

Code = PositionID + ColourID + StateFlag	
A r n	
A (PositionID)	Character associated with stud on the board (A-Z and 0-9)
r (ColourID)	r= red, b= blue, g= green, y=yellow
n (StateFlag)	n= new block, r= block removed

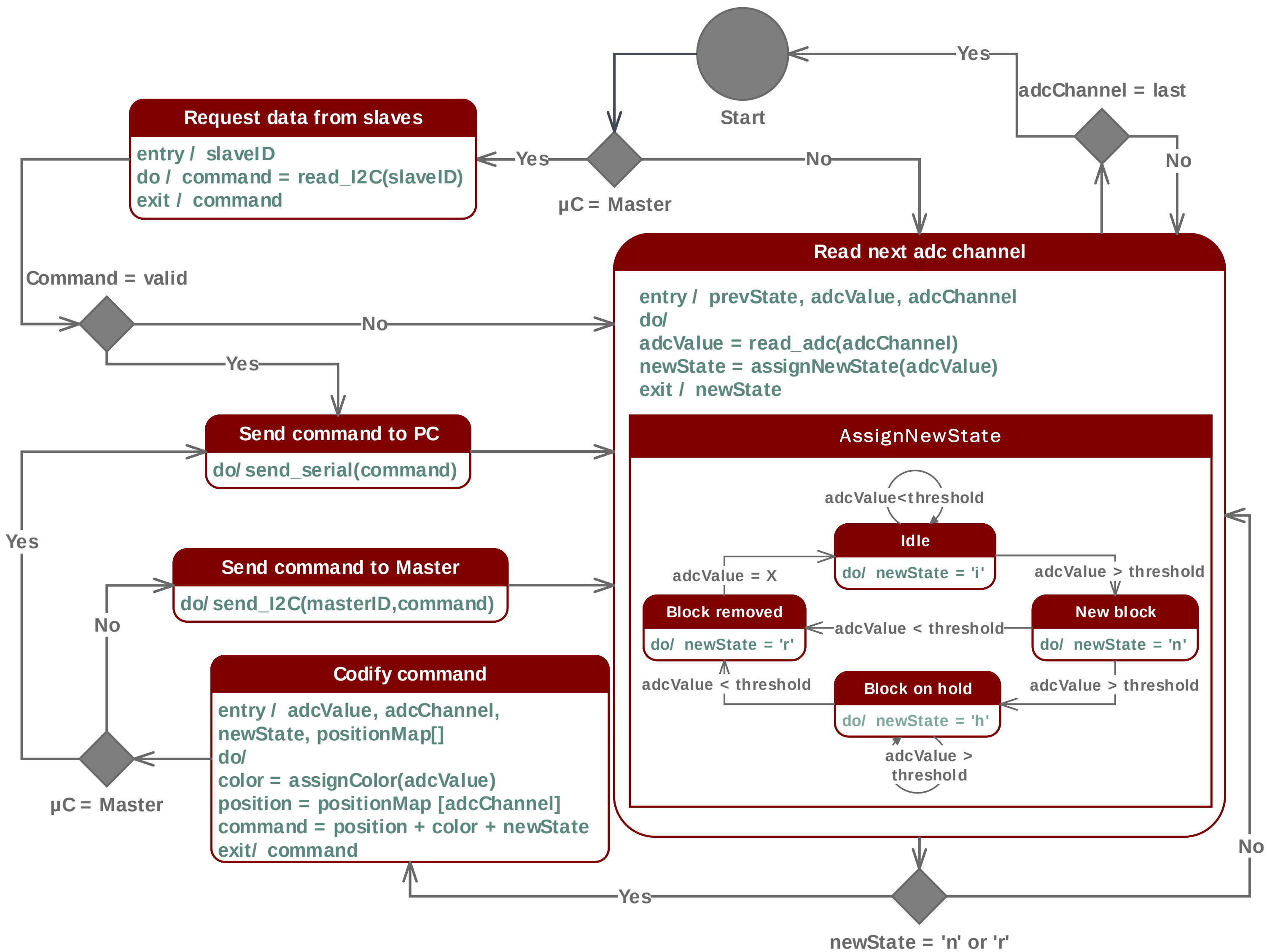

Figure 8: Microcontroller UML state machine

3.4.2. The GUI

The game features a 3D GUI to display a virtual representation of the TUI. From the main menu of the game, the player can choose between different available mini-games. Each mini-game consists of a different model representing a number, letter, or pattern. Figure 9 shows few examples of these mini-games. The player is assigned the task of replicating the target model given by the computer onto the physical board (i.e. TUI). Each time a block is placed on the board, the TUI reads the position of the block and relays the information to the GUI. Figure 9.1 and 15.2 show a transparent white models (i.e. target models). This means that the user(s) only needs to match the pattern for level 1 (i.e. the number 2 and letter A). Figure 9.3 and 15.4 depict colored models (i.e. target models) and hence the user(s) has to match both colour and pattern in level 2.

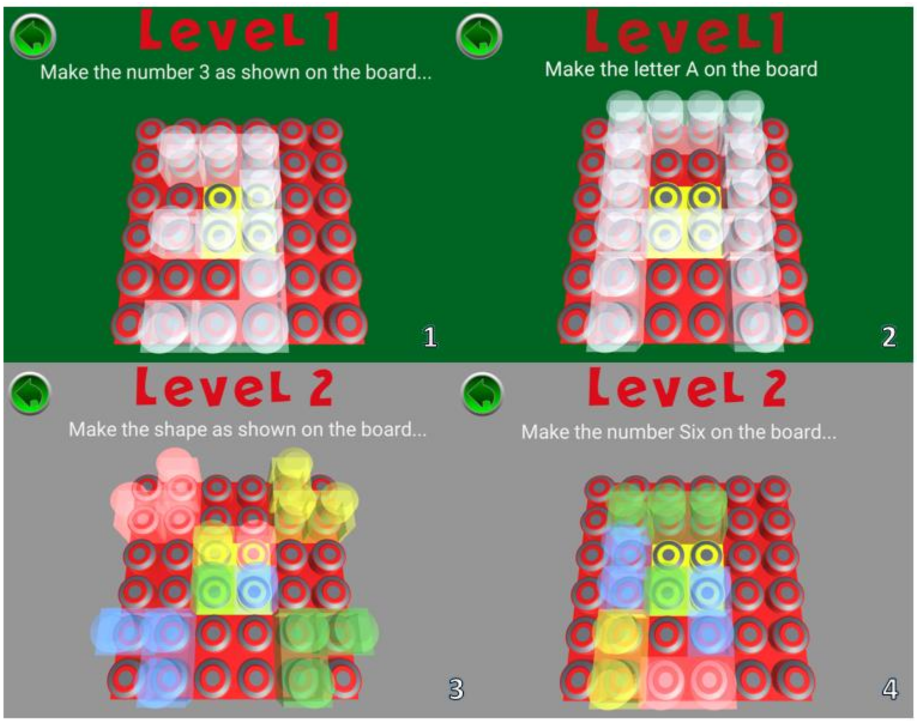

Figure 9: Examples of mini-games

Functionality:

Figure 10 shows a sequence of moves to complete a mini-game. At the start of the mini-game, the screen shows the target model with transparent blocks (Figure 10.1), the timer starts running and the player needs to replicate the model on the physical board with the available blocks. If a block is placed on the correct position (Figure 10.2), the GUI presents a positive visual effect (e.g. glowing particles) and the transparent block becomes opaque matching the color of the corresponding physical block placed on the board. If the block is placed on the wrong position, the GUI outputs instructive feedback to remedy the problem, as shown in Figure 10.*4* (the feedback consists of a message indicating that the block is in the wrong position and the corresponding block is highlighted in white). We minimized the negative feedback to avoid any possible frustration by the users and to encourage them to try again. Once the user(s) complete(s) building the model, the game displays a success message (Figure 10.6) and asks the user(s) to remove all the blocks from the board to proceed to the next mini-game. Similarly, when all the mini-games from level 1 have been completed, the game moves to level 2.

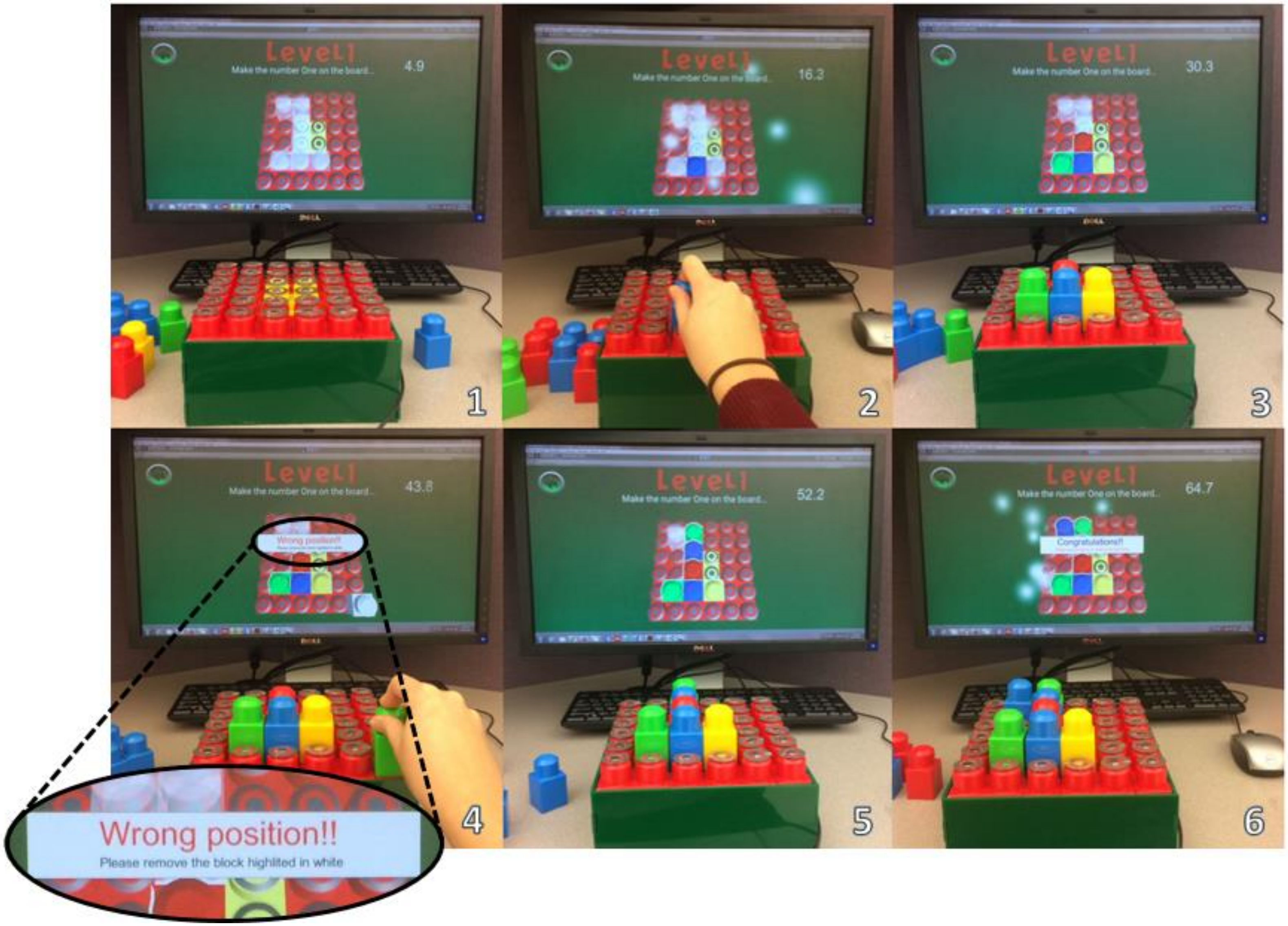

Figure 10: Game in action

Chapter 4. Evaluation Method

4.1. Experiment 1 (Unstructured play)

We conducted an experiment that compares the proposed SG (i.e. computer SG) with a non-computer SG , similar to the one described in [25] during a *LEGO®-based Therapy* session. For the purpose of the statistical analysis, we considered the computer SG to be the "intervention" method and the non-computer SG to be the "control" method. Even though this experiment was originally planned to involve structured play (i.e. assigning different roles to the players), our setup was not ideal and children were not able to assume such roles. Therefore, we decided to drop role assignment and consider this experiment to involve "unstructured play" (i.e. players do not have specific roles). We deferred the structured play setup for experiment 2. More details about the difficulties that resulted in this decision are covered in the discussion sub-section 4.1.8. Experiment 2 (See section 4.3) describes the process for the structured play experiment, and section 4.2 includes the details of the modifications we made to the experiment setup to resolve the issues identified in experiment 1.

Our experiment was approved by the Office of Research Ethics and Integrity at University of Ottawa (File Number: H06-16-09). The experiment was conducted during two consecutive days; five children were tested on the first day and four children on the second day. The total duration of the experiment was approximately one hour each day. Parents of the participants were present at all times.

4.1.1. Participants

The participants were recruited from Children at Risk, a community organization in Ottawa that provides services to families of children diagnosed with ASD. Due to the nature of this research on a special population, the number of participants was limited. Nine children between the age of 6 and 15 years old (M=10, SD = 3.20) volunteered to participate. All participants were diagnosed with ASD according to clinical opinion, and all of them were boys. Given that ASD is significantly more common among boys than girls [2], it was not surprising that all volunteers that came forward were male.

4.1.2. Apparatus

Proposed SG (i.e. Intervention method): We developed a SG for children on the ASD composed of a TUI and a GUI, as described in Chapter 3. The SG is envisaged as a play therapy tool aimed at improving social and cognitive skills of children with ASD (See Figure 11).

Non-computer SG (i.e. Control method): The control method uses cards depicting an image of the model (See Figure 11); the cards are approximately 10 x 10 cm. This is a similar approach to the one used in *LEGO®-based Therapy* [25].

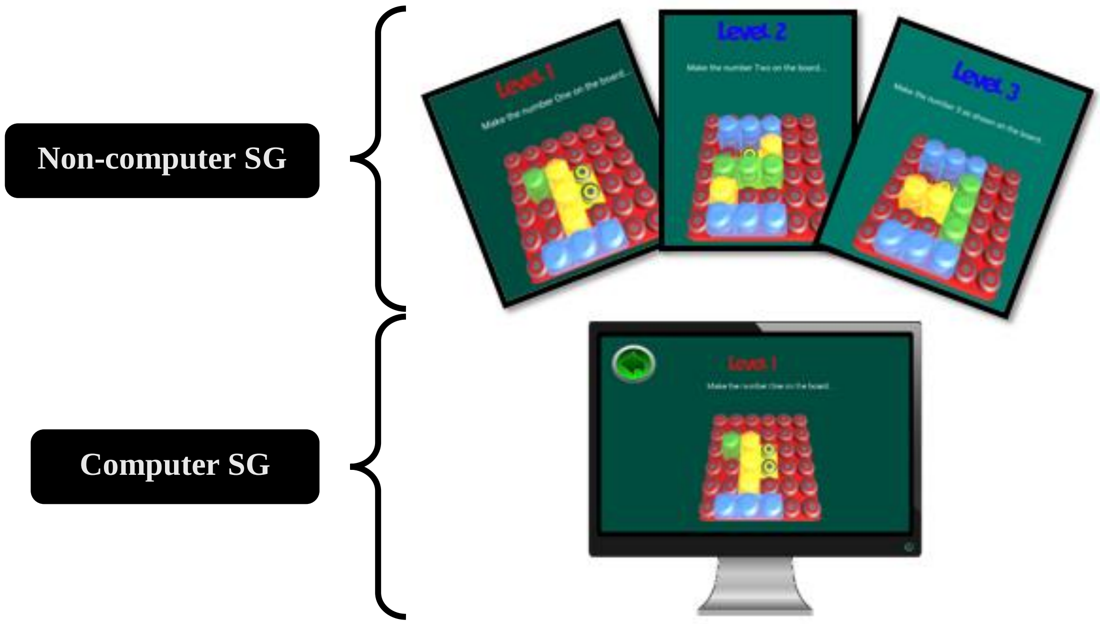

Figure 11: Non-computer SG vs Computer SG

4.1.3. Independent Variable and Dependent Measures

Independent variable: The type of game was our only independent variable, consisting of two levels: a) computer SG (intervention, i.e. proposed SG) and b) non-computer SG (control).

Dependent variables: These dependent variables were chosen to evaluate the targeted skills (i.e. conceptual and social). We used an observational grid and an exit survey (See Appendix 1 and Appendix 2) to record the following dependent variables:

- *Self-initiated social interaction (continuous):*

  The number of self-initiated social interactions. A social interaction was only counted if it met the following criteria: a) it was spontaneous and unprompted, b) it was not a response to another individual's contact, and c) it involved a clear attempt to communicate (verbal or nonverbal) with a peer or the instructor. Similarly, LeGoff used the variable "self-initiated social contact" in [6] to measure social interaction.

- *Solitary play (continuous):*

  The percentage of time the participant spent playing alone. The solitary play time was considered whenever the participant was not collaborating with anyone else and she/he was only playing by herself/himself. Farr et al. used a similar variable in [19] to observe solitary play behaviours.

- *Collaborative play (continuous):*

  The percentage of time the participant spent playing with other participants. The collaborative play time was only considered if the participant was cooperating and contributing to a common goal with other participants. Farr et al. used a similar variable in [19] to observe co-operative play behaviours.

- *Disengagement (continuous):*

  The percentage of time the player was not engaged in the game. This variable represents the percentage of time during which the participant was not actively participating in the game (i.e. performing another activity). Farr et al. used a similar variable in [19] to observe disengagement.

- *Positive vocalizations (continuous):*

  The number of times the participant expressed a positive thought about the game. A positive vocalization was considered if the participant showed one of the following behaviours while she or he was playing: a) laughing, b) expressing positive comments about the game, such as: "I like the colours", "I like this", "this is pretty", "this is fun", "I am having fun", etc. c) engaging excitable bouncing, d) uttering positive vocalization such as: “yes!”, “great!”, “yeah!”, etc. A similar metric was proposed in [17] to measure engagement.

- *Performance (continuous):*

  The number of mini levels (i.e. models) the player(s) successfully completed during play time. This variable considered the models completed collaboratively and individually.

- *Assistance (continuous):*

  The percentage of time we spent assisting the player(s) to complete the game. An assistance event was considered if one of the following scenarios occurred: a) the participant asked for help, b) the participant made a mistake in the game and needed correction, c) the participant disobeyed the rules or needed clarification, d) the participant required prompting to proceed with the game, d) the participant was not able to complete the task by herself/himself. Please note that this variable was calculated relative to the amount of time the player was engaged with the game as opposed to the total amount of time of play (which included periods of time where the player was performing non-game related activities). The amount of assistance needed was also considered by Sitdhisanguan et al. in [18] to assess the ease of use of a system.

- *Exploratory behavior (dichotomous)*:

  A yes or no variable that reflects whether the participant showed curiosity and interest beyond the objective of the game, such as: a) taking turns without prompting, b) organizing blocks per colours, or c) asking about the functionality of the system.

- *Preferred game (dichotomous):*

  At the end of the experiment, participants were asked to vote for their favourite type of SG (computer vs non-computer) during the exit survey (See Appendix 1).

4.1.4. Hypotheses

LEGO®-Based therapy has been shown to render short and long term social skill improvements for children with ASD [6][24]. Similarly, computer-based SGs have been shown to be useful for improving the social and cognitive skills of children on the ASD [3][14][15][16]. Furthermore, TUIs are easier to use for many human-computer interaction tasks, and have been proven to enhance task engagement, exploratory skills, and collaborative play [17][18][45][21]. Thus, in this experiment, we aim to empirically substantiate the following hypotheses:

- **H1**: There is a statistically significant increase in *self-initiated social interactions* when the computer SG is used compared to the non-computer SG.
- **H2**: There is a statistically significant decrease in *solitary play* when the computer SG is used compared to the non-computer SG.
- **H3**: There is a statistically significant increase in *collaborative play* when the computer SG is used compared to the non-computer SG.
- **H4**: There is a statistically significant decrease in *disengagement* when the computer SG is used compared to the non-computer SG.
- **H5**: There is a statistically significant increase in *positive vocalizations* when the computer SG is used compared to the non-computer SG.

- **H6**: There is a statistically significant increase in *performance* when the computer SG is used compared to the non-computer SG.
- **H7**: There is a statistically significant decrease in the *assistance* needed when the computer SG is used compared to the non-computer SG.
- **H8**: There is a statistically significant increase in *exploratory behavior* when the computer SG is used compared to the non-computer SG.
- **H9**: There is a statistically significant *preference* for the computer SG over the non-computer SG.

4.1.5. Procedure

On *Day 1*, at the beginning of the experiment, the parents of the participants signed a consent form and answered a questionnaire about their children. The questionnaire included questions about their children's experience with using computer applications and educational games (See Appendix 1). Then, the children were divided into two teams (Team A and Team B) according to their age (i.e. young children grouped together and older children grouped together). Each team had two or three members. For the first phase of the experiment, Team A was assigned to play with the non-computer SG (i.e. control method) and Team B was assigned to play with the computer SG (i.e. intervention method). Both teams received relevant instructions for their assigned game. They were given 15 minutes to play. The difficulty level of the game was adjusted when necessary (i.e. if the teams found it too easy or too hard to complete).

For the second phase of the experiment, the teams switched SGs and they were given the same amount of time (15 minutes) to play. Finally, at the end of the experiment, participants were asked to choose their preferred game. On *Day 2*, the same procedure was repeated for Team C and Team D.

Figure 12 shows a diagram of the experimental setup. The participants were sitting in front of the computer screen (or the cards, if the non-computer SG was used). The participants were instructed to work together to build the model displayed on the screen (or depicted on the cards). We video recorded the experimental session for later analysis. The instructor was near the participants, assisting them whenever it was necessary (i.e. when they became uncooperative). The parents were sitting away observing the experiment, and they only interfered if the participant did not listen to the instructor. At the end of the experiment, parents were asked to fill a survey to provide their feedback (See Appendix 1).

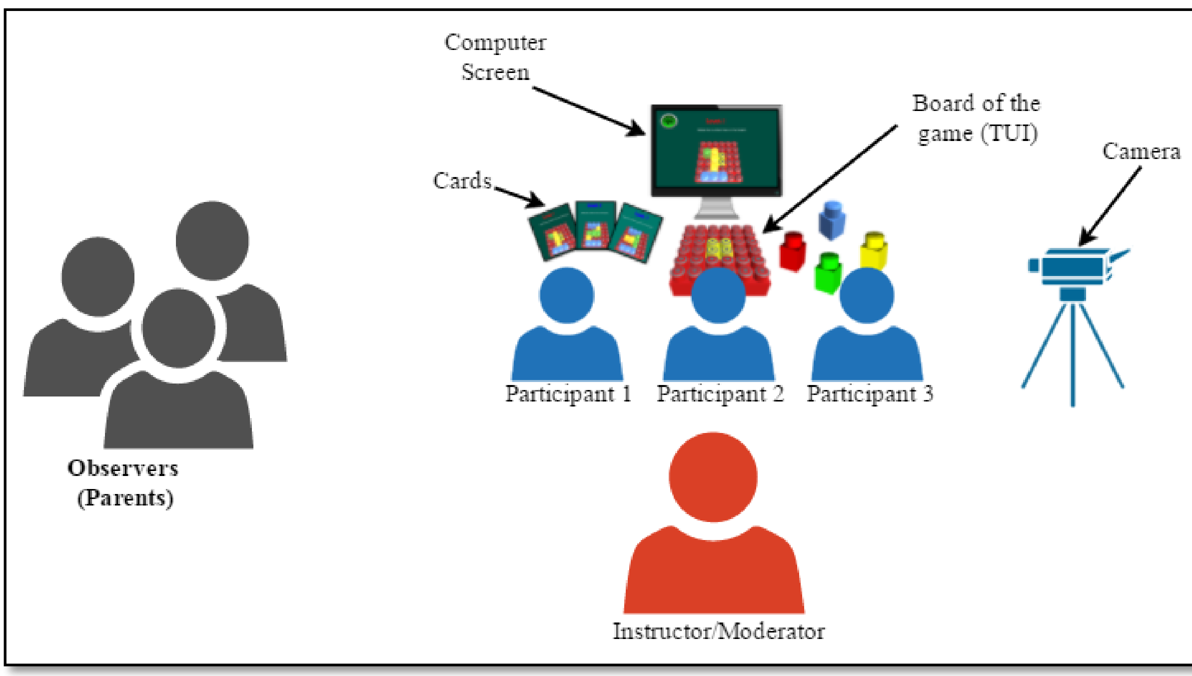

Figure 12: Experiment 1 setup

4.1.6. Experimental Design and Data Analysis

The experiment employed a repeated measures cross-over design (i.e. counterbalanced) with 9 participants. The dependent variables being measured were: *self-initiated social interaction*, *solitary play*, *collaborative play*, *disengagemen*t, *positive vocalizations*, *performance*, *assistance*, *exploratory behavior* and *preferred game*. The independent variable being manipulated was the type of SG, which had two related groups: 1) computer SG (i.e. intervention) and 2) non-computer SG (i.e. control). The participants were exposed to these two different conditions in a different order. The data was extracted from the recorded videos using an observational grid (See Appendix 2).The variables were analyzed using a paired-samples t-test (for continuous dependent variables), a chi-square goodness-of-fit test, or a McNemar's test (for dichotomous dependent variables), to determine whether there is a statistically significant difference between the two conditions (i.e. the two related groups).

4.1.7. Results

In this section we analyze the experimental results obtained for each one of the dependent variables described in section 4.1.3 and correspondingly accept or reject the hypotheses described in section 4.1.4.

i. Self-Initiated Social Interaction:

A paired-samples t-test was used to determine whether there was a statically significant mean difference in the *self-initiated social interactions* between the computer SG and non-computer SG. There were no outliers in the data, as assessed by inspection of a boxplot. The difference in self-initiated social interactions between the computer SG and the non-computer SG were normally distributed, as assessed by Shapiro-Wilk's test (p = 0.13). Participants initiated social contact more times when the computer SG was used (M= 3.56, SD=1.74) compared to the non-computer SG (M=1.11, SD=1.27).The computer SG elicited a mean increase of 2.444, 95 CI [1.00, 3.89] in the number of initiated social interactions during the experiment compared to the non-computer SG (See Figure 13). There was a statistically significance increase in the number of *self-initiated social interactions* when the computer SG is used during the 15-minutes of play time compared to the non-computer SG, t (8) = 3.904, p = 0.005, d = 1.30. Therefore, we can accept hypothesis H1 as stated in section 4.1.4.

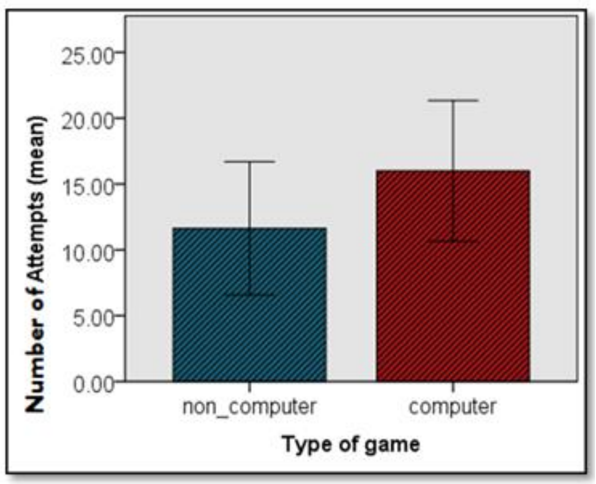

Figure 13: Self-initiated social interactions

ii. Solitary play

A paired-samples t-test was used to determine whether there was a statistically significant mean difference in *solitary play* when participants play with the computer SG compared to the non-computer SG. There were no outliers detected by inspection of a boxplot. The assumption of normality was met as assessed by the Shapiro-Wilk's test (p = 0.55). Participants showed less *solitary play* when they were playing with the computer

SG (M = 25.48 %, SD = 20.19) compared to the non-computer SG (M = 45.63%, SD = 34.55), with a statistically significant mean difference of -20.15 (i.e. decrease of 20.15%), 95% CI [-39.64, -0.65], t (8) = -2.383, p = 0.044, d = 0.79 (See Figure 14). Therefore, hypothesis H2 from section 4.1.4 is supported by the results.

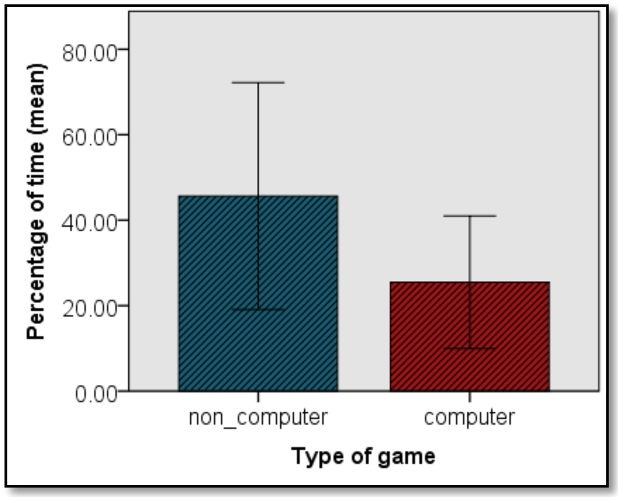

Figure 14: Solitary play

iii. Collaborative play

A paired-samples t-test was used to determine if there was a statistically significant mean difference between the *collaborative play* when participants use the computer SG in comparison with the non-computer SG. There were no outliers detected by inspection of a boxplot. The assumption of normality was violated as assessed by Shapiro-Wilk's test (p = 0.015), the data was moderately skewed, thus we applied a square root transformation (p = 0.083). After applying the transformation, the paired differences showed comparable results to the original data, therefore we were able to continue the analysis with the original data. Participants showed an increase in *collaborative play* when they were interacting with the computer SG (M = 56.00%, SD = 27.68) as opposed to the non-computer SG (M = 26.07%, SD = 42.13), a statistically significant mean increase of 29.93%, 95% CI

[12.51, 47.34], *t* (8) = 3.962, *p* = 0.004, *d* = 1.320 (See Figure 15). Hence, we accept the hypothesis H3 from section 4.1.4.

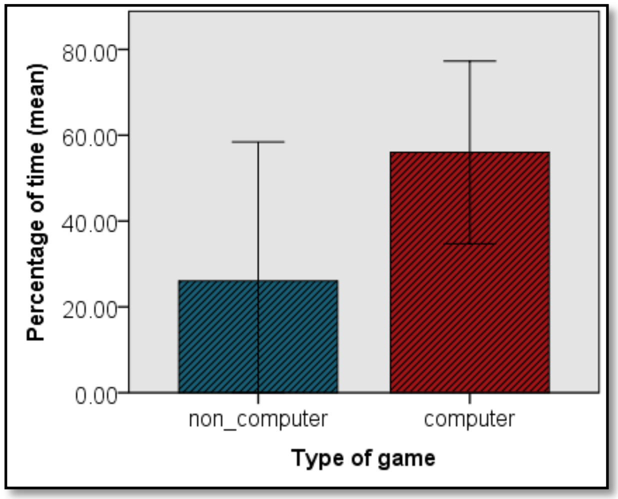

Figure 15: Collaborative play

iv. Disengagement

A paired-samples t-test was used to determine if there was a statistically significant mean difference in the *disengagement* between the computer SG and non-computer SG. There were three extreme outliers in our data, thus we decided to analyze the data with and without the outliers. Neither one of the results showed statistical significance difference (*p* = 0.330 with outliers and *p* = 0.569 without outliers), therefore we cannot accept hypothesis H4 from section 4.1.4.

v. Positive vocalizations

A paired-samples t-test was used to determine if there was a statistically significant mean difference between the numbers of *positive vocalizations* when the participants were playing with the computer SG, compared to the non-computer game. There were two extreme outliers in our data, thus we decided to analyze the data with and without the outliers. Neither of the results showed statistical significance difference (*p* = 0.074 with outliers and $p = 0.143$ without the outliers). Therefore we cannot accept hypothesis H5 from section.

vi. Performance

A paired-samples t-test was used to determine if there was a statistically significant mean difference in the *performance* when participants played with the computer SG, compared to the non-computer SG. One extreme outlier was detected that was more than 1.5 box-lengths from the edge of the box in the boxplot. After replacing the outlier with a less extreme value, the paired differences showed comparable results to the original data; therefore we decided to keep the outlier in the analysis. The assumption of normality was met as assessed by Shapiro-Wilk's test ($p = 0.33$). Participants using the computer SG performed better (M = 6.11, SD = 4.70) compared to the non-computer SG (M = 2.44, SD = 2.35), with a statistically significant mean increase of 3.67 models, 95% CI [1.18, 6.16], $t(8) = 3.40$, $p = 0.009$, $d = 1.13$ (See Figure 16). Therefore, we accept hypothesis H6 from section 4.1.4.

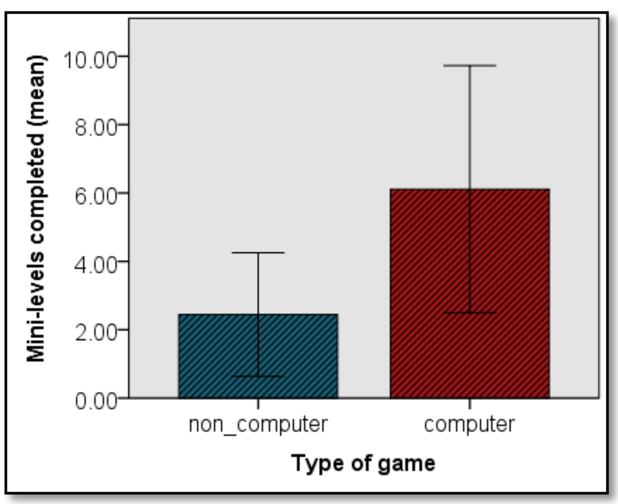

Figure 16: Performance

vii. Assistance

A paired-samples t-test was used to determine whether there was a statistically significant mean difference in the *assistance* variable when participants were playing with the computer SG compared to the non-computer SG. No outliers were detected as assessed by inspection of the boxplot. The assumption of normality was met as assessed by the Shapiro-Wilk's test (p = 0.064). Participants required less *assistance* during the computer game (M = 34.22 %, SD = 40.10) as opposed to the non-computer game (M = 54.18 %, SD = 37.20), (See Figure 17). Therefore, we can accept the hypothesis H7 from section 4.1.4.

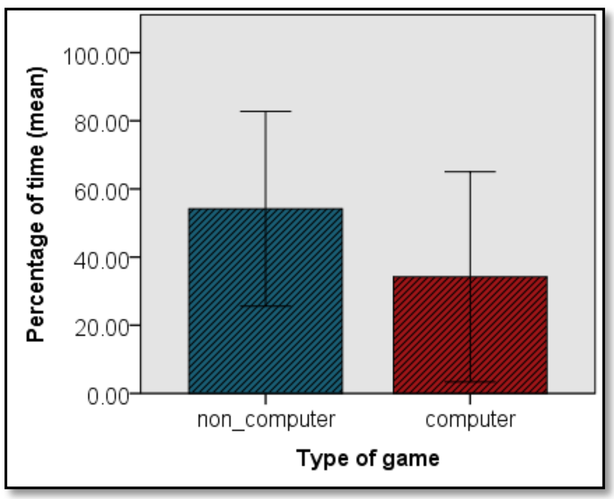

Figure 17: Assistance

viii. Exploratory behavior

Of the 9 participants recruited for the study, 6 participants showed *exploratory behavior* while playing with the computer SG compared to 3 with the non-computer SG. An exact McNemar's test determined that the difference in the proportion of subjects that explored beyond the game's objectives when computer SG was applied compared to the non-computer SG was not statistically significant, $p = 0.375$. Therefore we cannot accept the hypothesis H8 from section 4.1.4.

ix. Preferred game

Of the 9 participants recruited for the study, 6 voted for the computer SG as their *preferred game* and 3 voted for the non-computed SG. A chi-square goodness-of-fit test was conducted to determine whether the game preference was equal. The minimum expected frequency was 4.5, which means that the assumption of expected frequency of at least 5 was violated. However, we decided to continue with the analysis. The chi-square goodness-of-fit test indicated that the preferred game was not statistically significantly different ($X^2(1) = 1.000$, $p = 0.317$). Therefore, hypothesis H7 from section 4.1.4 was not supported by the results.

Table 4: Experiment 1 summary

Variable	Non-computer		Computer		Difference		Hypothesis	Conclusion
	Mean	SD	Mean	SD	Mean	SD		
Self-initiated social interaction (number of attempts)	1.11	1.27	3.55	1.74	2.44	1.88	There is a statistically significant increase in *self-initiated social interactions* when the computer SG is used compared to the non-computer SG.	Hypothesis accepted (p = 0.005)
Solitary Play (percentage of time)	45.63%	34.55	25.48%	20.19	-20.15%	25.36	There is a statistically significant decrease in *solitary play* when the computer SG is used compared to the non-computer SG	Hypothesis accepted (p = 0.044)
Collaborative play (percentage of time)	26.07%	42.12	56.00%	27.68	29.92%	22.66	There is a statistically significant increase in *collaborative play* when the computer SG is used compared to the non-computer SG	Hypothesis accepted (p = 0.004)
Disengagement (percentage of time)	28.29%	29.01	18.52%	21.37	-7.77%	28.29	There is a statistically significant decrease in *disengagement* when the computer SG is used compared to the non-computer SG	Hypothesis not accepted (p = 0.330)
Positive vocalizations(number of attempts)	1.11	0.93	4.00	4.18	2.88	4.23	There is a statistically significant increase in positive vocalizations when the computer SG is used compared to the non-computer SG.	Hypothesis not accepted (p = 0.074)
Performance (mini-levels completed)	2.44	2.35	6.11	4.70	3.67	3.24	There is a statistically significant increase in *performance* when the computer SG is used compared to the non-computer SG.	Hypothesis accepted (p = 0.009)
Assistance (percentage of time)	54.18%	37.20	34.22%	40.10	-19.95%	18.97	There is a statistically significant decrease in the *assistance* needed when the computer SG is used compared to the non-computer SG.	Hypothesis accepted (p = 0.014)
Variable	**Non-computer**			**Computer**			**Hypothesis**	**Conclusion**
Exploratory behavior (occurrences)	3			6			There is a statistically significant increase in *exploration* when the computer SG is used compared to the non-computer SG.	Hypothesis not accepted (p = 0.375)
Preferred game (occurrences)	3			6			There is a statistically significant *preference* for the computer SG over the non-computer SG.	Hypothesis Rejected (p = 0.317)

4.1.8. Discussion

As it has been previously shown, SGs involving building blocks can be used to promote social skills for children with ASD [19][24][25]. But also, the results from our experiment suggest that computer SGs can encourage more social interaction and collaborative play than similar non-computer SGs. Our conclusions are compatible with existing works on the topic [3][14][16]. Engaging with a more interactive game seems to motivate children to work together on a common goal. The children enjoyed manipulating physical objects and seeing the effects on the computer screen as a result of their actions. The latter finding agrees with Farr et al. [19] and Sitdhisanguan et al. [18].

We also noted in our experiment that the children's performance was significantly better with the computer SG as opposed to the non-computer SG. The visual and interactive feedback offered by the computer allowed them to complete the game's levels faster as they were able to follow instructions more easily and intuitively. However, there was one subject that liked the negative feedback presented on the GUI and consequently committed mistakes on purpose. One possible way to resolve this issue in future iterations of the SG is to increase the visual stimulation for success (e.g. display smiley faces, confetti, and sounds) and reduce it for mistakes. Our results support the notion that visual support is a very important factor to consider when working with children with ASD.

Moreover, the amount of assistance needed when the computer SG was used was significantly lower than the non-computer SG. We postulate that the visual feedback provided by the computer helped children understand better what was needed to do to achieve the game's objectives. We observed how the participants were able to relate the virtual representation of the board with the physical board. They were able to take corrective measures when they did an incorrect placement of the block, because the computer screen showed them what they did wrong. Whereas with the cards they needed extra help from the instructor to realize when they were doing something wrong.

We found that the time the children spent engaging in other activities did not present a significant difference between the two compared games. We think that the way the experiment was set up might have affected this result. There were some distractors in the room that interfered with the dynamics of the games. For instance, since the parents were present at all times, some of the children got distracted interacting with them, and hence had some difficulty following instructions. Also, the children did not have a prior relationship with the researcher before the experiment. This might have made it more difficult for them to trust her and follow her directions. Also, a few of the older and higher functioning participants lost interest in both games after several minutes, as they found them to be too easy. This can be avoided in future work by introducing more challenging levels. Furthermore, because there were two teams playing with different games at the same time, some of the children wanted to play with the computer SG while they were supposed to be playing with the non-computer SG.

Even though the number of positive vocalizations was greater with the computer SG, the results did not show statistically significant differences. There were two extreme outliers in our data which were caused by two participants that showed no interest in the non-computer SG. However, when interacted with the computer SG, they started laughing and made a series of positive comments about the game throughout the session.

Even though we observed more exploratory behavior when the participants interacted with the computer SG, we did not obtain statistically significant results, possibly due to the limited size of our experiment. Similarly for the preferred game, our data set was perhaps too small to reach statistical significance. We can potentially reach more conclusive results for the latter two variables with a bigger sample size.

As previously mentioned, the non-computer SG we used was based on LEGO® therapy [25]. However, we adapted the game to allow for a comparison with the proposed computer SG. For instance, we did not use LEGO® blocks; instead we used MEGA BLOKS® (bigger blocks). And even though we tried to assign the roles of "Engineer and Builder" as proposed by LeGoff, only one team was able to assume such roles. This may be due to the fact that the participants were not familiar with the method and possibly needed more time to process the rules and understand the difference between the roles. One of the parents suggested using hats with different colours to help the children differentiate between roles. We adopted this advice for experiment 2 (described in section 4.3). Moreover, there were two teams per session (i.e. one playing the computer SG while another playing the non-computer SG). This caused a lot of distraction to the participants as some of them wanted to switch back and forth between teams; with the distractions, it was hard for the instructor to keep the children focused on their roles. For experiment 2 we only tested one team per session to avoid this situation.

There were some limitations to our experiment. Although we observed statistically significant differences on several key metrics between the non-computer SG and computer SG, the number of subjects employed limits our ability to generalize our results. However, this is a common limitation among work on the topic. Also, the experiment did not address long term behavioral changes achieved with the help of the proposed SG. Our immediate aim is to demonstrate the potential for such games in encouraging social interaction and achieving a higher level of engagement. Further investigation is required to study long term effects of employing the proposed computer SG.

4.1.9. Conclusions

We observed significant differences between the proposed computer SG and a conventional non-computer SG used for play therapy. Similar to Farr et al.[19], we found that TUIs can stimulate social interaction and collaborative play in children with ASD. We observed that children engaged in less solitary play and achieved better performance with the computer SG. We also found that the assistance needed when the computer SG was used was significantly reduced compared to the non-computer SG. Our results suggest that using a SG, consisting of a blocks-based TUI and a GUI, offers a promising method that could be used in play therapy for young children with ASD.

4.2. Modifications to the implementation and evaluation method

After assessing the results obtained from experiment 1, we decided to make a few modifications to the computer SG and the experimental set-up before conducting the second experiment. In this section we describe the modifications made to our system and the evaluation method.

4.2.1. Implementation changes

During experiment 1, some of the parents of the participants commented that the positive feedback provided by the computer was too subtle. They said that their children tend to respond better to exaggerated visual stimulation. They suggested adding bigger visual components and subtle sounds. Therefore, we decided to integrate these elements into our system. Figure 18 shows the modifications we made to the GUI, including a big smiley face when the user makes a correct placement. We also added a “ding sound effect” to indicate the correct placement. The rest of the system remained the same as before, including the negative feedback.

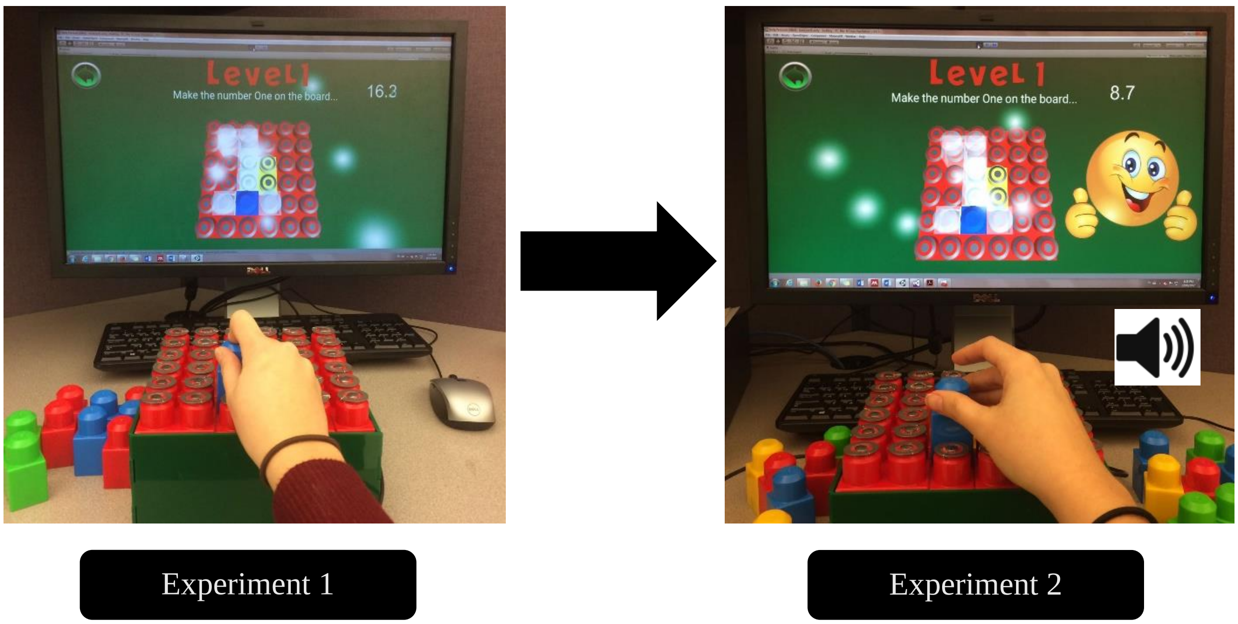

Figure 18: System modifications

4.2.2. Changes to the evaluation method

During experiment 1, we found that the older and higher functioning children lost interest in the game after a few minutes of play. They expressed that the game was not challenging enough. Hence for experiment 2, we decided to recruit younger children (i.e. between 5-9 years old). Also, during experiment 1 we failed to assign roles to the players to achieve a “structured play” setup. In section 4.1.8 we discussed the reasons behind this shortcoming. Therefore, we decided to make changes to the experimental setup to remedy the problems we previously faced. First, we limited the number of children per session to 3 (during the first experiment we had 4 or 5 children booked for the same session). This would limit children distraction and permits the instructor to better engage the group. Second, we adopted the advice of one of the parents from experiment 1 by introducing hats and props to help children differentiate between roles. LeGoff suggested the roles of “builder”, “engineer” and “supplier”, but we decided to slightly adjust these roles to make them more suitable to our system and experimental setup. We chose the roles of *builder*, *demolisher* and *supplier*; we used two hats of different colour and a security vest as wearable props that indicate the role (See Figure 19). We assigned the red hat to the *builder*, yellow hat to the *demolisher* and security vest to the *supplier*. Section 4.3.5 provides a description of the tasks associated with each one of the roles and details the experimental setup.

Figure 19: Toy props

4.3. Experiment 2 (Structured play)

We conducted a second experiment with younger subjects comparing the proposed computer SG with a non-computer SG, similar to the one described in [25]. Unlike the first experiment, this time we were able to use structured play including role play. The changes to our experimental setup were approved by the Office of Research Ethics and Integrity at University of Ottawa (File Number: H06-16-09). The experiment was conducted during two consecutive weekends (two different days), three children were assessed during the first day and eight during the second. The participants were divided into different sessions consisting of two or three children per session. Each participant completed only one session. The total duration of the study was approximately one hour per session. Most of the parents were present at all time, but two of them decided to wait outside the experiment's room.

4.3.1. Participants

Participants were recruited from different sources. Most of the participants were recruited from Children at Risk, the same community organization we used for experiment 1. However, all the participants were different from experiment 1. We also recruited participants through other autism support organizations such as: Autism Family Advisory Committee (AFAC), Facebook groups, and the Ottawa yahoo support group (i.e. autismsupportottawa@yahoogroups.com). Even though we managed to recruit more participants than the first time, the sample size was still limited. Eleven children between the ages of 5 and 8 years old (M= 6.8, SD= 1.07) volunteered to participate. All participants were diagnosed with ASD according to clinical opinion, 3 of the participants were girls and

8 boys. As we mentioned previously, ASD is significantly more common among boys than girls [2], which explains the gender imbalance among participants.

4.3.2. Apparatus

Proposed SG (i.e. Intervention method): We used the computer SG from Chapter 3 with the modifications stated in section 4.2.

Non-computer SG (i.e. Control method): We used the same cards described in section 4.1.2 with the additional props described in section 4.2.

4.3.3. Independent Variables and Dependent Measures

The same independent variable (type of game) and dependent measures (*Self-initiated social interaction*, *solitary play*, *collaborative play*, *disengagement*, *positive vocalizations*, *performance*, *assistance*, *exploratory behavior*, and *preferred game*) were analyzed, see section 4.1.3 for detailed descriptions.

4.3.4. Hypotheses

The same hypotheses as the first experiment were assessed (H1-H9), See section 4.1.4 for description.

4.3.5. Procedure

The procedure was very similar to the one we used for the first experiment, with few modifications. We divided the participants into four teams composed of two or three children (Team E, Team F, team G, and Team H). Unlike the first experiment, only one team per session was assessed. We did this to avoid distractions when the children were using the other game. Similar to the first experiment, at the beginning of each session, parents were asked to sign a consent form and answer a questionnaire about their children's experience with computer games (See Appendix 1). The sessions were counterbalanced to reduce bias, i.e. two teams started with the non-computer SG followed by the computer SG, and the two others did it in the opposite order. The participants were instructed to play with the SG in turn (i.e. computer or non-computer) and were assigned different roles (following a similar concept to the one proposed by LeGoff in [25]):

1) *The builder*: In charge of building the model displayed on the computer screen or model card. The builder was sitting in front of the computer screen (or cards) and the board. We instructed the child playing this role to wear a red hat (See Figure 20).
2) *The supplier*: Responsible for providing the necessary blocks as requested by the builder. The supplier was sitting in front of a table with the blocks. We instructed the child playing this role to wear a vest (See Figure 20).
3) *The demolisher*: In charge of removing the blocks once a model was completed by the builder, and this participant was also responsible to return the blocks to the supplier. The demolisher was sitting next to the builder. We instructed the child playing this role to wear a red hat (See Figure 20).

During the 30 minutes of play time (i.e. 15 minutes for the computer SG and another 15 minutes for the non-computer game), the roles were rotating between the participants so that everyone had the time to experience each role. At the end of the experiment, participants were asked to vote for their preferred game.

Figure 20 shows a diagram of the experimental setup. Similar to the previous experiment, the instructor was near the participants providing assistance whenever needed. We also had a camera recording the sessions for later analysis and most of the parents were observing the experiment and interfering only whenever it was necessary (i.e. when the children became uncooperative). Unlike the previous experiment (See Figure 12), only one participant at a time had access to the game's board: which was the *builder* during construction and *demolisher* during destruction of the model. The blocks were placed in front of the *supplier* at the beginning of each turn and were passed to the *builder* at her/his request. At the end of the study, parents were asked to fill up a survey to provide their feedback (See Appendix 1).

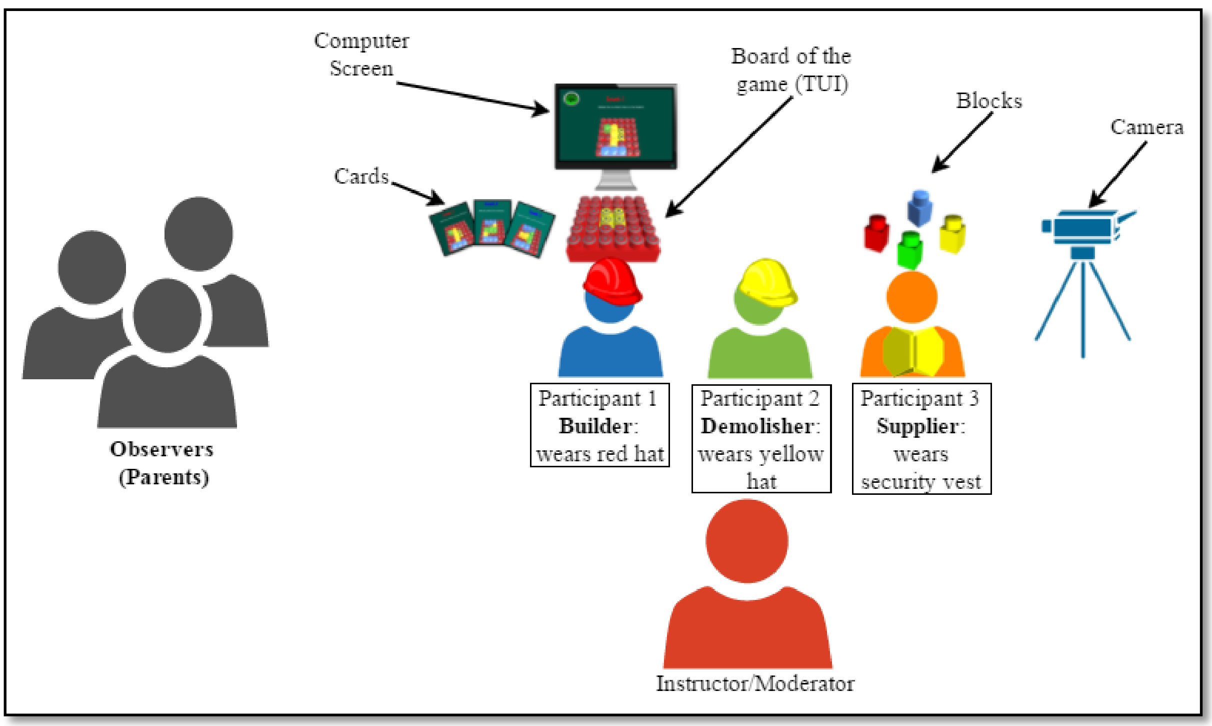

Figure 20: Experiment 2 setup

4.3.6. Experimental Design and Data Analysis

We used the same experimental design as in the first experiment, a repeated measures cross-over design (i.e. counterbalanced) with 11 participants. The dependent variables being measured were: *social interaction*, *solitary play*, *collaborative play*, *disengagement*, *performance*, *assistance*, *exploratory behavior and preferred game*. The independent variable being manipulated was also the same (the type of game), which had two related groups: 1) the proposed computer SG (i.e. the intervention) and 2) a similar non-computer game (i.e. the control). The participants were exposed to these two different conditions in a different order. The data was extracted from the recorded videos using an observational grid (See Appendix 2). The variables were analyzed using a paired-samples t-test (for continues dependent variables) or a McNemar's test (for dichotomous dependent variables), to determine whether there is a statistically significant difference between the two conditions (i.e. the two related groups).

4.3.7. Results

In this section we will analyze the results of experiment 2 for each one of the dependent variables described in section 4.1.3., and we will reach conclusions whether we can accept the hypotheses described in section 4.1.4.

i. Self-Initiated Social Interaction:

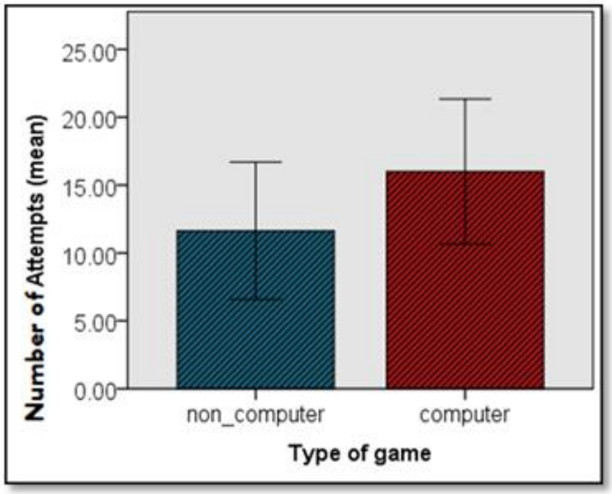

Figure 21: Self-initiated social interaction

A paired-samples t-test was used to determine whether there was a statistically significant mean difference between the numbers of *self-initiated social interactions* when playing with the computer game, as opposed to the non-computer game. No outliers were detected as assessed by a boxplot. The assumption of normality was not violated, as assessed by Shapiro-Wilk's test (p = 0.906). Participants initiated social contact more times with the computer game (M = 16.000, SD = 7.95) as opposed to the non-computer game (M = 11.64, SD = 7.53), a statistically significant mean increase of 4.36, 95% CI [0.49, 8.24], t (10) = 2.51, p = 0.031, d = 0.77 (See Figure 21). Therefore, we can accept the hypothesis H1 as stated in section 4.1.4.

ii. Solitary play, collaborative play, and disengagement:

With the small modifications we made to experiment 2, children were engaged in the game during the entire period of play. Since only two or three children were present at a time, there were no extra distractors to keep them off task. With fewer children per session, the instructor had better control of the situation. The instructor was more involved by assisting the children whenever necessary, and making sure they followed the rules of the game and assumed their assigned roles. We observed that all the participants spent 100% of their time playing collaboratively regardless of the type of game. Therefore there were not statistically significant differences in the *solitary play*, *collaborative play* or *disengagement* variables. Therefore we cannot accept the hypotheses H2, H3 and H4 from section 4.1.4.

iii. Positive vocalizations:

A paired-samples t-test was used to determine whether there was a statistically significant difference between the *positive vocalizations* when the participants played with the computer SG compared to the non-computer SG. One outlier was detected that was more than 1.5 box-length from the edge of the box in a boxplot. Inspection of its value did not reveal that it was extreme and hence was kept in the analysis. The assumption of normality was violated, as assessed by Shapiro Wilk's test ($p = 0.004$), the data was moderately skewed, thus we applied a square root transformation ($p = 0.89$). After applying the transformation, the paired differences showed comparable results to the original data, therefore we were able to continue the analysis with the original data. Participants showed an increase in *positive vocalizations* when using the computer SG (M = 2.09, SD = 1.81) compared to the non-computer SG (M = 1.31, SD = 0.63), a statistically significant increase of 1.64 [0.251, 3.022], t (10) = 2.63, $p = 0.025$, $d = 0.79$ (See Figure 22). Therefore, we can accept the hypothesis H5 from section 4.1.4.

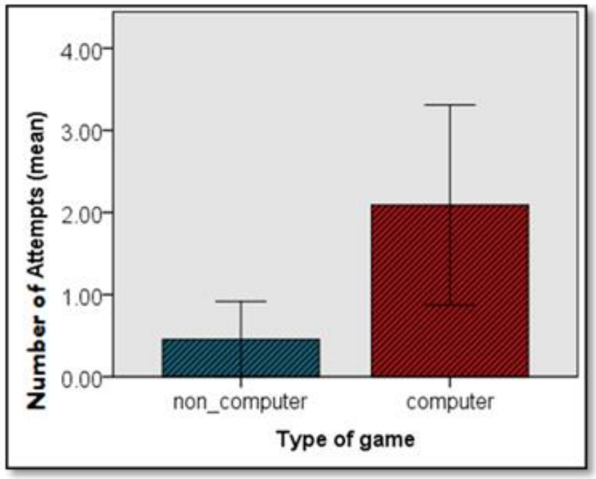

Figure 22: Positive vocalizations

iv. Performance:

A paired-samples t-test was used to determine whether there was a statistically significant difference in the performance of the participants with the computer SG compared to the non-computer SG. No outliers were detected as assessed by a boxplot. The assumption of normality was violated, as assessed by Shapiro Wilk's test (p = 0.035), the data was moderately skewed, thus we applied a square root transformation (p = 0.091). After applying the transformation, the paired differences of neither of the results showed statistical significance (*p* = 0.138 with original data and *p* = 0.196 with transformed data). Therefore, we cannot accept hypothesis H6 from section 4.1.4.

v. Assistance:

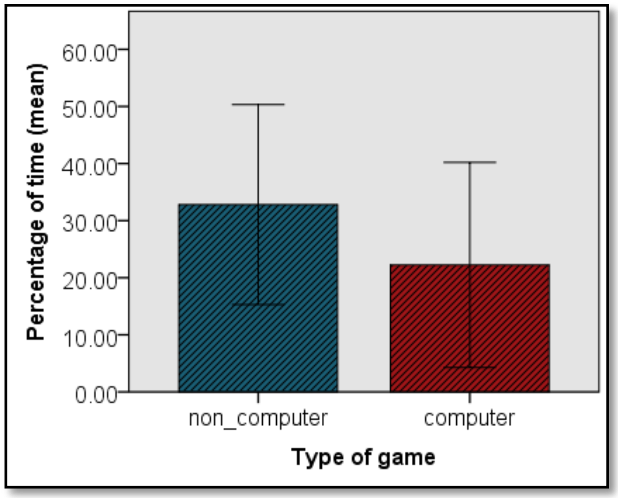

Figure 23: Assistance

A paired-samples t-test was used to determine if there was a statistically significant mean difference between the *assistance* needed by the participants when they played with the computer SG, compared to the non-computer SG. One extreme outlier was detected that was more than 1.5 box-lengths from the edge of the box in the boxplot. After modifying the outlier by replacing it with a less extreme value, the paired differences showed comparable results compared to the original data, therefore we decided to keep the outlier in the analysis. The assumption of normality was violated, as assessed by Shapiro Wilk's test (p = 0.000), the data was strongly skewed, thus we applied a logarithmic transformation (p = 0.203). After applying the transformation the paired differences showed comparable results to the original data, therefore we were able to continue the analysis with the original data. Participants needed less *assistance* when using the computer game (M = 22.244%, SD = 26.74) as opposed to the non-computer game (M = 32.82%, SD = 26.08), a statistically significant mean decrease of 10.57% (i.e. -10.57%), 95% CI [-20.41, -0.73], t (10) = -2.39, *p* = 0.038, *d* = 0.722 (See Figure 23). Therefore we can accept the hypothesis H7 from section 4.1.4.

vi. Exploratory behavior:

Of the 11 participants recruited for the study, 8 participants showed *exploratory behavior* while playing with the computer SG and only one with the non-computer SG. An exact McNemar's test determined that the difference in the proportion of exploration between the computer SG and the non-computer SG was statistically significant, $p = 0.016$ (See Figure 24). Therefore we can accept the hypothesis H8 from section 4.1.4.

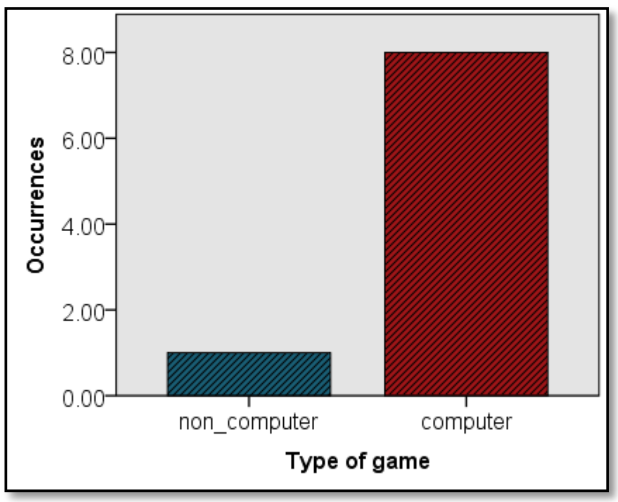

Figure 24: Exploratory behavior

vii. Preferred game:

Of the 11 participants recruited for the study, 9 voted for the computer SG as their *preferred game* and 2 voted for the non-computer SG. A chi-square goodness-of-fit test was conducted to determine whether the participants' preference was the same for both games. The minimum expected frequency was 5.5. The chi-square goodness-of-fit test indicated that the *preferred game* was statistically significantly different (X^2 (1) = 4.555, $p = 0.035$), see Figure 25. Therefore we can accept the hypothesis H9 from section 4.1.4.

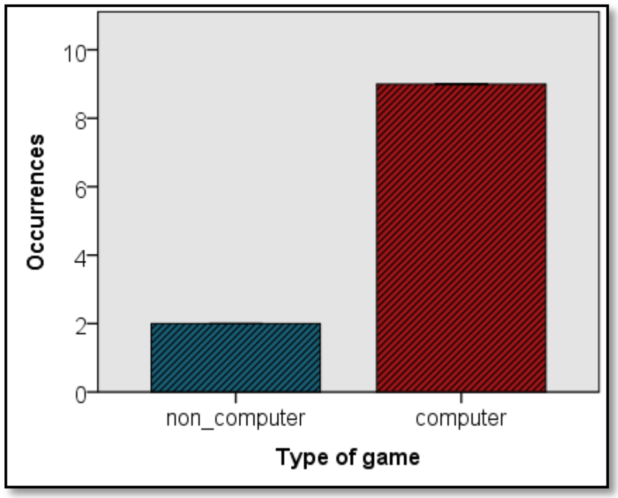

Figure 25: Preferred game

Table 5: Experiment 2 summary

Variable	Non-computer		Computer		Difference		Hypothesis	Conclusion
	Mean	SD	Mean	SD	Mean	SD		
Self-initiated social interaction (number of attempts)	11.64	7.53	16.00	7.95	4.36	5.76	There is a statistically significant increase in *self-initiated social interactions* when the computer SG is used compared to the non-computer SG.	Hypothesis accepted ($p = 0.031$)
Solitary Play (percentage of time)	0%	0	0%	0	0%	0	There is a statistically significant decrease in *solitary play* when the computer SG is used compared to the non-computer SG.	Hypothesis not accepted
Collaborative play (percentage of time)	100%	0	100%	0	0%	0	There is a statistically significant increase in *collaborative play* when the computer SG is used compared to the non-computer SG.	Hypothesis not accepted
Disengagement (percentage of time)	0%	0	0%	0	0%	0	There is a statistically significant decrease in *disengagement* when the computer SG is used compared to the non-computer SG.	Hypothesis not accepted
Positive vocalizations (number of attempts)	1.31	0.63	2.09	1.81	1.64	2.06	There is a statistically significant increase in *positive vocalizations* when the computer SG is used compared to the non-computer SG.	Hypothesis accepted ($p = 0.025$)
Performance (mini-levels completed)	2.09	0.30	2.55	1.13	0.45	0.93	There is a statistically significant increase in *performance* when the computer SG is used compared to the non-computer SG.	Hypothesis not accepted ($p = 0.138$)
Assistance (percentage of time)	32.82%	26.08	22.24%	26.74	-10.57%	14.65	There is a statistically significant decrease in the *assistance* needed when the computer SG is used compared to the non-computer SG.	Hypothesis accepted ($p = 0.038$)
Variable	**Non-computer**			**Computer**			**Hypothesis**	**Conclusion**
Exploratory behavior (occurrences)	1			8			There is a statistically significant increase in *exploratory behavior* when the computer SG is used compared to the non-computer SG.	Hypothesis accepted ($p = 0.016$)
Preferred game (occurrences)	2			9			There is a statistically significant *preference* for the computer SG over the non-computer SG.	Hypothesis accepted ($p = 0.035$)

4.3.8. Discussion

Two of the analyzed variables showed statistical significance across both experiments: self-initiated social interaction and assistance needed during the game. However, not all the statistically significant results found in experiment 1 were also obtained in experiment 2. In this section, we explain the results differences between both experiments and present some observations we made during experiment 2.

Similar to experiment 1, we observed how block-based games can promote social interaction among children with ASD. We confirmed that a computer SG can increase significantly the number of self-initiated social interactions, compared to a non-computer SG. We suppose that the addition of technology (in this case an interactive computer SG) can increase engagement which in turn encourages cooperation between children as they work towards a common goal they are eager to achieve. Furthermore, during experiment 2, there was higher level of social interactions (as evidenced by the calculated mean of the self-initiated social interaction metric) compared to experiment 1. This might be the result of role assignment that helped create more organized and focused teams.

We also perceived an increase in exploratory behavior with the computer SG. Few participants were curious about the functionality of the game and asked about the technical details of the system such as: "how is the computer connected to the board?", "how was it able to provide feedback according to their actions?", and "how does it detect the different colours of the blocks?". Some participants were talking among each other about similar technologies they are aware of. Hence, technology seems to stimulate the curiosity of some of the subjects.

Furthermore, we observed an increase in positive vocalizations with the computer SG. Participants were often laughing and celebrating their performance right after receiving a positive feedback from the computer. We think that the images and sounds displayed by the computer helped them remain motivated and enjoy the game. Experiment 1 did not show statistically significant differences for this variable. This is possibly due to the presence of two extreme outliers and small size of the data set. Furthermore, the positive feedback employed in experiment 1 was much more subtle than that of experiment 2 which could have affected this variable. In experiment 2, the obtained results were more homogenous and the difference between the control and intervention method was statistically significant.

Unlike experiment 1, we did not obtain statistically significant differences for the solitary play and collaborative play. As we previously stated, the setup of experiment 2 allows the instructor to better control the progress of the experiment. There were at most three participants per session, which meant that the instructor was able to keep the children focused on the game. There were less distractors in the room and with the assigned roles, the participants were able to play collaboratively the entire time for both games. The props used to indicate roles helped children understand the differences between the roles, as well as to follow their assigned tasks and respect turn taking. Our observations concur with previous work that showed that role-playing can improve social behaviour and collaborative play [5][6][22][43][51].

We did not observe statistically significant differences in the performance during experiment 2. We suspect that the roles assigned interfered with the time a team required to complete each one of the models. During experiment 2, we encouraged children to respect role responsibility, rather than focus on speed of execution.

The assistance needed was reduced with the computer game, as in experiment 1. But we also observed a decrease in the calculated means compared to experiment 1. We suppose that with the structured play (roles assigned), the children were able to better understand the game and complete their tasks with less assistance from the instructor. We also observed that the children were helping each other more often when they had questions about their tasks.

Finally, when we asked the participants to vote for their preferred game, the majority chose the computer SG. For those who chose the computer SG, we followed up by asking them why they chose the computer SG. Their answers included some of the following statements: “because it has a computer screen”, “because it has sounds”, “because of the smiley faces”. We estimate that the visual and auditory feedback kept the children motivated and made the game more enjoyable.

4.3.9. Conclusions

During experiment 2, we perceived more engagement from the participants compared to experiment 1. Thus, we deduce that the appropriate age for the proposed computer SG is between 5 and 9 years old. Unlike experiment 1, the children were engaged in both games (computer SG and non-computer SG) during the entire period of play. We also observed some of the benefits of structured play. Our findings concur with those of LeGoff [25], as we registered an increase in social interaction and engagement when the role-playing technique was used. Furthermore, we observed statistically significant improvements on several key metrics when the computer SG was employed as opposed to the non-computer SG. This suggests that the proposed computer SG can serve as an effective tool for play therapy. With the computer SG, we perceived an increase in the number of *self-initiated social interactions* and *positive vocalizations* about the game. The proposed system also required less *assistance* compared to the non-computer SG. This feature can be useful for therapists and children during play therapy as it can grant the former more time to observe behavioral trends and the latter a level of independence. Additionally, we saw an increase in *exploratory behavior*, since the children showed more curiosity towards the computer SG. Finally, when we asked children about their *preference*, they chose the computer SG over the non-computer SG. This implies that the computer SG is more entertaining and possibly engaging for young children with ASD.

Chapter 5. Conclusions and Future Work

In this thesis we proposed an interactive SG as a tool for play therapy intended to improve social and cognitive skills for young children with ASD. Our approach consisted of a combination of a TUI and GUI; we adopt building blocks as our TUI and use a computer screen to display a GUI. The interaction between the users and the system was achieved through the manipulation of physical building blocks (i.e. TUI) while the GUI provided visual feedback. Furthermore, we conducted a usability study comparing the proposed system with a conventional non-computer SG. The usability study consisted of two experiments using unstructured and structured play approaches. Our results suggest that the proposed system shows potential as a tool for play therapy. The following sections summarize the accomplishments and provide direction for future works.

5.1. Accomplishments

We enhanced regular building blocks with technology, creating a new SG capable of providing instant visual and auditory feedback. The proposed SG is inspired from the concept of *LEGO®-based therapy* as proposed by LeGoff in [6]. Hence, our system is intended to be used within the same play therapy settings as the ones described by LeGoff [6].

According to our evaluation results, we found statistically significant differences between our proposed system and a non-computer SG. For the first experiment, using unstructured play with children from 9-15 years old, our system showed an improvement over the non-computer SG in: social interaction, collaborative play, and performance, and a reduction in solitary play. For the second experiment, using structured play with children from 5-8 years old, we observed improvements in social interaction, positive vocalizations and exploratory behavior with our system compared to the non-computer SG. Furthermore, participants expressed their preference towards our proposed system compared to the non-computer SG. We also observed during both experiments that players required less assistance while interacting with the proposed SG compared to the non-computer SG. Moreover, there were no signs that our system performed worse than the non-computer SG on any of the metrics that we considered.

5.2. Direction for future works

Below, we present few ideas for the improvement of the proposed system:

- **TUI improvement:** An extended (i.e. larger) version of the board leaving room for more complex models that the children can replicate and therefore render the game more challenging. Also, the addition of another TUI would allow multiple players to build models at the same time.
- **GUI improvement:** Add more levels including dynamic models that change during the course of the game. Children with Autism tend to look for patterns and show repetitive behaviors [49]. Hence, it might be useful to add some unpredictability to the game as a departure from repetitive game behavior. One of the parents of the participants from experiment 2 suggested the addition of a level where the model suddenly changes to a different one. This way, the children could learn to respond to unpredictable situations. Another possible addition is to include a reward system by assigning badges as suggested in [25] with the *"LEGO® Club" Level system*; this

system has five levels: “LEGO® Helper”, “LEGO Builder”, “LEGO® Creator”, “LEGO Master”, and “LEGO Genius”. This feature can be either be incorporated into the SG’s GUI or implemented during the evaluation using stickers.

Long-term evaluation: Long-term evaluation of the proposed system is required to assess whether the advantages found during our experiments can translate to short and long-term benefits.

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Appendix 1: Initial Interview and exit survey

Initial Interview

Please provide the bellow information about your child:

1. Name:____Age: _____
2. Diagnosis/condition (ASD, Asperger's, PDD-NOS, etc):
   ____
3. Previous experience with video games (Yes/no):
   ____
4. Previous experience with building blocks, LEGO or similar, (Yes/no):
   ____
5. Favorite toy
   ____
6. Favorite application, or video game
   ____

Exit survey

1. How did you find out about the study:
   a. Children at Risk
   b. CHEO
   c. Facebook
   d. Other:____________________
2. Rate the computer game (between 1 and 5, 5 being very good)
   1 2 3 4 5
3. Which game do they think their children enjoyed the most?
   a. Computer game
   b. Blocks without computer
4. Comments and suggestions about the game:

____
____
____

If you wish to receive further information about the study please provide your contact information:

Name:____
e-mail:____
Phone number:_______________________________________

Appendix 2: Observational grid

Group________________

Computer SG								
Part. ID	Self-Initiated social interaction (Occurrences)	Solitary play (time stamp)	Collaborative play (time stamp)	Disengagement (time stamp)	Positive vocalization (occurrences)	Performance (mini-games completed)	Assistance (time stamp)	Exploratory skills (occurrences)
Non-computer SG								

Preferred game:
Computer SG: _____ Non-computer SG: ____

Comments:

____
____
____
____