# Lands of Fog: Helping Children with Autism in Social Interaction through a Full-Body Interactive Experience

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## ABSTRACT

Autism Spectrum Disorder is characterized by impaired social communication capacities which can prevent the formation of social relationships with peers. In recent years, potential programs for people with ASD have increasingly used Information and Communication Technologies mainly motivated by the affinity that people with ASD show towards technology-supported tasks. We present the design of a full-body interaction experience called Lands of Fog, in which a child with ASD plays together with a typically developed child. The system is aimed towards fostering social interaction behaviors and collaboration. We have undertaken user trials with 34 ASD children through which Lands of Fog has proven to be a useful tool to foster social interaction. In this paper, we focus on the description of the interaction design process, methods and criteria that support the final experience. We then provide preliminary results from the user trials which provide a first hint of the efficacy of the system in fostering user's engagement and making socialization attitudes emerge.

### Author Keywords

Autism Spectrum Disorder; ASD; Embodied Cognition; Full-body Interaction; Social Interaction; Encouraged Collaboration; Children; Information and Communication Technologies; Interaction Design

### ACM Classification Keywords

K.3.1 **[Computers and Education]:** Computer Uses in Education: Collaborative Learning; D.2.6 **[Software Engineering]:** Programming Environments: Interactive environments



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## INTRODUCTION

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder which manifests itself in marked impairments in a wide range of social behaviors and repetitive actions and interests [3]. It can lead to impairments in reciprocal conversation and verbal and non-verbal communication. In addition, individuals with ASD may experience difficulties forming and keeping relationships with peers and taking part in imaginative play.

Individuals who are diagnosed with ASD show a broad range of symptoms [52]. Even individuals with the same functioning level in ASD diagnostic tests may present a wide range of manifesting symptoms. Nonetheless, one of the most challenging characteristics shown in ASD is a lack of the social abilities necessary for daily functioning with other people [46]. Although individuals with HFASD (high-functioning ASD and IQ $\geq$ 70) show normative performances in social capacities in front of structured social tests [23], in more spontaneous, real-time social scenarios there are discrepancies in their performance when compared to neurotypical individuals with similar IQ and age [32].

### Autism and difficulties with social relationships

Relationships with peers may suffer as a result of impairments in social communication abilities. For example, unspoken social norms and expectations can be difficult to grasp for people with ASD, as they are typically coordinated through non-verbal interactions with others [29]. Individuals with ASD also may not properly interpret others' speech by not taking into account contextual information, which can lead to misunderstandings regarding non-literal elements of the conversation [25]. Furthermore, due misunderstanding non-verbal social cues, people with ASD have difficulties in social engagement, and may persist with long, egocentric discourse after the interlocutor has shown a loss of interest [7].

Studies on unstructured playground dynamics suggest that children with ASD may show a higher frequency of engaging in solitary, nonsocial play than their typically developed counterparts [6,31,51]. Even in the case that they want to become involved in activities with peers, they may not possess the communication skills necessary to create socially appropriate dialogue and integrate themselves [7]. These challenges may lead to increased instances of social fragmentation in school contexts for children with ASD. Thus it might be necessary to provide support during unstructured social times to counter social fragmentation [2].

### Autism and ICT

It has been shown that people with ASD tend to enjoy computer-based tasks [14]. While conducting research on how to engage children with ASD, Brown and Murray [12] found that individuals with ASD showed a great affinity towards information and communication technologies (ICT). This could be due to the predictable and structured nature of computer-based technologies. Given this affinity, there has been an increase in the research and development of computer-based technologies for intervention as a way to engage the attention of children with ASD. Davis et al. [18] recommended developing ICT with design features which would be readily accepted by individuals with ASD in therapy settings, such as task consistency and predictability as well as the gradual introduction of novel elements. Therefore, ICT approaches are ideal as they can easily regulate change [1], and feedback can be programmed to be immediate and consistent [41].

Practicing socialization in a Virtual Environment (VE) catered towards individuals with ASD can be a way to reduce anxiety while simultaneously forming behavioral patterns. One example is the ‘AS Interactive Project’ by Parsons, et al. [45] in which ASD children were trained in a variety of virtual social scenarios, such as finding a seat in a cafe or on a bus.

### Embodied cognition and virtual environments

Traditional Cartesian views of cognition regarded the mind and the body as two separate entities, where the mind was the center of all cognitive activity and the body was a mere support for it. Embodied Cognition theories challenge this understanding, holding that the functionality of the mind must be understood in unison with its connection to the body [19][58]. In the lens of embodied cognition, human knowledge is not only something abstract but is also linked to our active engagement with the world through our body [10]. With the formation of a unique viewpoint, each individual's cognition is influenced by and connected with their corresponding bodily dynamics and social context [48]. Activity Theory claims that intra-psychological processes emerge from activity between humans and objects in a relevant environmental context [57].

Navigating through physical environments allows a better creation of a mental model and deeper understanding of one's surroundings than simply viewing a two-dimensional representation [5]. In addition, full-body interactive environments allow for the body and gestures to become the focus, as participants may operate the system through natural kinesthetic movements [24][42].

In this respect, full-body interactive environments which allow for the use of body language and communication gestures could be particularly useful for facilitating social understanding.

### Our approach

Lands of Fog is a full-body interaction system designed to improve behavioral and cognitive skills in children with HFASD. The collaborative virtual environment was designed to scaffold social interaction by creating scenarios which would enable children with ASD to work together with typically developed children towards a common goal.

Before describing the project, in the next section we will present an overview on related work. We then describe the goals of the research and the design process, followed by a detailed explanation of the process of translating goals into interaction design criteria. We will then describe the installation and its experimental assessment and will finally discuss the results obtained.

## RELATED WORK

In the last two decades there has been increasing research and interest in using ICT for ASD therapy and intervention. Most research projects have been prompted by the affinity of people with ASD towards ICT, as explained in the introduction, and also by the proliferation of technological devices in everyday life. Opportunities to utilize ICT-based therapies and interventions for children with ASD include fostering language acquisition with the use of desktop applications [11,53], aiding communication using handheld devices [20,39] and learning social conventions and abilities using head mounted displays [44,50].

### Skills acquisition through technology

There is evidence of the acquisition of diverse skills by children with ASD through ICT. In the domain of Video Modeling (i.e. teaching by displaying video recordings as a visual support) research shows ICT potential for achieving task completion [27,36]. Teaching with desktop computer applications has also been successful for the acquisition of reading and listening abilities [16,33,55]. Multimedia in handheld devices has also been used for supporting the teaching of Mind Reading abilities (i.e. recognition of complex emotions in face and voice) [4] or even "interaction immediacy" (i.e. maintaining appropriate spatial boundaries in social interaction) [54].

### Virtual Environments and collaboration

In the field of Virtual Environments (VE), research focuses on the positive potentialities of mediating collaborative environments [15,38]. Projects involving individuals with ASD are categorized into either single user virtual environments (SVE) or collaborative virtual environments (CVE) [40], depending on the user capacity and desired functionality of the project.

In the case of multiple users, shared activity surfaces (SAS) and full-body virtual environments may be designed to co-locate users in the same physical space, which allows for direct communication. Alternatively, users may be placed in separate spaces with communication between on-screen avatars. The Island of Ideas [37] was a collaborative VE where users accessed a virtual environment from different laptops. One example of a co-located SAS was the Story Table [6]. The research found that the use of a multi-user, multi-touch device had a positive effect on social interaction between two children with HFASD. The Join-In project also proved that co-located SAS intervention can have great potential for engaging users [56]. Another co-located experience is the Collaborative Puzzle Game by Ben-Sasson et al. [8], which was based on completing puzzles on a SAS. The research compared two approaches, Free Play (FP), where each player could move any puzzle piece whenever they wanted, and Enforced Collaboration (EC), where both players were told to move the same puzzle piece in unison. Results showed that EC led to more interaction and negotiation, although the increased challenge in the EC versus FP mode led to a higher number of uncompleted trials and a lower positive effect than the Free Play approach.

### Full-body interaction technologies for Autism

Regarding full-body interaction systems one of the first approaches was the MEDIATE project. MEDIATE was a multimodal adaptive environment for children with low functioning ASD (LFASD) with the goal of providing a sense of control and agency [43]. MEDIATE was designed "for children with autism to have fun and have the chance to play, explore, and be creative in a controllable and safe space".

Another full-body interactive project for acquiring social skills was The Echoes Project [47]. The scope of this project included developing a virtual environment which would encourage children with ASD between the ages of 5 and 7 to explore and acquire social interaction skills. The system was based on a virtual environment where a digital avatar was able to interact with the children. The system used an artificial vision subsystem to interact with the children and track children's focus towards the virtual objects. This way the system allowed for activities where joint attention, such as pointing, could be practiced.

The Pictogram Room was a full-body interaction videogame in which pictograms were superimposed over the bodies of children with ASD. The purpose of the project was to help understand the relation between pictograms and the body. Moreover the project was aimed at supporting communication, joint attention and imitation therapy for social behavior learning [13].

In recent years, Kinect has proved a useful technology for creating full-body interactive environments catered towards socialization in children with ASD. Malinverni et al. [34] present a Kinect-based full-body interaction system structured through a story line of helping a stranded alien. This system showed positive results for promoting social abilities such as stimuli discrimination, joint-attention, verbalization and turn-taking. Bhattacharya et al. [9] also presented research using Microsoft Kinect in a classroom setting to promote engagement with peers and social behaviors in children with ASD.

## PROJECT PREDECESSOR

The project presented in this article was inspired by a full-body interaction artistic installation for the general public called "El Ball del Fanalet or Lightpools" [28]. This project explored the social potential of full-body interaction technologies. Up to four users explored virtual content through the use of hand-held pointers shaped as paper lanterns. While exploring, users could “feed” very basic virtual objects with light to obtain more complex abstract objects, which later could be trained to perform simple choreographies.

In 2001, an informal play session of a group of ASD children within Lightpools showed the potential of the installation to spark social interaction behaviors in HFASD children. The original artistic approach of fostering social interaction in typical users seemed to be also useful for ASD children. Years later we decided to formally explore this potential and take advantage of selected formal properties of Lightpools in a new experience completely conceived for ASD children. Lands of Fog became the resulting experience, using a similar interaction paradigm to Lightpools but applying a contemporary view on autism and allowing ASD children to collaborate in the creation through Participatory Design [35].

## GOALS OF LANDS OF FOG

Lands of Fog was created within the project IN-AUTIS-TIC: Integration of Children with Autism into Society using ICT, funded by the RecerCaixa 2013 grants program. The project was developed within the Full-Body Interaction Lab in the CMTech research group at Universitat Pompeu Fabra in Barcelona (Spain) with the collaboration of lead psychologist Pamela Heaton from Goldsmiths (University of London) and the Special Unit for Developmental Disorders from Hospital Sant Joan de Déu (Barcelona).

The primary goal of the research project was to design a full-body interactive environment where children with HFASD could learn social interaction behaviors and understand the benefits of collaboration while playing, exploring, and being creative alongside a typically developed companion. We decided not to address specific social skills since we believe that a first essential step in the process of helping children with ASD is to scaffold them in finding mechanisms for social initiation (making demands, joint attention, non-verbal communication, etc.) and help them realize that very often it is better to collaborate with others than to work on their own. Given the affinity that ASD children show towards ICT technologies, the project aimed to explore the potential of different technological media for developing systems for therapy and intervention.

Full-body interactive virtual environments allow for users to physically move in space and within the virtual environment. In the case of collaborative virtual environments, multiple users may be co-located in the experience. Given that users have their peers and content close at hand, full-body interaction media have the potential for developing systems where users can construct deep meaning from the activity as their conscious thought processes are embedded in the context [30].

The goal of promoting collaboration is threefold. On the one hand, collaboration requires different types of communication for the users to agree on their common goals and the strategies to attain them. This makes them naturally practice social communication abilities. On the other hand, promoting collaboration could motivate users to see their peers as valuable play partners. Given the challenges in social integration and maintaining social relationships in children with ASD, creating scenarios where users see each other as valuable partners could help in developing and maintaining friendship. Social inclusion has benefits for children with ASD as it helps them acquire and develop positive social skills[26], and helps to generalize their social skills to new contexts [49]. Finally, placing ASD children in a collaborative context teaches them that often working alone does not allow them to reach their goals, and that they need the help of others to succeed.

Another goal of the project was to develop a system that would intelligently respond to children's behavior and adapt to the different contexts. The system was designed to reduce user's anxiety by gradually introducing new elements, while offering a high aesthetic value that would match available commercial videogames and would therefore meet children's expectations.

### Hypotheses

From the previously defined goals for the research, three hypotheses were proposed: 1) children would show motivation to engage in playful experiences in the virtual environment, 2) this full body interactive experience would increase the propensity of each child to engage with other people, and 3) positive social initiation attitudes would be observed between the child with ASD and the neurotypical child during the sharing of the experience.

## LANDS OF FOG INTERACTION DESIGN

The design strategies presented were aimed at achieving the three hypotheses; therefore, the description of the design process will be organized according to these objectives. Each design strategy will be described by framing it in relation to the previous experience with Lightpools, our knowledge as interaction designers, the Participatory Design workshops, and related technical considerations.

### Participatory Design

When designing systems for people with special needs, it is important that these individuals are included as informants for the design process [22]. Doing so can allow for increased understanding of the requirements specific to that population. One of the most common approaches is the use of Participatory Design (PD) which involves people of the target population in the design of the technology [21].

For the definition of the narrative and interaction content, five PD sessions were conducted where four children with HFASD gave their input and ideas. During these sessions, children were engaged in a number of activities to design much of the visual content of the system and to define the game mechanics. For example, during the second session children with ASD had the opportunity to design the environment through a collage activity. In another session children had the chance to propose which creatures would inhabit the environment, and then enact them to define their behaviors. The outcomes of these contributions will be explained in the following section. For a full description of the PD process conducted for the design of Lands of Fog, please refer to [35].

### The physical interface

The physical configuration of the experience has been designed around a circular projection of 6 meters in diameter (see figure 1). This is based on the experience of Lightpools which also used this configuration. Specifically, the circular projection does not provide corners in which ASD children can isolate themselves from the typically developed child, and movement is always directed back into the main playing area. Additionally, the diameter of 6 meters was found to allow for free roaming of the children within the VE. This allows them to easily adopt exploratory attitudes as they wander through the physical space. This large physical size allows each user to have their own space and not feel pressed to interact with the other. At the same time it affords serendipitous encounters of the two children providing opportunities for them to start interaction; either physically, or through the events occurring in the VE.

From the experience with Lightpools, we speculated whether Lands of Fog would also provide users with a handheld physical pointer object to interact with the virtual world. Although the pointer was originally used in Lightpools for tracking users and was also seen as a good technical solution for Lands of Fog, we questioned whether it would be adequate for ASD children. The psychologists in our team considered that the handheld object would act as a cognitive offloader and help the children with ASD to focus on the relevant virtual elements, allowing them to better grasp the system's responses to their actions. This approach seemed successful in Lightpools to help users focus while interacting with the system. Having a physical object tied to a virtual representation can help users to form the mental mapping between the physical and virtual world.

### Engaging the user

As stated previously, children with ASD are characterized by limited interests and repetitive behaviors. This may lead to difficulties in focusing and maintaining attention towards intervention and therapy activities. Thus, it is important to design solutions that engage players with ASD to keep interest and focus towards the experience.

**Figure 1. Picture of the system during a experimental session. Two children are playing in the play area, with the psychologist in the background and the parents observing in the foreground.**

*A world covered by fog*

The virtual world was designed in collaboration with the children with ASD during the PD sessions. It was designed to be a unique place where different kinds of biomes meet and where strange and unique insects and creatures live. The world is based on four different environments that coalesce in a unique space. The virtual world was designed as a place where a grass field with a pond lies beside a snowy and icy patch, which meets a solidified magma terrain, all traversed by a cobbled road. Children specified that each zone would be populated by unique objects and creatures (figure 2).

The users cannot see all of the VE at once; which is similar to how Lightpools worked. If the users were allowed to see the entire VE at once, they would be less motivated to explore the space by physically moving around. Hence, we thought the VE needed to be covered by a layer of fog and the users would only be able to see part of the environment through a hole in the fog (figure 3). As the system tracks the user's position, it opens a hole in the virtual fog at that point and reveals part of the hidden VE. As the users move in space, their hole follows them and can therefore gradually start to understand the structure of the VE.

This practice of restricting the view to reveal only a small section of the environment is referred to as creating a "peephole", a design strategy which Dalsgaard and Dindler [17] have shown to be a good practice for promoting exploration. In the case of children with ASD, who typically show difficulties when presented with numerous stimuli, peepholes, such as these openings in the fog, can help them focus on a single piece of relevant information and eliminate distractions, which could be a source of anxiety. Hence, having the rich world covered by a mantle of fog was meant to help as well as motivate users' engagement and exploration by increasing the interest to discover surprising elements which may lie below.

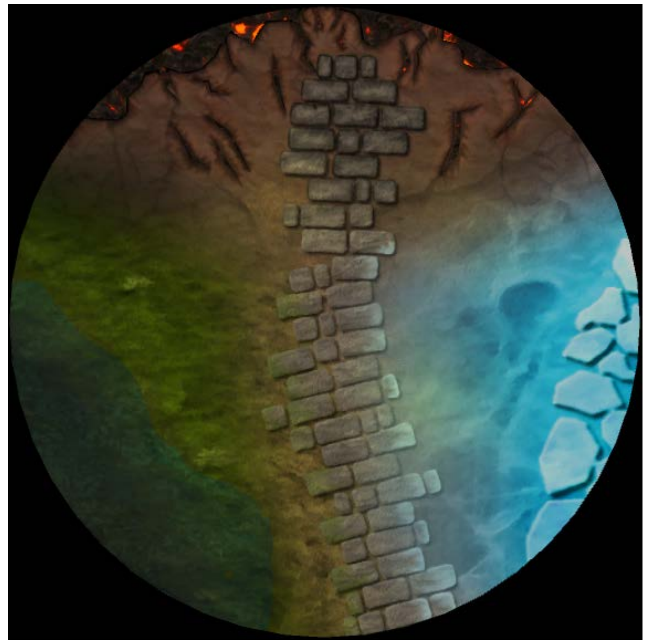

**Figure 2. Overview of the virtual environment (clockwise from the top): lava zone, ice zone, and grass and pond, all traversed by the cobblestone path.**

*Hunting Insects*

Children with ASD sometimes adopt passive attitudes when placed in unknown environments. To avoid this, and to foster exploration of physical and virtual space through the hole in the fog, we decided to incorporate mysterious groups of elements that move about in flocks through the virtual fog and hence, potentially tickle the curiosity of children to find out what they are. These elements appear in the form of "swarms" of objects, moving about in random trajectories above and below the fog. Users may catch these objects with their handheld pointing device such that those which are caught stay within the hole that the user generates in the fog.

If the child shows no special interest for these swarms during a limited time, the system subtly changes their trajectories gradually bringing them closer and closer to the child so as to make them more evident and more accessible to him. Even up to a point in which the child can catch some of the objects in the swarm almost without effort. This subtle reaction of the system is unnoticeable by the child and therefore, an extra help is being provided without causing stigmatization. This game mechanic, which was not used in Lightpools, has been introduced in the design specifically considering the requirements for children with ASD.

To attract users' attention, we decided that the swarms would emit a bright light, so children could see "pools of light" moving below the fog (see figure 3). Nonetheless, these swarms occasionally fly above the fog to show that some virtual objects exist in the virtual environment. During the PD sessions children proposed that the objects could be fireflies and that these could be captured using the handheld pointer in the shape of a butterfly net (figure 4). By hovering the net over a nearby swarm, the captured fireflies would change color and then follow the user as they continue exploration. Technically, these nets are also useful to track the users via a computer vision system. We can identify each user by making each net a different color.

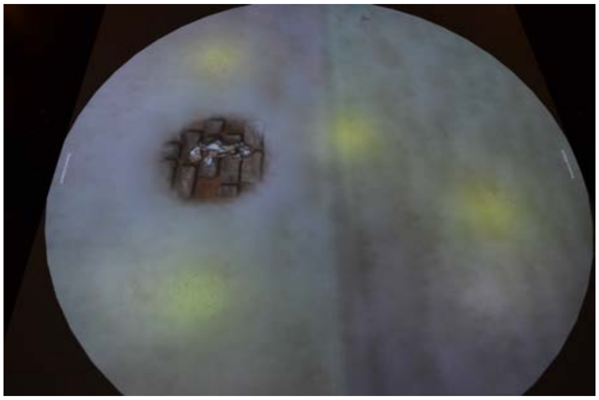

**Figure 3. The user sees the world below through the hole in the dense fog. The lit circles represent swarms of fireflies moving just below the fog.**

In the final design, when a user brings the net close to a flock of fireflies, two are caught at once. This is represented by changing the color of the fireflies to match the user's butterfly net color, while the rest of the swarm moves away from the user. Making the swarm move away from the user was implemented to foster them to move around the environment following the swarm to try to catch more fireflies, hence promoting spontaneous exploration.

After hunting a certain amount of fireflies, we decided that they would blend together and transform into a creature that would become a virtual partner for the user. The design strategy of beginning interaction with simple objects and transitioning to more complex objects was adapted from the Lightpools project, where users could grow simple proto-objects into more complex (albeit abstract) virtual partners. These partners opened a richer interaction level with the system. Adapting this interaction mechanic in Lands of Fog, novel elements were being introduced gradually during the experience through the repetition of an easy to grasp mechanic, a design approach suggested by Davis et al. [18].

*Creatures*

Lightpools' virtual partners were seen as helpful elements for fostering socialization. When adopting the mechanic of having virtual partners in Lands of Fog, we imagined that creatures could be suitable for subtly driving users together and gently introducing opportunities for collaboration. In Lands of Fog, we decided creatures would follow the users while they move around the environment, as virtual partners did in Lightpools, so the children could form a sense of empathy and companionship with their creature (see figure 4).

During two PD sessions, children gave ideas regarding the different creatures that could inhabit the virtual world. Children proposed creatures such as a Yeti, a Golem, a Coral Girl, and even a Crab Man. Our co-designers conceived a total of 14 creatures that could be discovered, although each child could only have one creature at any one time. The creatures were associated with the different regions of the environment. The PD participants also had the chance to define how the creatures would appear and interact.

In order to maintain user engagement with the system, another mechanic was devised. As users that already have a creature continue hunting fireflies, their creature changes appearance when a number of new fireflies has been attained. This mechanic was implemented to continue fostering the children's sense of exploration as they discover different versions of their creatures. In total, there are 4 different versions for each creature, summing up to 56 creature possibilities.

**Figure 4. Two pointers held together with both users' creatures below.**

When users adopt a passive attitude towards the game, the system uses the creatures to motivate users to play. For example, after 10 seconds of inactivity, the creature begins showing signs of boredom. After 30 seconds, the creature autonomously ventures a certain distance towards the other user. When the two creatures (one from each child) move within close proximity, they greet each other to signal that a possibility of interaction exists.

*Interactive virtual elements*

In Lands of Fog the virtual environment is filled with interactive virtual elements that are hidden by the fog and can only be discovered when users get within close proximity to them. When thinking about the objects that users would interact with, we thought these elements could be transformed by both users working together. Transforming those elements seemed an interesting way to generate surprise, thus fostering dialogue and social initiation with other users (both in TD children and in children with ASD). As users explored, creatures would point to nearby elements to hint that the elements were interactive.

Children with ASD in the PD sessions had the chance to propose what kind of objects could be found in the environment, and they conceived a total of 16 different objects. These co-designers also suggested the reactions of the objects when transformed, with unique animations and sound effects that would catch the interest of the players. Having different virtual elements to transform was meant to engage users to continue exploring for novel features in the environment as well as collaborate with each other.

### Promoting socialization and scaffolding collaboration

The main goal of the research project was to develop a system where children with ASD could learn and practice social interaction. As previously mentioned, co-located experiences can maximize the cognitive outcomes of social experiences, thus the game was designed to allow for two users to play together. This situation could also help the typically developed children to see the children with ASD as valuable play partners, encouraging social integration.

#### *Reducing competitive behaviors*

Rather than using competition as a motivator for engaging in gameplay, we wanted to use positive values to dissuade the children from embracing a competitive mentality. Plot strategies of the experience aimed at preventing competition included creating a sense of empathy between the children and their creatures, and teaching the children about the positive effects of collaboration.

While the children were collecting fireflies, there was a risk that they would try to steal fireflies from their partner or compete for the same firefly swarm. To prevent this, we employed three design strategies. The first strategy involved programming the swarms to stay dispersed evenly over the virtual world. By preventing swarms from grouping or clustering together, children would not be tempted to compete for the same one. The second design strategy was to change the body color of fireflies to the player's net color after they had been caught. This helped children to understand that those fireflies now belonged to their personal swarm and were not available to be caught by the other user. The third strategy was to represent the swarm of collected fireflies as a randomly, chaotically moving, uncountable cluster that grows. Not having a clear idea of how many fireflies the child has would prevent children from trying to compare their amounts.

The game was designed to embrace an open ended play format as in Lightpools, where users could continue playing for an undefined length of time. This was adopted so that children would not be focused on competing to reach a particular goal or ending, but would rather focus on the process of exploring the world with their partner and sharing their discoveries. Therefore, we designed the game to lack a concrete plot line or ending.

#### *Socializing through the creatures*

One of the first new interactions that we devised happens when only one user obtains a creature (from having caught sufficient fireflies). At this point, the user is able to share the creature with the other user by bringing their nets together, constituting an easy interaction and thus simplifying the understanding that things can be shared. This sharing occurs by having the creature replicate itself and transferring one of the copies to the other user.

As described before, once the two users have a creature each, when the two creatures come close to each other at a certain distance, they greet the other. This gesture tries to make the children aware of the fact that they too can interact with the other child. It also opens the door to new interactions between the creatures.

One such interaction is when users bring their creatures together at any point in the environment (where no virtual elements are located). The creatures then perform a choreographed encounter to magically merge and create two new creatures, which replace the old ones. The mechanic of merging creatures shows the children that if they want to discover all the creatures that inhabit the virtual world, they have to collaborate and work together to merge their creatures.

Another mechanic is when both children bring their creatures to a virtual element of the game. The creatures then interact with it and produce an animated response from the element. By including these surprising game responses, the children can learn that when playing together, they are able to experience a more exciting and surprising gameplay than playing alone.

#### *Encouraged collaboration*

When designing Lands of Fog, we decided to give children the chance to play by themselves so they could have their own unique game experience. We have seen from previous research that children with ASD show a tendency towards solitary play, and we wanted to give them the chance to be comfortable in the environment and choose their preferred style of playing. Once they understood the basic gameplay mechanics, we decided to slowly introduce the concept of playing together with their partner with the use of collaborative mechanics and shared objectives. Nonetheless, we wanted to adopt what we call an "encouraged collaboration" approach, which means that children were not forced to collaborate in the game. Instead, the game presented interesting incentives so the children would want to collaborate by their own volition.

## TECHNICAL DESIGN

### State diagrams for game design

As the system had to account for player navigation, movement of virtual objects, and interaction with virtual elements embedded in the environment, it was necessary to find a way to manage how all these would interact with each other.

For managing the complexity of relationships between users and virtual elements, we used state diagrams. With state diagrams we could model different behaviors that users would adopt, and assign system responses (figure 5). The nodes or states in the diagram represent the behaviors that users may adopt at different points in the experience. The transitions between states represent users' actions and system timings. During the experience, the system keeps a state diagram for each user. In figure 5, we can see black lines that represent actions of the user that owns this state diagram, while red transitions represent actions preformed by the other user which affect the first.

In the user state diagram we can see some of the behaviors that the system adopts to foster social situations. For example, if a child does not hunt insects for a certain time, the system changes swarm behavior to approach the child. Another response was designed for when one user still does not have a creature. In this scenario, the creature of one user would casually wander towards the other user, increasing the chances of generating a creature sharing event.

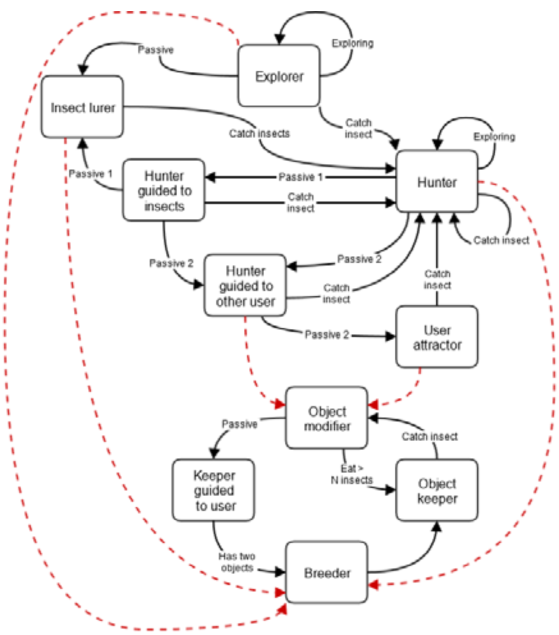


**Figure 5. Initial state diagram for a player's logical state and changes depending on the desired behaviors by the research objectives. Transitions are based on user activity, behavior and system time.**

### Technical development

This application was developed with Unity game engine using MiddleVR to manage the double projector system that forms a single HD image (1920x1920). The tracking system of the nets that the users hold was custom developed by our team using openFrameworks in C++ and will eventually be published as an open source system.

## EVALUATION OF THE SYSTEM

The research methodology, protocol for user trials and informed consets were validated by the ethical committee from Hospital Sant Joan de Déu in Barcelona. The ethical committee of Goldsmiths, University of London validated the study and trials undertaken at the The Elmgreen School in London.

We conducted two studies in different contexts to evaluate the system design and efficacy. The first study was done at Universitat Pompeu Fabra, Barcelona, as a controlled laboratory setting. In this study each child participated in a total of three sessions, to monitor progress and changes over time. The second study was done in The Elmgreen School, an inclusive public primary school in London. In these trials children played one session with the system, and the study was aimed at testing the system in a classroom setting.

Evaluation criteria of the system focused on motivation of the child to play in the system, propensity of the child to engage with other people, and visible social interaction attitudes. In both studies, the experimental setup allowed information to be collected from three sources: video coding analysis, the tracking system, and questionnaires. Each study had its own questionnaire designed to be consistent with the setting's goals. In Barcelona a pre-test and three post-tests (one after each session) were administered to parents of children with ASD, who were present during the experiments. Parents were asked to rate their children's performance in comparison to everyday life. In London, a unique post-test was administered by the psychologists of the school to each participant. In addition, the special needs worker at the school completed a background questionnaire for each child. As in the case of parents, the psychologist would have some previous knowledge of the children which would serve as a baseline for rating children's answers.

### Procedures

A total of 68 children played in pairs with the system (34 children with HFASD and 34 typically developed children) during six weeks of trials in Barcelona (N=28) and one week in London (N = 40). Every pair of children, composed of one child with HFASD and one typically developed child, played in the system for a duration of 15 minutes, which after a series of pilot trials was deemed an appropriate length of time for the attention span of the children with ASD and also allowed time for each of the game elements to be explored. Upon arrival to each playing session, the child with ASD and the typically developed child were introduced and were told that they would play together. Game playing instructions were simple and standardized, such that children could discover on their own how to play the game, a practice which encouraged sharing of knowledge between the children while playing.

In the controlled laboratory setting in Barcelona, children with HFASD were recruited from nearby autism centers. In the school setting in South East London, children with HFASD and typically developed children belonged to the inclusive school, where children with HFASD were integrated in classroom activities with their typically developed peers. In both settings, we verified that none of the children had a close existing relationship with their playing partner, so that each game provided a unique opportunity for the child with ASD to practice social initiation and response with a new companion.

## DISCUSSION

We now discuss the preliminary results we have obtained up to this point from the user trials we conducted in Barcelona and in London.

### User Engagement

The system was received positively by the participants of the Barcelona trials, as the children showed a general enthusiasm for playing and exploring the environment. The children showed an increase in the number of game elements with which they interacted as sessions passed. We may understand this as a willingness to engage in ongoing game play and partake in exploration of new game elements during the session. It may be noted that not only did the children show an increase in solitary playing actions, like catching fireflies, but they also showed an increase in collaborative actions, such as manipulating environmental elements or merging their creatures. This means that not only were the children becoming more active, but they were also engaging in a larger breadth of actions, some of which involved coordination and collaboration.

In the laboratory setting, parents of children with ASD reported that their children showed a significantly increasing level of flexibility throughout the course of the sessions as children were willing to hold off on their own playing agenda and be open to collaborating with their peer. This was also confirmed by psychologists from the school study. As children with ASD may struggle with limited interests and repeating behavior, this increase in flexibility shows that the children were able to focus on the game and break away from a constrained range of activities commonly associated with their condition.

In addition, the special needs personnel at the integrative school in London noted that the children with ASD showed more willingness to engage in play with their partner than in normal school settings (such as science class, drama class and even playground time). This view was supported by questionnaire data where 80 per cent of the children responded that it was easier to get their partner to play as time went on compared to other school activities. The staff of the school agreed with the opinion that the game served as a source for unifying children of various social groups through a unique shared experience.

We believe that the fog also served as a motivator for exploration. Results show a significant decrease in the distance traveled by the children during the game sessions which could indicate that during the first session the children were exploring the environment more since it was hidden by the fog and therefore unknown.

Hunting fireflies was a simple introductory game mechanic which children easily understood. The use of a simple introductory mechanic seems to have been successful in making children engage more with the system, as results show an increase on children's activity over the course of the sessions. Slowly building the complexity of the interaction helped maintain the interest of children in addition to serving as an opportunity to spark conversation between the two players.

### Promoting socialization

In terms of design strategies aimed at fostering socialization, an increase in social behaviors was observed in children with ASD throughout sessions in the laboratory setting study. This was observed in the results of video coding the verbal social initiations, non-verbal social initiations, requests, and responses, which were considered positive social behaviors. From this, it may be understood that, while gaining familiarity with the game, the children also felt more comfortable communicating with their partner. Video coding revealed that an average of 80.4 per cent of social activity in the laboratory and school studies was directly related to game events. Thus, we can see that the game successfully served as a catalyst for starting communication between the children.

The game was designed to be a co-located virtual environment, so that users would be able to practice socialization face-to-face in real time while playing. As results showed an increase in social behaviors over the course of the sessions, such as commenting on passing events or asking for help from their peer, we therefore believe that designing co-located virtual environments can be a successful approach for fostering and scaffolding social behaviors.

### Reinforcing collaboration

In terms of collaboration, it was seen that the children understood the need to communicate and decide upon a unified plan of action, which was necessary for manipulating the environmental elements or for getting their creatures to merge.

After children gained a creature, their creature generated opportunities to collaborate and opened access to richer interactions with more exciting feedback. This approach, which we called Encouraged Collaboration, aimed to offer incentives for collaboration. Results showed that children responded positively with willful engagement in collaborative play. We believe that with a well-thought design, it is not necessary to enforce collaboration, thus giving users the freedom to continue with solo play, but still achieving positive results with regard to demonstrated collaboration attitudes.

The mean distance between players (calculated by averaging the distance between users through a whole session) was also seen to decrease as the children played. This increasing proximity might indicate that the game allowed players to feel gradually more comfortable with their companion In addition, as this decrease in the mean distance corresponds to the increase in number of environmental elements manipulated, which was a collaborative activity, we can see that not only were the players approaching one another more frequently, but also that these approaches had valuable outcomes in terms of collaborative events generated.

## CONCLUSIONS

In this article we have presented an example of an implementation of a full-body interactive environment for promoting social behaviors for children with ASD. Our approach was driven by a series of goals from which design strategies were derived to meet the specific objectives of the research.

We specifically chose ICT as a medium due to its demonstrated success in garnering the interest of children with ASD. As shown by the preliminary results, the use of an ICT system can be effective in motivating users to engage during sessions. We believe that the use of characters and narratives derived from the ideas of children with ASD can be useful in creating a game which those specific users will enjoy.

The use of a "peephole" effect by parting the fog was a design strategy put in place to help children concentrate on relevant information. This reduced the risk of overwhelming players with distracting amounts of information that could be presented in the large scale projection.

Beginning the game with a simple to grasp mechanic, such as hunting fireflies, seems to have been successful for helping children get acquainted with the system and was also useful as an initial way of fostering engagement. The slow introduction of richer interactions has proven to be positive for helping children get comfortable with the system and gently encouraging socialization and collaboration behaviors.

Further research should focus on evaluating specific design mechanics implemented and how they affect users' behavior by controlling them as independent variables. Also, it would be interesting to compare the effect of this co-located, face-to-face, full-body interactive paradigm with respect to other videogames based on other types of interfaces, set-ups and paradigms to verify that the properties of our environment are indeed providing a new potential. Furthermore, it is necessary to develop an experimental plan with a longer time span to see the effects on behavior in the long term with a larger population.

## SELECTION AND PARTICIPATION OF CHILDREN

In the controlled laboratory experiments, held at Universitat Pompeu Fabra, a psychologist recruited children with ASD from autism centers in the Barcelona area. TD children were recruited through posters in schools. In the inclusive elementary school experiments, all participants were children from the school, who lived in the neighborhood in South East London. All recruited children with ASD were between ages 10 – 14 in Barcelona, and 11 – 15 in London, had a formal diagnosis of Autism and no epilepsy nor ADHD. All TD children who participated in the experiments were within the same age ranges. At the beginning of each session children were introduced to each other and told they would be playing an interactive videogame together and were given total freedom to stop playing at any moment they desired. Consent forms were given to parents before the start of sessions.

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