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PRISCILA LYRA CABRAL

SOCIAL ROBOT AS MINDFULNESS TOOL FOR CHILDREN

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ABSTRACT

Nowadays, robot technology use has spread everywhere, including usage by children in education, healthcare, and entertainment contexts. Research with social robots for children's healthcare is a growing research field that has already shown great potential in both feasibility and effectiveness respects such as being a distraction during flu vaccination and reducing anxiety, depression and anger symptoms after robot assisted therapy sessions. Adverse events like the COVID-19 pandemic affect children's mental health. Despite the benefits, social isolation, used to mitigate the spread of the disease, significantly impacted children's mental. Such impacts included fear of asking about the epidemics and relatives' health, poor sleep, nightmares, poor appetite, physical discomfort, agitation and inattention, and clinginess, among other psychological conditions observed in related literature. Mindfulness exercises can work as a tool to enhance children's mental health by increasing personal insight and decreasing repetitive negative thinking (e.g., rumination, worry and concerns). Yoga practice is beneficial since it also includes physical activity. This research objective was to investigate, design, develop, and test an application using a social robot for children. The robot is supposed to be a companion and guide the child through a mindfulness yoga practice activity. The social robot model used was the Zenbo Junior from ASUSTeK Computer Inc. This work describes the Human-Centered Design (HCD) stages for application development, named inspiration, ideation, and implementation, and details of application aspects, such as requirements, scripting, workflow, features and system architecture. It also covers user tests, interview scripts, setup, data-gathering methods, and results. The user tests consisted of a single session including 14 children (8 girls, 6 boys) and 8 parents/guardians (5 female, 3 male). Quantitative data from System Usability Scale (SUS) (75,71 for children and 80,31 for guardians) and qualitative data from observation and semi-structured interviews analysis indicate that the sample well accepted the application. Children were captivated by the guided physical activity accompanied by the social robot. In future, this study plans to perform a long-term investigation, including other mindfulness activities and more accessible features. Furthermore, a systematic review of state of the art can increase the present contribution impact.

Keywords: social robots; children's mental health; mindfulness practice activity; Covid-19.

RESUMO

Atualmente, o uso da tecnologia de robôs se espalhou em todo lugar, incluindo o uso por crianças em contextos de educação, saúde e entretenimento. A pesquisa com robôs sociais para a saúde infantil é um campo de pesquisa crescente que já demonstrou grande potencial em termos de viabilidade e eficácia, como ser uma distração durante a vacinação contra a gripe e reduzir os sintomas de ansiedade, depressão e raiva após sessões de terapia assistida por robôs. Eventos adversos como a pandemia de COVID-19 tem grande impacto na saúde mental de crianças. O isolamento social utilizado para mitigar a disseminação da doença impactou significativamente a saúde mental das crianças. Tais impactos incluíram falta de sono, pesadelos, falta de apetite, desconforto físico, agitação e desatenção, entre outras condições psicológicas observadas na literatura relacionada. Os exercícios de atenção plena (*mindfulness*) podem ser uma ferramenta útil para fortalecer a saúde mental das crianças, aumentando a percepção pessoal e diminuindo o pensamento negativo repetitivo (por exemplo, ruminação e preocupação). O objetivo desta pesquisa foi investigar, projetar, desenvolver e testar um aplicativo utilizando um robô social para crianças. O robô deveria ser um companheiro e guia para a criança durante uma atividade de *mindfulness* yoga. O modelo de robô social utilizado foi o Zenbo Junior da ASUSTeK Computer Inc. Este trabalho descreve as etapas de *Human-Centered Design* (HCD) para desenvolvimento de aplicações, denominadas inspiração, ideação e implementação, e detalha aspectos da aplicação, como requisitos, scripting, fluxo de trabalho, recursos e arquitetura do sistema. Ele também cobre testes de usuário, roteiros de entrevista, configuração, métodos de coleta de dados e resultados. Os testes de usuário consistiram em sessões únicas com 14 crianças (8 meninas, 6 meninos) e 8 pais/responsáveis (5 mulheres, 3 homens). Dados quantitativos da Escala de Usabilidade de Sistema (SUS, da sigla em inglês) (75,71 para crianças e 80,31 para responsáveis) e dados qualitativos da observação e análise de entrevistas semiestruturadas indicam que a amostra aceitou bem o aplicativo. As crianças ficaram cativadas pela atividade física guiada e acompanhada pelo robô social. No futuro, este estudo planeja realizar uma investigação de longo prazo, incluindo outras atividades de *mindfulness* e recursos mais acessíveis. Além disso, uma revisão sistemática do estado da arte pode aumentar o impacto da contribuição atual.

Palavras-chave: robôs sociais; saúde mental infantil; atividade prática de mindfulness; Covid-19.

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LIST OF ABBREVIATIONS AND ACRONYMS

ADHD	Attention Deficit Hyperactivity Disorder
AI	Artificial Intelligence
APA	American Psychological Association
ASD	Autism Spectrum Disorder
ASUS	©ASUSTeK Computer Inc.
CALD	Culturally and Linguistically Diverse
CCT	Compensatory Cognitive Training
CSR	Continuous Speech Recognition
DOA	Direction of Arrival
DS	Dialogue System
EAL	English as an additional language
EDA	Electrodermal Activity
EEG	Electroencephalogram
HCD	Human-Centered Design
HRI	Human-Robot Interaction
HRV	Heart Rate Variability
PA	Physical Activity
PCA	Principal Component Analysis
PHSMs	Public Health and Social Measures
POR	Personality of Robots
PwMCI	People with Mild Cognitive Impairment
RCTs	Randomized Controlled Trials
ROS	Robot Operating System
SAD	Social Anxiety Disorder
SAR	Social Assistive Robots

SARS-CoV-2	Severe Acute Respiratory Syndrome Coronavirus-2
SLU	Spoken Language Understanding
SRAT	Social Robot-Assisted Therapy
SUS	System Usability Scale
WHO	World Health Organization
YPI	Yoga Pose Instructions

CONTENTS

1 INTRODUCTION

Robots' definitions are constantly evolving. A description through the lines of humanlike machines states that a robot automates or reproduces specific human capabilities and is a programmable autonomous or semi-autonomous machine (BARTNECK et al., 2020). Robots reproducing social skills to interact with humans in the social world are called social robots (BARTNECK et al., 2020).

Social robots are increasingly used in healthcare (care for elderly and autism spectrum disorders therapy, for example), housekeeping, social companionship, and pet-substitutes (SCOGLIO et al., 2019). Untreated mental health issues in children, such as anxiety and depression, are associated with poorer educational outcomes and the development of mental illness later in life (GOLBERSTEIN; WEN; MILLER, 2020).

Social robots can be a helpful tool for reducing feelings of anxiety and depression and have emerged in recent years as potential tools to promote and support mental health in children (KABACIŃSKA; PRESCOTT; ROBILLARD, 2021)(LITTLER et al., 2021). The COVID-19 era brought fast digitalization and the adoption of information and communication technologies on an unprecedented scale (LATIKKA et al., 2021).

Since 2020's beginning, the world has faced a significant health crisis. A new strain in the coronavirus family, provisionally named 2019 novel coronavirus (2019-nCoV), first identified in China in 2019, caused a new viral disease (BROOKS et al., 2020). Later, it became known as Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2) or COVID-19. In March 2020, the World Health Organization (WHO) declared that COVID-19 had become a pandemic[1] (WHO, 2020f).

As it is a new disease, the first challenge was to identify the infected people. The first symptoms were similar to the common flu[2] - dry cough, fever, and shortness of breath (MATIAS; DOMINSKI; MARKS, 2020)(WHO, 2020c). This disease became a scientific, medical and public health challenge due to the range of severity that a person infected with the virus could present and its high transmission rate (WHO, 2020b).

While there were no definitive answers about the SARS-CoV-2 virus and COVID-19 disease, researchers appointed likely social, economic, and political impacts of the COVID-19 pandemic

1 https://www.who.int/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19—11-march-2020

2 https://www.who.int/health-topics/coronavirus

(BROOKS et al., 2020). They suggested measures to contain and mitigate some of these impacts, using the knowledge from earlier endemics and pandemic situations (WHO, 2020e)(BROOKS et al., 2020).

To reduce the virus transmission, mortality and morbidity from COVID-19, Public Health and Social Measures (PHSMs) were applied. Keeping a physical distance, wearing face masks (covering mouth and nose), frequent cleaning of contact surfaces (such as doorknobs and handrails), frequent hand washing and social isolation (VIOLANT-HOLZ et al., 2020)(WHO, 2020a) are some of the measures suggested and implemented in many places.

Although quite controversial, as it has significant social and economic impact, both when related to specific individuals and when applied to the general population (BROOKS et al., 2020), social isolation, in the forms of quarantine or major lockdown for the entire population was recommended and established, in various countries, as a form of prevention, with the temporary closure of schools, shops, service provision, etc. (VIOLANT-HOLZ et al., 2020)(WHO, 2020a).

Everyone was greatly affected by the COVID-19 pandemic. WHO (2020d) showed concern for people's mental health during the COVID-19 outbreak (WHO, 2020d), especially children and older people (HENKEL et al., 2020).

Social isolation might significantly impact a child's development, including physical, cognitive, and emotional aspects. The combination of the public health crisis - that caused feelings such as fear, confusion, loneliness, and anger (BROOKS et al., 2020)(JIAO et al., 2020), - social isolation (lockdown measures resulting in a reduction of social interactions) - and economic recession caused distress on children (VIOLANT-HOLZ et al., 2020) and might have worsened previous mental illness or led to anxiety, depression, and other mental conditions (MATIAS; DOMINSKI; MARKS, 2020), which may cause a substantial impact on their futures (GOLBERSTEIN; WEN; MILLER, 2020).

The lockdown measures included temporally closing schools, disrupting children's routines, and having consequences for child health (GOLBERSTEIN; WEN; MILLER, 2020). Based on data from before (September 2019) and after a long period of school closure (March-May 2020) due COVID-19 pandemic, a considerable impact on children's and adolescent's daily lives, social interactions, screen time, mental health, and subjective well-being due to home confinement were identified (SHOSHANI; KOR, 2021).

Strengthening the mental health resilience of children and adolescents should be part of an overall systemic program involving families, schools, and communities, aiming to "promote their long-term ability to overcome stress and adversity" (SHOSHANI; KOR, 2021). Chinese pediatricians suggested to parents, caregivers, and families increasing communication with children, playing collaborative games, encouraging activities that promote Physical Activity (PA), and using music therapy in the form of singing to help children through the COVID-19 epidemic (JIAO et al., 2020).

Previous experience told that elders, adults, adolescents, and children all had shown some adverse effects on mental health after a similar health crisis. To mitigate some of these mental health impacts, some health organizations, such as American Psychological Association (APA), suggested practicing mindfulness exercises such as breathing exercises, meditation, and yoga (NAMI, 2020).

Mindfulness is a much broader concept than is commonly understood (SLIWINSKI; KATSIKITIS; JONES, 2017). However, the simplified way of understanding the idea facilitates its practice and enables several benefits. So, mindfulness can constitute the ability to focus on the present moment (ALIMARDANI et al., 2020), ignoring past and future thoughts.

PA is a habit that enhances health and mental well-being (VIOLANT-HOLZ et al., 2020). PA is a common self-care tool for health enhancement (MATIAS; DOMINSKI; MARKS, 2020). PA has two significant aspects: a physiologic that affects the immune system and psychological well-being (MATIAS; DOMINSKI; MARKS, 2020). Due to the restrictions imposed by social isolation, PA at home was one of the few ways to enhance people's feeling of competence, contributing to the feelings of internal goals achievement and self-satisfaction (MATIAS; DOMINSKI; MARKS, 2020).

PA with mindfulness-related techniques was one of the factors that significantly impacted PA benefits to mental health (MATIAS; DOMINSKI; MARKS, 2020). When performing a PA at home without the guidance of a specialized instructor, people need to be aware of their limitations to avoid aggravating previous conditions or creating some health issues (MATIAS; DOMINSKI; MARKS, 2020). Yoga is a PA that has a rhythm adaptable to who is practicing it. Asthmatic children who typically struggle to exercise successfully participated in a mindfulness yoga session (LACK et al., 2020).

Another factor positively impacting PA benefits to mental health is the motivation to keep exercising (MATIAS; DOMINSKI; MARKS, 2020). Exercising at home has the positive aspect of excluding self-criticism in front of others, which usually increases pressure and self-judgment, hindering the psychological benefits of PA (MATIAS; DOMINSKI; MARKS, 2020). Conversely, exercising at home might feel lonely, reducing one's motivation. During the COVID-19 pandemic, many people engaged in virtual social connections to create a social network, encouraging each other to exercise by participating in exercise challenges, for example (MATIAS; DOMINSKI; MARKS, 2020).

Children who stay home for PA activity (JIAO et al., 2020). Even during school holidays, children usually don't engage in PAs (WANG et al., 2020). Anxiety, depression, lethargy, impaired social interaction, and reduced appetite are common psychological effects reported, and a weakened or compromised immune system is a physiological effect (JIAO et al., 2020).

Researchers pointed out that artificially intelligent systems, like robots, can support mitigating risks associated with the COVID-19 outbreak (GHAFURIAN; ELLARD; DAUTENHAHN, 2021). Robots might be used as an intermediary between infected and healthy people, including doctors and nurses (YANG et al., 2020)(HENKEL et al., 2020)(SCASSELLATI; VáZQUEZ, 2020). Many robot applications surged during the COVID-19 pandemic (GONZáLEZ-GONZáLEZ; VIOLANT-HOLZ; GIL-IRANZO, 2021), from disinfecting areas to medical education passing through helping people stay connected (GHAFURIAN; ELLARD; DAUTENHAHN, 2021).

When dealing with the psychological impacts of the pandemic and the lockdown measures used to control it, social robots have a promising role in helping counter loneliness, improve people's mood, reduce depression and anxiety symptoms, and supporting general well-being (GHAFURIAN; ELLARD; DAUTENHAHN, 2021)(HENKEL et al., 2020)(GONZáLEZ-GONZáLEZ; VIOLANT-HOLZ; GIL-IRANZO, 2021).

People generally trust technology and accept the information transmitted by robots as accurate (ULLRICH; DIEFENBACH, 2017). A robot in humanoid form causes a feeling of physical closeness and a sense of presence that leads people to think of the robot as a real being and induces the social behavior of people to interact with the robot (POWERS et al., 2007). An avatar projection that conveys similar information has less effect than a robot (PAN; STEED, 2016).

Human-Robot Interaction (HRI) results better when users accept the robot well. The increase in robotics applications in real-life settings due COVID-19 pandemic positively changed how people saw robots, specifically social robots (GHAFURIAN; ELLARD; DAUTENHAHN, 2021). The robot's shape, which resembles a human being, helps the child to recognize it as someone worth having as a companion. In other words, embodiment into a robot can increase its acceptability (VENTRE-DOMINEY et al., 2019).

A social robot can assume the role of a mentor to engage people in PA, which usually require the presence of a professional service provider (for example, education, physio- and psycho-therapy) (HENKEL et al., 2020). In this scenario, the social robot can help users to engage in PA (HENKEL et al., 2020). It can also assume the role of an exercise companion, reducing loneliness and encouraging PA.

The social isolation imposed by Covid-19 drew attention to many people who need social isolation due to compromised immune systems. Social robots can help meet those needs (GHAFURIAN; ELLARD; DAUTENHAHN, 2021). The robot's material and design would need to be further studied for immunocompromised people to avoid compromising the user's health. However, in some cases, robots can be placed together with people in social isolation after careful sanitation. Some research on children in hospitals has reported how they would sanitize the robot between interactions with children (KABACIŃSKA; PRESCOTT; ROBILLARD, 2021).

1.1 JUSTIFICATION

The COVID-19 pandemic generated a highly unfavorable situation for the mental health of children all over the world. The combination of feelings of fear and anguish due to the threat of the disease, loneliness due to confinement at home, and economic instability, created a scenario conducive to developing or worsening mental illnesses such as anxiety and depression.

There are several ways to deal with the effects of an adverse event on children's mental health. One involves preventive measures, strengthening children's mental health. Mindfulness techniques have shown promising results in improving mental health. It can be practiced in many ways, one of which is the practice of yoga.

More and more technologies merge into our daily lives. Technology, particularly social robots, can be an ally in inserting a new practice into children's routines. The proposed solution in this work is a social robot as an additional tool in practicing mindfulness yoga, assuming roles of guide and companion during the proposed PA.

1.2 OBJECTIVES

This research aims to investigate HRI for children during mindfulness practice. This work describes the design, development, and test of a social robot application where the robot works as a tool for mindfulness practice, assuming the roles of a guide and peer companion. The robot model used was the ASUS Zenbo Junior (Zenbo). The HRI application's main objective was to invite and encourage children to do a mindfulness yoga practice. The guided practice must include encouragement to focus on feelings and body sensations in the present moment, PA instructions, breathing exercise practice, and meditation. Another important aspect is the robot's social capabilities, meaning to mimic the peer characteristics, so the child (user) can create a relative bond with the peer robot.

1.2.1 Specific objectives

The following specific objectives aim to achieve the main research goal:

1. Create a solution to mitigate the impacts of school closure and social isolation situations.
2. Investigate if the social robot can perform as a peer for children between 6 and 12 years old.
3. Identify similar works where robots supported mindfulness activities.
4. Investigate if the chosen social robot model (Zenbo) can perform as a PA guide, considering it doesn't have limbs to show the predicted movements from PA.
5. Investigate if the social robot could be a tool for mindfulness practice.
6. Observe if the social robot could be a factor in motivating children in PA.
7. Evaluate if children could enjoy an activity with mindfulness directions, PA, breathing exercises, and meditation.

1.3 RESEARCH QUESTIONS

RQ1: Will children aged 6 to 12 accept the social robot model (Zenbo Junior) as a companion?

RQ2: Can the social robot help children (6-12 years old) practice a mindfulness technique?

RQ3: Can the social robot's companionship encourage and motivate PA practice?

RQ4: Can children correctly follow a social robot application with PA instructions?

The rest of this document is organized as follows. Chapter 2 shows some academic works related to this project theme. Later, in Chapter 3, the methodology used is described. It includes the development stages and architecture of the application designed and implemented. Chapter

4 describes the results of this research's user tests and analysis, presenting and discussing the data gathered. Lastly, chapter 5 has the conclusions from this work.

2 BASIC CONCEPTS

2.1 ROBOTS AND SOCIAL ROBOTS

The name "robot" was first used in 1920 by Karel Capek to designate a machine that would replace man (BARTNECK; FORLIZZI, 2004). Currently, the robot definition is more complex than this. Robot definitions have changed through the years in many ways, and it is still not unanimous. Robots are generally programmable machines that can perform several tasks autonomously or semi-autonomously.

Goodrich and Schultz, 2007, did a survey on HRI, where they presented HRI as a field of study "dedicated to understanding, designing, and evaluating robotic systems for use by or with humans." (GOODRICH; SCHULTZ, 2008). They say that HRI uses proximity between humans and robots to classify interactions into remote or proximate interactions. Its application can distinguish these categories into mobility, physical manipulation, or social interaction.

Social robots can interact socially with humans in many different environments and contexts so that they may perform many kinds of roles. They can express themselves through verbal and non-verbal language, sometimes presenting some personality. A social robot embodiment usually has a head, body, and limbs - or a similar structure that plays the role of these human-like parts. There are no rules for robot embodiment, and finding some social robots with no limbs or constituted by a single piece is possible.

At the beginning of the 21st century, Breazeal shared some thought-provoking papers defining social robots as sociable robots that would be able to understand, communicate, interact, learn, and grow with us (BREAZEAL, 2003). Social robots must interact with people, following programmable rules to perform institutional or domestic services. Social robots must have properties related to social norms, form, modality, autonomy, and interactivity (BARTNECK; FORLIZZI, 2004).

Social robots must follow behavioral norms expected by the people to interact with them. They must present some skills, such as having a voice, emitting lights and sounds, offering mobility and mimicking emotions. Bartneck and Forlizzi (2004) define a social robot as an autonomous or semi-autonomous robot that interacts and communicates with humans. So, these robots must have similarities with humans, be socially intelligent and should be collaborators and companions of people (BARTNECK; FORLIZZI, 2004).

A chapter from Robots and Humans book surveys some of the principal research trends in

Social Robotics and its application to HRI (BREAZEAL; DAUTENHAHN; KANDA, 2016). Authors defined social or sociable robots as robots *"designed to interact with people in a natural, interpersonal manner - often to achieve positive outcomes in diverse applications such as education, health, quality of life, entertainment, communication, and tasks requiring collaborative teamwork."*

Social interactions involve emotions and cognitive and social skills. Thus, they are complex and require a multidisciplinary view of the HRI (GOODRICH; SCHULTZ, 2008). For a robot's social applications, social and psychological factors need to be considered, such as how a robot is perceived, trusted, and accepted (ULLRICH; DIEFENBACH, 2017).

Several authors have used interdisciplinary concepts in psychology and computer science, combining theories of social roles, social identity, and group dynamics with Artificial Intelligence (AI) to build the knowledge for an efficient HRI. Researchers that use the psychological approach highlight the importance of robots' personalities, which could be neutral, positive (i.e., nice or friendly) or negative (i.e., grumbling or stubborn), to create better, trusted and accepted social robots (ULLRICH; DIEFENBACH, 2017).

Many researchers have tried to establish a framework for HRI based on Social Psychology using methodologies and results from psychology to develop strategies for HRI. Other researchers have questioned the ties with social and cognitive psychology due to several failures to replicate the social performance of robots (IRFAN et al., 2018).

Not every robot has psychological matters, but social robots are a big part of the HRI. Thus, a better understanding of psychological issues is essential. Irfan et al. (2018) recommend that HRI widen its multidisciplinary background. It should continue to work grounded in various psychological theories but previously testing them and building new links with other academic fields (IRFAN et al., 2018).

Rosenberg-Kima, Koren, and Gordon (2020) experimented with undergraduates during classes where these students were placed in groups to discuss an addressed topic. They used three different setups to compare the results: a human instructor, a tablet, and a robot with a tablet. The robot setup included a tablet to supply some input deficiencies of the robot model (ROSENBERG-KIMA; KOREN; GORDON, 2020).

After testing, the data gathered indicated a positive overview of the robot, but with some caveats. The students pointed out the teacher-robot's positive points: saving human resources and scalability, non-judgmental and objective facilitation, and increased focus and efficiency of activity management (ROSENBERG-KIMA; KOREN; GORDON, 2020).

According to the authors, the novelty effect of the robot may have contributed to a positive perception of it (ROSENBERG-KIMA; KOREN; GORDON, 2020). Still, they also believe that the teacher-instructor configuration, using the robot as the instructor as a form of collaborative teaching, may be instrumental in the future, especially when using the "flipped classroom"[1] methodology.

A promising aspect of social robots is their use in educational contexts. The growing number of students per classroom and the demand for greater personalization of curricula increases the need for technological support in education.

Belpaeme *et. al.* (2018) say that, particularly for children, the robot can assume a teacher or tutor role while keeping company and entertaining the child in some activity. Virtual agents such as laptops, tablets or phones can support education and training, but physically embodied robots offer some advantages. The authors highlight these advantages:

- Robots can compose curricula that require engagement with the physical world;
- Users show more social behaviors that are beneficial for learning when engaging with a physically embodied system;
- Users gain learning when interacting with physically embodied systems over virtual agents (BELPAEME et al., 2018).

In interaction with children, physical robots are more likely to elicit social behaviors that benefit learning (KENNEDY; BAXTER; BELPAEME, 2015). Robots are more engaging and enjoyable for cooperative tasks and are perceived more positively (BELPAEME et al., 2018).

Robots can supply part of the current education needs, and generally, they yield good compliance to its requests and obtain enhanced learning. A robot's characteristic for teaching and training is the personalized service for each child, presenting a new subject only when the user assimilates the previous topic. Substantial research has focused on customized services using computational techniques to provide more complex problems gradually, step by step (GORDON; BREAZEAL, 2015).

Gordon, Breazeal, and Engel (2015) set up an experiment to analyze how interaction with a curious robot promotes children's curiosity. Curiosity is the fundamental drive to ask questions and understand events better. Their research objective was to make the children learn new things and stimulate their drive to learn and explore, i.e., increase their inherent curiosity. The

[1] "Flipped classroom" methodology is a method where students learn the lesson material at home via on-line learning platforms and later discuss and practice studied subject in small groups in the classroom.

experiment included, beyond the robot, a tablet with three apps: a story-maker app and two curiosity-assessment apps (GORDON; BREAZEAL; ENGEL, 2015).

During the story-maker app, the robot's behavior expressed want and enthusiasm to learn new words and presented wonder and imagination about future events, thus exhibiting curiosity aspects. Then, children's curiosity was accessed using two different apps and accessing three different quantitative measures: free exploration, question generation and uncertainty seeking. They have shown that a fully autonomous robot can model as a peer, impacting curiosity behaviors in children. Their results suggest subtle social interaction utterances and expressions can impact children's curiosity (GORDON; BREAZEAL; ENGEL, 2015).

Belpaeme et al. (2018) performed a comprehensive review of more than 100 papers on the subject of social robots for education. They have tried to answer the questions about the robot's efficacy (cognitive and affective outcomes of robots used in education), the robot's embodiment (impact of using a physically embodied robot), and the robot's interaction role (different roles the robot can take in an educational context). The results have confirmed the promise of social robots for education and training, but it needs a tightly integrated endeavor and involves solving technical challenges and changing educational practice.

The following section introduces the use of robots in the health field.

2.2 ROBOTS IN HEALTH FIELD

Robot applications for health care vary from simple interactions to interventions inside the body. Robots have many health applications, such as surgical robots, hospital management support, healthcare worker and robot cooperation, patient interactions, physical and mental rehabilitation, "at home" assistance, and smart prevention. Bardaro, Antonini and Motta (2021) generally classified robots used in health care into three categories: surgical, rehabilitation and social robots (Table 1). These categories are primarily different from each other, varying target-audience and objectives, so they don't have overlaps, except for the cognitive rehabilitation tasks that can be on both rehabilitation and social robot categories (BARDARO; ANTONINI; MOTTA, 2022). Each category can be subdivided many times according to specific uses. Social robots have two primary purposes: service and companionship.

Csala, Németh and Zainkó (2012) experimented with hospitalized marrow-transplanted children who had to stay in sterile rooms for long periods due to their health condition. Their experiment consisted of four short motivational acts where the social robot NAO (from

Table 1 – Classification of robotics in the healthcare field.

Classification	Surgical	Rehabilitation	Social: Service	Social: Companion
Definition	Tools for performing medical tasks	Physically assistive devices to assist and compensate natural human movements	Tool for performing tasks that are dirty, dull, dangerous, or repetitive outside of industrial settings	Robots designed to foster a sense of companionship for their users
Target user	Surgeons	Patients	Patients	Patients
Focus	Enhancing user's capabilities	Compensating user's capabilities	Engaging users in cognitive and physical activities	

Source: Adapted from Bardaro, Antonini and Motta (2022)

Softbanks) would try to engage children in some daily tasks (eating, taking medication, physical exercises, and bathing) that they often are unwilling to do. Even though it consisted of one-way dialogue acts, the robot's application received positive feedback from all participants, parents and medical staff (CSALA; NéMETH; ZAINKó, 2012).

One common disease that leads to social isolation is cancer. Alemi, in 2015, explored the effect of a social humanoid robot as a therapy-assistive tool (ALEMI et al., 2016). Through an eight-week experiment, they observe anxiety, anger, and depression in children with cancer. The participants were composed of two therapy groups. One group had the NAO social robot and a psychologist; the other only the psychologist. Figure 1 shows some scenarios of the group with the robot participation.

Figure 1 – NAO robot in a therapy group session (a) One of the SRAT with NAO Robot. (b) NAO Robot acting ill - to help create a bond with the children.

Source: (ALEMI et al., 2016)

During the eight weeks' sessions, participant children replied to questionnaires with parents' help. The children in the Social Robot-Assisted Therapy (SRAT) group gave the three aspects studied a significantly lower score than the control group. They also showed positive reactions to the robot's presence. After the experiment, they concluded that a humanoid robot could be more efficient in interventions and instigate children to be more interactive and cooperative in their sessions.

Another important finding by Alemi *et. al.* is that the children were able to bond with the robot and, with this, the robot was able to teach them about their affliction and instruct them in techniques that could help them deal with their own distresses (ALEMI et al., 2016).

Newhart, Warschauer and Sender (2016) experimented with a teleoperated robot by children so they could attend school despite social isolation due to immunity disease. These children often missed school days and felt lonely, angry and depressed. The child using a device connected to the robot controlled it throughout the school. The robot had a video display where the child could interact with other students and teachers. They intended this experiment to address some of these children's needs, such as reducing children's loneliness, depression, and isolation (NEWHART; WARSCHAUER; SENDER, 2016).

Pérez (2016) conducted experiments using positive psychology exercises with older adults. In his short-term study, he observed that a direct intervention in which the participant was aware of the activity's psychotherapy background resulted in better outcomes than when the participant was not aware. Two of his three long-term studies had a single participant, and the third involved a married couple. Pérez found that the robot-mediated programs could achieve their respective objectives (matching with results found in psychology literature). Still, the user's perception and acceptance of the robot were not ideal, as the participants reported the robot more like a machine than a companion, with some exceptions. One user, who lived alone and felt lonely, said he appreciated having a "buddy" robot. Another user, although generally considering the robot non-intelligent and without emotions, found at the end of the four weeks experiment some human traces in the robot that she didn't observe in the beginning (Gallego Pérez, 2016).

Social Assistive Robots (SAR) use in mental health research has not been widespread (SCOGLIO et al., 2019). Scoglio *et al.* (2019) systematically synthesized the literature between 2008-2018 that examines the use of social robots in mental health and psychological well-being. The fields of robotics and artificial intelligence are rapidly changing, and this review aims to synthesize and describe the rise of research in this area. After carefully selecting, they found 12 papers related to empirical studies involving data collected on the direct interactions between a human participant (18 years or older) and a social robot (an embodied robotic platform to form an assistive or affective connection with users). The 12 studies used five different social robots, including three major areas of robotic applications for mental health: comfort/companionship, stress reduction and motivation.

Overall, results regarding the impact of the social robot-delivered mental health interventions and interactions ranged from generally positive to mixed. Most studies focused on symptom reduction related to mood and positive quality of life changes after robot interactions. Most (n=11) reported positive mood, comfort, or stress reduction increases following the social robot interventions. However, nearly all studies aimed to assess the social robot's feasibility or usability in a given population, and the results were good (SCOGLIO et al., 2019). They concluded that using SAR in mental health research and interventions is nascent. There is abundant opportunity in this area for growth and expansion to improve usability and efficacy in advancing this field (SCOGLIO et al., 2019).

Rasouli *et al.* (2022) have proposed incorporating social robots in conventional treatments for children and adolescents with Social Anxiety Disorder (SAD), among the most common anxiety disorders. Individuals with this condition find numerous routine life situations, such as meeting new people, speaking during meetings or class, and even using public washrooms difficult and fear- or anxiety-inducing.

The research involved 68 students at the University of Waterloo (38 female, 28 male, and two non-binary) who were 17 years old (adolescents). They concluded that social robots could be beneficial tools to support children and adolescents with social anxiety, aiming to improve treatment utilization and treatment outcomes. They also concluded that social robots should not be substitutes for experienced practitioners and human partners. Still, they could be helpful as complementary tools in the initial stages of treatment to encourage people with SAD to seek and engage in treatment (RASOULI et al., 2022).

Dawe *et al.* (2018) did a scoping review to describe the literature's state and explore possible directions for future research and practice on using social robots for children's healthcare. The study included seventy-three publications with *"conceptualization, development, testing or evaluation of social robots for use with children with any mental or physical health condition or disability."* Most studies were feasibility studies suggesting general acceptance of robots. They found twenty-six different robots, some in development stages, but most studies used the NAO robot. They concluded that the healthcare context is a potential field for social robot use, and the research area needs improvement on experimental design quality and a larger sample size (DAWE et al., 2019).

Robinson *et al.* (2019) recognize the crescent development of robot's uses for medical treatments and did a systematic review of Randomized Controlled Trials (RCTs) on psychosocial health interventions by social robots to synthesize RCTs *"across all health domains where social robots have been tested"* (ROBINSON; COTTIER; KAVANAGH, 2019). They included papers reporting a social robot used to deliver psychosocial intervention for health and well-being. They examined the effects of at least two conditions on RCTs over at least two measurements. They included 27 trials, of which 6 were interventions for a child's health or well-being, 9 reported interventions for children with autism spectrum disorder and 12 trials of robot interventions for older adults. They hadn't identified any works with adolescents, young adults, or other problem areas. Neither found interventions where the participant's verbal response would change the robot's speech. They observed that more recent trials had more suitable methodological quality. They concluded that *"research on social robot interventions in clinical and health settings needs to transition from exploratory investigations to include large-scale controlled trials with a sophisticated methodology to increase confidence in their efficacy"* (ROBINSON; COTTIER; KAVANAGH, 2019).

Moerman *et al.* (2019) did a systematic state-of-art review to summarize *"the use of SARs in a hospital to support children's well-being and what the effects are"* (MOERMAN; HEIDE; HEERINK, 2019). They considered ten publications (related to eight different studies) relevant. The studies reported using six different types of robots with three main objectives (distraction during medical procedures, emotional support for dealing with a disease or support of well-being during a hospital stay). A study on a psychiatric ward had mixed results, including likes and dislikes of the robot and violent attitudes toward the robot. Other studies showed positive effects on children (MOERMAN; HEIDE; HEERINK, 2019).

Kabacińska *et al.* (2021) pointed out that, regardless of preliminary evidence suggesting that SARs are potentially helpful in addressing stress and anxiety in children, robotic interventions' impact on children requires a careful examination. Since the area of SAR for pediatric mental health is relatively new, they chose to do a scoping review on *"how social robots are investigated as means to support mental health in children."* They aimed to understand the current landscape of SAR as tools to improve mental health outcomes in children and identify critical gaps in this field through the "map" provided by this review that had *"an interdisciplinary approach at an intersection of robotics and medicine."* They limited the timeframe search to 10 years (2009-Nov 6th, 2019). After carefully screening the databases search and additional manual search on Google Scholar, applying inclusion and exclusion criteria, 16 publications, which reported 12 research studies, were included. Five different robots were used in these studies (KABACIŃSKA; PRESCOTT; ROBILLARD, 2021).

Overall, studies analyzed pointed out positive outcomes of robot interventions for children's mental health outcomes. Kabacińska *et al.* (2021) observed many disparities in outcome measures, robots used and study quality in this sample. It can imply a challenge to *"draw patterns or relationships within the data."* They draw attention to this sample's current limitations, knowledge gaps and quality evidence. Nevertheless, they provided a list of recommendations to be addressed in future research studies to improve findings in the area of SAR for pediatric mental health (KABACIŃSKA; PRESCOTT; ROBILLARD, 2021).

Given anxiety and distress in children while attending a clinical or hospital environment, social robots can support reducing these emotional states. Littler *et al.* (2021) systematically review the literature to assess *"evidence on the types of social robots used and their impact on children's anxiety or distress levels"* in hospitals or clinical environments. Their search included papers published between January 2009 and August 2020. They found ten studies which used seven different robot types. After interacting with a social robot, children showed reduced levels of anxiety and distress. Littler *et al.* (2021) concluded that even though this research field is at an early stage, it shows *"a promising role in reducing levels of anxiety or distress in children visiting the hospital"* (LITTLER et al., 2021).

Table 2.2 shows a summary of the reviews cited above. Although they have some similarities, they have different objectives. Some conclusions are similar as well.

Table 2 – Summary of reviews which had robots and children and well-being as search target

Author, (year)	**Dawe, (2019)**	**Moerman, (2019)**	**Robinson, (2019)**	**Kabacińska, (2021)**	**Littler, (2021)**
Review design	Scoping review	Systematic state-of-art review	Systematic review of RCTs	Scoping review	Systematic review
Databases searched	▪ Engineering Village ▪ IEEE Xplore ▪ Medline ▪ PsycINFO ▪ Scopus	▪ Cinahl ▪ Medline ▪ Embase ▪ PsycInfo ▪ IEEE Xplore	▪ Medline ▪ PsycInfo ▪ ScienceDirect ▪ Scopus ▪ Engineering Village	▪ EMBASE ▪ PubMed ▪ MEDLINE ▪ PsycINFO	▪ Via OvidSP (MEDLINE, PubMed and PsychINFO) ▪ Via WoS (Web of Science) - IEEE Xplore ▪ Google Scholar ▪ Grey literature databases (BASE and Clinical Trials)
Objectives	To review research on social robots to help children in healthcare contexts in order to describe the current state of the literature and explore future directions for research and practice.	To summarize the use of SARs in hospital to support children's well-being and what the effects are.	To undertake a systematic review examining current evidence from RCTs on the effects of psychosocial interventions by social robots on health or well-being.	To describe the current landscape of SAR as tools to improve mental health outcomes in children and to identify critical gaps in the research in this field through an interdisciplinary approach at an intersection of robotics and medicine.	Assess the current evidence on the types of social robots used and their impact on children's anxiety or distress levels when visiting the hospital for outpatient appointments or planned admissions.

Continued

Continuation of Table 2

Author, (year)	Dawe, (2019)	Moerman, (2019)	Robinson, (2019)	Kabacińska, (2021)	Littler, (2021)
Conclusion	▪ Social robots hold significant promise and potential to help children in healthcare contexts. ▪ Higher quality research is required with experimental designs and larger sample sizes.	▪ SARs may have a potentially positive influence on a child's well-being. ▪ Further research is needed to determine: –the effect of using SARs and –how to integrate the use in the working routines of health personnel.	▪ Early stage (few trials identified) of health, well-being, and psychosocial interventions by social robot. ▪ Reduced methodological quality in many trials (small sample sizes, absence of independent randomization, blind assessment or follow-up, and their somewhat rudimentary statistical analyses). ▪ Recent trials show higher quality resulting in optimism in future research.	▪ SAR interventions for children's mental health has potential for positive outcomes. ▪ List of recommendations for designing studies in this area. ▪ More RCT is need in this area.	▪ Social robots hold a promising role in reducing levels of anxiety or distress in children visiting the hospital; ▪ Further research providing high-quality evidence is required.

Continued

Continuation of Table 2

Author, (year)	**Dawe, (2019)**	**Moerman, (2019)**	**Robinson, (2019)**	**Kabacińska, (2021)**	**Littler, (2021)**
Inclusion criteria	▪ Included publications that described: –conceptualization, –development, –testing or evaluation ▪ Social robots for children (aged 0-18 years) with any kind of mental or physical health condition or disability; ▪ Publications focusing on the broader classification of neurodevelopmental disorders (other than ASD) ▪ Publications were not excluded on the basis of methodological quality due to the emergent nature of the field.	▪ Whether the study assessed children (0-18 years old) ▪ Whether the robot involved had interactive properties ▪ Whether the children included underwent a medical treatment in the hospital or at an ambulatory healthcare facility	▪ Peer-reviewed journal or conference proceedings. ▪ Published in any year[c] ▪ Described intervention: –where a social robot delivers a psychosocial intervention for health or well-being (i.e. one that used verbal communication or other social interaction); –examined the effects of at least 2 conditions in an RCT over at least 2 measurement occasions. ▪ The included trials could use Wizard of Oz controlled robots	▪ Peer-reviewed study or a conference proceeding; ▪ Intervention reported focused on children (0-18 years old); ▪ English text only; ▪ Study assesses aspects of mental health outcomes[d] *No restriction on mental or health status of participants.	▪ Described intervention: –with children (aged 0-18 years) who were visiting the hospital or clinical environment (children with any psychological or physical health condition). –where a social robot provided companionship with verbal or physical interactions[e]. –compared to either usual care or to another control intervention[f]. ▪ Reported the effects each social robot had on anxiety, or distress on their participants. ▪ Both qualitative and quantitative studies.

Continued

Continuation of Table 2

Author, (year)	**Dawe, (2019)**	**Moerman, (2019)**	**Robinson, (2019)**	**Kabacińska, (2021)**	**Littler, (2021)**
Exclusion criteria	▪ Book chapters, monographs ▪ Publications focusing exclusively on autism[a] ▪ Publications on preventative health behaviors in children without identified health conditions; ▪ Publications on social robots in the context of normative child development. ▪ Physically-assistive mechanical or surgical robots and virtual reality interventions.	▪ When sum score[b] by assessors was lower than 3, publication was considered irrelevant and was exclude.	▪ Trials using technological agents without embodiment (eg, chatbots or avatars) ▪ Robotic devices without communicative abilities, such as prosthetic devices and teleoperated, surgical, and exoskeletal robots	▪ Publication does not report on a mental health intervention; ▪ Publication solely describes robot development; ▪ The robot is used for diagnosis of a mental health disorder; ▪ Publication examines only social outcomes of robot intervention (e.g., gaze, social skills, communication skills).	▪ Studies that didn't focus on children in a hospital or clinical environment. ▪ Papers that solely focused on children with ASD. ▪ Studies that didn't have social robots as an intervention. ▪ Studies that didn't aim to reduce anxiety or distress. ▪ Academic thesis papers and protocols were not included.

Source: Elaborated by author (2023).

[a] Publications focusing exclusively on autism has been reviewed previously.
[b] Three assessors independently assigned a score to each reference: 0 (not relevant), 1 (potentially relevant) or 2 (relevant). By adding up the scores a reference could receive a sum score between 0 and 6.
[c] Multiple papers on different aspects of a single trial were all used to provide information, but if multiple papers presented the same material, the most complete and current report was selected for evaluation and review.
[d] Mental health outcomes: changes in mental well-being and mental illness symptoms as a result of treatment or intervention that can be quantified or described qualitatively.
[e] Provided companionship at any point of the visit (before, during or after the treatment).
[f] Another control intervention such as a teddy bear or a virtual character.

As mentioned before, there are many techniques to help increase mental health and well-being. One possible way widely used nowadays is mindfulness techniques. In this context, mindfulness comes from Buddhist philosophy, which includes three dimensions: present self, ethics, and spirit. Mindfulness is a concept that has yet to achieve a theoretical consensus. In classical Buddhist literature, it is a personal and cognitive transformation. Academic literature defines it as simply cognitive and emotional regulatory skills. For the public in general, mindfulness only addresses the traditional meaning of present-moment awareness (SLIWINSKI; KATSIKITIS; JONES, 2017).

The following section presents some works where robots support mindfulness activities.

2.3 ROBOTS AND MINDFULNESS

There are many ways to practice mindfulness daily, from simple exercises like focusing on the smell, taste, and texture of a snack, breathing exercises, or meditation to more elaborate activities like mindful yoga.

As an ancient practice, yoga was adapted to occidental needs, expectations, and daily lives. It is a practice that requires both mental and physical involvement since its objective is meditation while staying in different poses. A mindfulness yoga practice is an adaptation in which the PA of yoga includes instructions to focus on breathing and sensations that conscious movements provoke. As it is adaptable to the user's physical condition, yoga could serve as a PA for children in isolation due to illness. Lack et al. (2020) conducted a pilot experiment with children with severe asthma with positive results: the children practiced a PA that they could complete without going into crisis, and in the process, they still had fun (LACK et al., 2020).

Sliwinski (2015) employed Bergomi et al. (2014) individual factors of the mindfulness model to look at the feasibility of interactive technologies and digital games to improve mindfulness. Later, Sliwinski (2017) did a review on interactive technologies as support tools for cultivating mindfulness and was able to conclude that, even if more studies are needed, interactive technologies, and particularly digital games, are promising tools for developing each factor of mindfulness and, thus, improving mindfulness (SLIWINSKI; KATSIKITIS; JONES, 2017).

Reynolds-Cuéllar et al. (2017) explored the intersection of human emotions and social robotics research. They aimed to observe how robot companions can be leveraged for human emotion elicitation and what role social robot companions can play in promoting self-awareness, mindfulness, or introspective activities. Their experiment included a game for engaging humans in introspection. Participants believed that the robot would be able to access participants' facial expressions and other data such as Electroencephalogram (EEG) signals, Electrodermal Activity (EDA) and Heart Rate Variability (HRV). However, the authors used a Wizard-of-Oz approach[2], where all robot responses were teleoperated by one of the researchers. Their results showed the potential of social robots to be placed as companions for tasks related to self-awareness, mindfulness, and introspection (REYNOLDS-CUéLLAR; BREAZEAL, 2017).

Pérez (2016) did three experiments with elderly living alone in their homes. One of those experiments had a breathing meditation exercise based on a mindfulness meditation program delivered remotely through the robot at home. The other two used other psychological strategies to assess the elder emotional and mental states aiming to reduce loneliness and improve a positive view of life (Gallego Pérez, 2016).

Mindfulness meditation can help reduce stress and anxiety, regulate emotions and treat depression. Alimardani et al. (2020) have studied a meditative Brain-Computer Interaction system for administering mindfulness practice through a social robot. They have used multiple EEG features for meditation and mindful state to provide feedback for the robot's action.

Their research included twenty-eight participants (mean age = 20.2), where the Pepper robot (SoftBank robotics) provided instruction in a natural tone. Assistive systems provide objective feedback that monitors users' neurophysiological responses in real-time, helping them sustain a mindful state and avoid mind wandering (ALIMARDANI et al., 2020). The experiment report concludes that "mindfulness meditation guided by a social robot can induce significant changes in the brain activity even in novice users during a single practice session and that these objective features can be employed in the development of adaptive interventions and personalized SARs in mental healthcare" (YOON; ALIMARDANI; HIRAKI, 2021).

Shamekhi and Bickmore (2018) developed a way of human-computer interaction using a breath sensor that sends a message to a virtual meditation coach. An embodied conversational agent guides meditation instruction and receives feedback from chest-expansion-based respiration as an interaction modality, taking a step towards developing interactive virtual robots for calming applications (SHAMEKHI; BICKMORE, 2018).

Participants reported that their meditation was significantly more relaxing and helpful when

2 The Wizard-of-Oz approach is used in HCI research where a user interacts with a computational agent believing it to be autonomous. However, an unseen researcher is teleoperating it, or other mechanisms exist to mimic the actual behavior.

the coach responded to their breathing. They also had a significantly stronger respiration regulation with the breath-sensitive coach as measured by their respiration rate during meditation. They highlighted the importance of the agent's voice in mindfulness applications. Results indicate that the virtual meditation coach responsive to user respiration is an ideal medium for teaching guided meditation. However, the appearance and voice should be more human-like for optimal effectiveness, at least with new users (SHAMEKHI; BICKMORE, 2018).

Axelsson et al. (2021) did a Participatory Design study with prospective users and well-being instructors. Their study discussed how a robot could function as a mental well-being coach. They compiled and discussed the data gathered on the developed themes regarding robot features, form, behaviors, robot-led well-being practices, and the advantages and disadvantages these could provide (AXELSSON; BODALA; GUNES, 2021). They concluded, *"that while there is a range of potential application areas for a robotic well-being coach, prospective users and well-being instructors bring up similar expectations for robot capabilities, as well as advantages and disadvantages."* Beyond this, they could not conclude regarding the robot's embodiment and interaction level. Some would prefer an abstract-looking robot that should not imitate a human, while others expected a human-like robot with similar verbal expressions. Either way, participants emphasized the need for robust technology for two-way communication to avoid disappointment. The consulted well-being coaches said some exercises could be implemented verbally with little input from the user.

Kubota et al. (2020) used existing control synthesis methods coupled with an accessible high-level specification interface to create an end-to-end system that enables programmers of any level to quickly and easily program social robots to exhibit complex behaviors: JESSIE (Just Express Specifications, Synthesize, and Interact). Their system includes Robot Operating System (ROS) nodes representing sensor information and behaviors for a social robot. They tested their system with clinical research participants who created personalized treatments for People with Mild Cognitive Impairment (PwMCI) on Kuri, a social robot from Mayfield Robotics. Authors considered three types of propositions and their grounding as ROS nodes: Activity module - nodes represent behaviors the robot can execute during the session (e.g., give a greeting, practice number game); Activity completion - nodes signal the completion of activity modules; Sensor - nodes are associated with stimuli the robot should respond to (e.g. whether the person touched the robot). Activity modules represent a particular action which clinicians can have the robot execute. For example: In the Mindfulness exercise module, Kuri asks the PwMCI to close their eyes, then talks them through a script to improve self-awareness

(KUBOTA et al., 2020).

Later, Kubota et al. (2022) conducted interviews with two groups of participants (clinical neuropsychologists and PwMCI) before and after showing video demonstrations of their existing Compensatory Cognitive Training (CCT) activities on their robot prototypes. The prototypes included the following components: Word Game; Color Game; Number Game; Mindful Breathing Exercise, and storyboards of potential new activities to practice the strategies. They reported their findings and specified design patterns and considerations for translating neurorehabilitation interventions to robots (KUBOTA et al., 2022).

Kewalramani et al. (2021) surveyed parents and children to examine whether and how technologies smart toys in a home-based setting might socially and emotionally support children with diverse needs (such as Attention Deficit Hyperactivity Disorder (ADHD), Culturally and Linguistically Diverse (CALD) and English as an additional language (EAL) background) through play. Four robots were sent home with each participating family: Alpha Mini, Coji, Qobo - the snail, and LegoBoost Bot. Each robot had different purposes but had some coding or programming features. Alpha Mini (a wireless AI robot (with voice and face recognition) that can be coded via an app to perform various actions) was used to perform repeated actions such as yoga poses. The collective data from both parents and children's (n = 5) Zoom interviews, digital observations and children's drawings demonstrated how children engaged with their robots in dialogues that generated happy feelings and a sense of 'imaginary' togetherness (KEWALRAMANI et al., 2021) with their robot during their coding experiences.

Bodala et al. (2020) did a long-term (5-week) experiment using a teleoperated robot to deliver mindfulness sessions. The study randomly assigned participants into two groups: one taught by a human coach; the other taught by a teleoperated robot through the same human coach (Robot Coach group). After each session, participants would fill out a "session experience questionnaire." This questionnaire was a combination of the Godspeed and other human-robot interaction questionnaire adapted to each group and included items on participants' feelings before and after the session.

Observing the Godspeed questionnaire results, the Robot Coach received high scores on concepts of Likeability and Perceived Intelligence but low scores on Anthropomorphism and Animacy concepts, so researchers believe that their robotic coach had positive responses even if it was too robot-like. They also observed the scores for motion and conversation increasing over time, suggesting that participants found the robot more coherent and easier to converse. When observing the effect of the mindfulness session on the participants, the study found a significant variation in the scores from the beginning and end of sessions, suggesting that, in the end, participants from both groups were calmer and more relaxed. Bodala et al. (2020) did not observe the novelty effect of the robotic coached group (BODALA; CHURAMANI; GUNES, 2020). They also observed that participants' personality traits, Conscientiousness and Neuroticism, for example, influence their perception of the robot coach (BODALA; CHURAMANI; GUNES, 2021).

A systematic review of robots used as a way or tool to deliver mindfulness training can support a comprehensive understanding of this robotic use case. The present research covers a non-exhaustive search of related works containing fewer than ten items. Still, the presented evidence in this section demonstrates different scenarios where robotics help children's psychosocial health suggesting that this field has promising success in assisting children to overcome adverse life events. The table 3 compares present research with related work items, highlighting the following aspects: robot model, application type, mindfulness activities, participants, user evaluation method, and results format.

Table 3 – Works relating robots used for mindfulness purpose.

First author, (year)	Robot model and role	HRI	Mindfulness activities	User Evaluation Method	Participants	Results format
Pérez, (2016)	A. Prototype similar in appearance e function to Care-O-Bot III –Role: Helper to daily breathing exercise B. Giraff robot from Giraff Technologies AB –Role: Guide activity C. Giraff robot from Giraff Technologies AB –Role: Guide activity	A. HRI through auxiliary tablet. B. HRI through WoZ. C. HRI through WoZ.	A. Daily breathing exercise based on mindfulness meditation program; B. Three-good-things exercise[a]; C. Loving Kindness Meditation[a].	A. Long-term (3 weeks) study at participant's home; B. Long-term (2 weeks) study at participant's home; C. Long-term (4 weeks) study at participants' home.	A. 1 men (74 y. o.) B. 1 man (77 y. o.) C. Married couple –1 man (70 y. o.); –1 woman (66 y. o.).	Report and recommendations

Continued

Continuation of Table 3

First author, (year)	**Robot model and role**	**HRI**	**Mindfulness activities**	**User Evaluation Method**	**Participants**	**Results format**
Reynolds-Cuéllar, (2017)	▪ TEGA (by the Personal Robots Group at the MIT Media Lab). –Role: Player agent in the game.	HRI through WoZ.	Emotions-based game for engaging users in introspection	▪ Two playtest; ▪ Short questionnaires with different focus on each playtest.	A.12 players –3 men; –9 women. B.11 players –6 men; –5 women.	Recommendations
Alimardani, (2020) Yoon, (2021)	▪ Pepper, from SoftBanks Robotics –Role: Guide meditation	Robot received feedback from user's real-time neurophysiological responses through EEG.	▪ Mindfulness meditation.	▪ Single practice session.	▪ 28 participants –M_{age}[b] = 20.2 years, SD = 3.4 years	Report and recommendations

Continued

Continuation of Table 3

First author, (year)	Robot model and role	HRI	Mindfulness activities	User Evaluation Method	Participants	Results format
Shamekhi, (2018)	▪ Embodied conversational agent. –Role: Meditation coach.	Virtual agent received user's feedback from chest-expansion-based breath sensor.	▪ Mindfulness meditation.	▪ One experiment session that included two treatments. Each treatment had: –2-3 minute math test (as a stressor) –1-2 baseline calibration (for breath sensor) –12-minute meditation –Post questionnaires	▪ 21 participants –62% female; –M_{age}[b] = 42 years, SD = 14 years	Report and recommendations

Continued

Continuation of Table 3

First author, (year)	Robot model and role	HRI	Mindfulness activities	User Evaluation Method	Participants	Results format
Kubota, (2020)	▪ Kuri, from Mayfield Robotics –Role: Demonstrated authors' system[c]	Testers did not interact directly with the Kuri nor auxiliar iPad.	▪ A mindfulness exercise module was avaiable to clinicians	▪ A single session in which participants learned the system and created interactive session for a PwMCI	▪ 6 neuropsychologists with no programming experience –5 female; 1 male –M_{age}[b] = 34 years, SD = 7.67 years –Experience working with PwMCI (M_{work}[d] = 6.53 years, SD_{work} = 8.31 years)	▪ Report on their system (JESSIE)

Continued

Continuation of Table 3

First author, (year)	Robot model and role	HRI	Mindfulness activities	User Evaluation Method	Participants	Results format
Kubota, (2022)	▪ Kuri, from Mayfield Robotics –Role: Demonstrated authors' system[e]	Testers did not interact directly with the Kuri nor auxiliar iPad.	▪ Mindfulness breathing exercise –Among other activities not related to mindfulness	A. Individual interview and 3 focus groups with 2 clinical researchers and some members from authors team. B. Individual, semi-structured interviews	A. 6 clinical researchers –All female –M_{age}[b] = 34.83 years, SD = 9.20 years –Experience working with PwMCI (M_{work}[d] = 6.50 years, SD_{work} = 9.18 years) B. 3 PwMCI –All were male –M_{age}[b] = 74.33 years, SD = 2.31 years –All completed CCT in a clinic-based setting; –They reported moderate familiarity with technology.	▪ Considerations and design patterns for HRI with PwMCI

Continued

Continuation of Table 3

First author, (year)	Robot model and role	HRI	Mindfulness activities	User Evaluation Method	Participants	Results format
Bodala, (2021)	▪ Pepper, from SoftBanks Robotics –Role: Guide meditation	▪ Robot was teleoperated by mindfulness coach	▪ Training sessions, each session focusing on a specific mindfulness topic ▪ Together, sessions were designed to: –provide an introduction to mindfulness techniques –suggest how to integrate mindfulness into daily life	▪ 5 mindfulness training sessions; ▪ One 40-minute group session for week; ▪ Groups with 4-5 participants	▪ Staff and students across university divided in two groups A. HC intervention guided by the human coach ∗2 males ∗7 females B. RC intervention guided by the teleoperated robot coach ∗6 males ∗3 females	Report and recommendations

Continued

Continuation of Table 3

First author, (year)	Robot model and role	HRI	Mindfulness activities	User Evaluation Method	Participants	Results format
Present study	▪ ZenboJunior from ASUS. –Role: Guide and companion	▪ Touchscreen selection ▪ QR code scan	▪ Yoga; ▪ Meditation	▪ Individual single 16-20 minutes test session	▪ Children 6-11(N=14); ▪ Guardians (N=8)	▪ Report and recommendations

Source: Elaborated by author (2023).

[a] These are not mindfulness activities, but they also aim personal well-being.
[b] M_{age} = Mean of participant's age
SD = Standard Deviation for participat's age
[c] This study aimed to create a end-to-end system wherewith clinicians could program Kuri robot to deliver a treatment session for their patients (who are PwMCI).
[d] M_{work} = Mean time of participant's working experience
SD_{work} = Standard Deviation for participat's working experience
[e] In this study authors explored possible uses for their end-to-end system, and design patterns for interactions between robots and PwMCI.

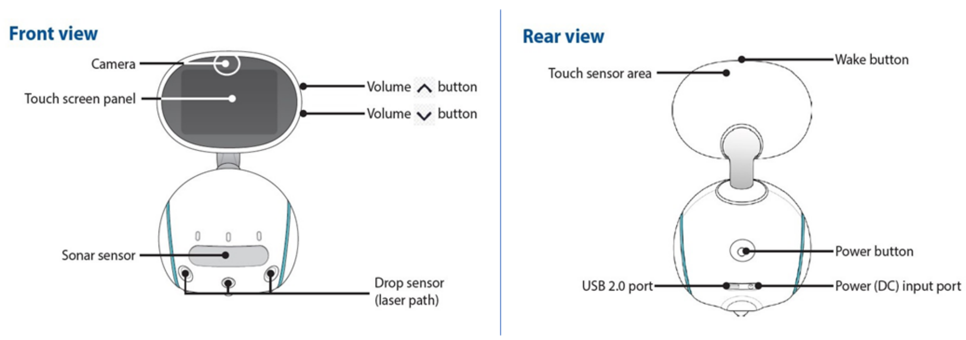
3 METHODOLOGY

The proposed solution consists of an application using the social robot Zenbo Junior, named ZZen. In the ZZen application, the social robot provides companionship and invites users to practice yoga. This activity includes PA and practices individual emotional and mental control.

3.1 ZENBO'S DESCRIPTION

Zenbo Junior (Zenbo) is a social robot designed, created, and manufactured by ©ASUSTeK Computer Inc. (ASUS) for domestic use. Zenbo's main physical characteristics are its round body without arms nor legs, with a neck and a head with a touchscreen display. It has different facial expressions displayed on its 6-inch LCD screen, where it can also show images or videos. It can move its head up and down and move its body, spinning and walking forward. As part of the body design, it has two circles of LEDs on its sides, an embedded camera, speakers, a capacitive sensor on the head, and volume buttons.

Figure 2 – Zenbo Junior devices and sensors.



Source: Adapted from official user's manual from (ASUS, 2019)

The ASUS Zenbo Junior website page[1] describes Zenbo as *"a lovely family companion. He is also a platform that allows designers and engineers to experience the joys of creating rich and interesting features and content."* ASUS (e) ASUS presents Zenbo as an entity, a five-year-old boy with thoughts and habits who is friendly, active, and has a given personality. They say Zenbo is energetic, polite, kind, optimistic, and enthusiastic. Zenbo loves to greet people and "show off," and it is emotionally expressive as a child.

[1] https://zenbo.asus.com/developer/documents/Overview/Design-Guideline/Zenbo-Introduction/

Table 4 – Zenbo Junior specifications.

Specifications	
Operating System	Android
Dimensions	18.5 x 18.5 x 31.5 cm
Weight	2.75kg
Display	6-inch LCD
Camera	13M Camera
Microphone	Digital Microphone
Memory	2G
Storage	16GB *Available storage space is less than actual storage space due to the storage of the operating system and other software used to operate the features
Connectivity	Wi-Fi 802.11 a/b/g/n/ac, 2.4GHz and 5GH Bluetooth BT4.0, CIR-940nm
Speaker	3W*2
Wheel LED	Left*14; Right*14
Sensors	Drop IR Sensor Sonar Sensor Capacitive Touch Sensor CIR Line Sensor
Power Adapter	Input: 100-240V AC 50/60Hz Output: 19V AC, 1.75A, 33W
Battery	Standby 5 hours Continuous use for 4 hours without interruption
I/O port	1 x USB 2.0 Type A port 1 x Micro-USB port

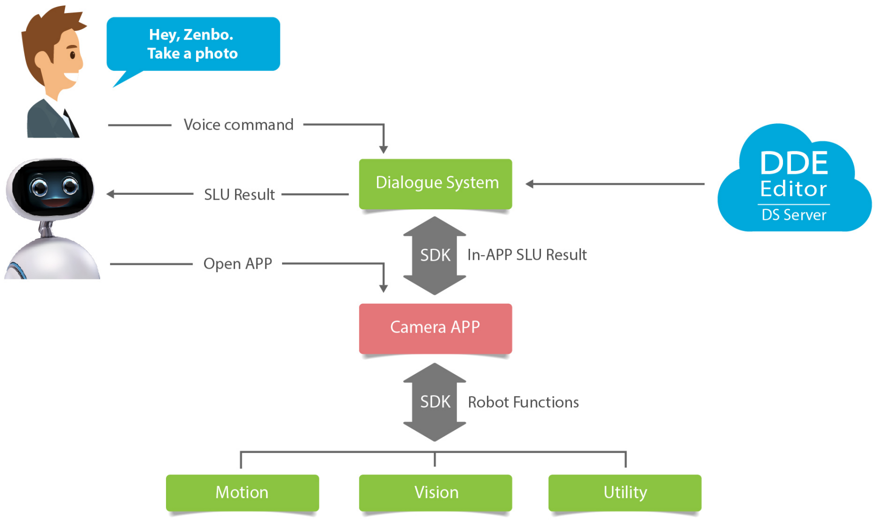
Source: Adapted from (ASUS, g) and (ASUS, 2019).

> "He's never afraid to show his emotions with his wealth of facial expressions and agile body. Zenbo never hides his feelings, and he smiles when he's happy and he shows his innocent frown when being yelled at for doing something bad. Being honest and direct pretty much sums up Zenbo's emotional expressions." (ASUS, e).

Zenbo robot offers 24 facial expressions that can be used individually or combined (ASUS, c). Figure 2 shows a schematic view of the Zenbo body and the sensors, devices, and inputs that compose it. When the sensor area on its head is touched, Zenbo will lower its head and display a "shy" expression, giving him a lovely reaction to the user's touch. Table 4 shows Zenbo's technical specifications (ASUS, g) (ASUS, 2019).

Zenbo has a Dialogue System (DS), including Continuous Speech Recognition (CSR) and Spoken Language Understanding (SLU) for English, Chinese, and Japanese (ASUS, f). Figure 3 shows an example of a user interacting by voice with Zenbo.

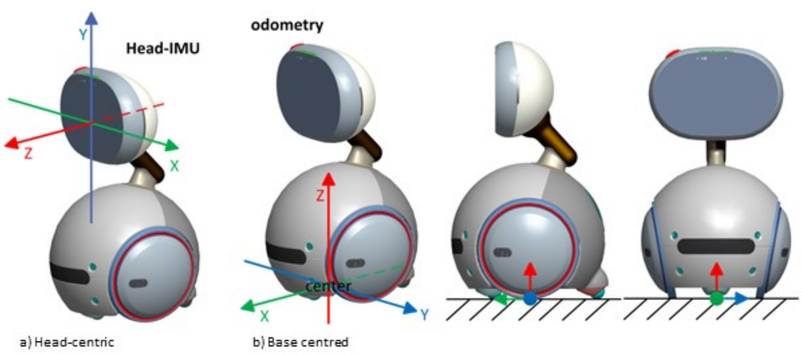
Figure 3 – Zenbo Dialog System example.



Source: Adapted from (ASUS, b)

Zenbo is a flexible robot with 41 built-in movements, which can be used separately or combined to create more complex sets of motions. When designing Zenbo's movements, it is helpful to consider an XYZ coordinate system (ASUS, b).

Figure 4 – XYZ coordinate system for Zenbo.



Source: Adapted from (ASUS,f)

Using the coordinate system centered on Zenbo's head shown in Figure 4 a), it is possible to determine that Zenbo's head has rotation movements on the X-axis. Robot's walking moves, using the coordinator system shown in 4 b), are available on the X-axis direction (Zenbo forward moves) and rotation on Z-axis (to the left by default).

Zenbo has some essential functions at its disposal: family member recognition (Zenbo may use face and voice detection), Direction of Arrival (DOA) (it uses the microphones to determine the direction where sound is coming), family tree (it recognizes how one family member addresses another), SLAM map (after scanning and labeling the SLAM Map, Zenbo will be able to navigate through the environment), finding a person (it can locate a registered person), follow me (Zenbo can follow user while doing other function), Mobile APP (designed to work with Zenbo, sending and receiving notifications, administrating permissions and privileges, video phone and home cam) (ASUS, a).

Users can interact with Zenbo in many ways. ASUS indicates, on their website, three significant characteristics of Zenbo's interactive behavior for designing and interacting with Zenbo: variations based on the distance of interaction (if user and robot are in close, medium, or long proximity), voice interaction, and expressing emotions.

Zenbo's system is based on the Android system and split into two working modes: Zenbo (Robot) mode and Android mode. When turned on, the system will enter the Robot mode by default, but users can easily switch it to Android mode (ASUS, d).

3.2 PROJECT IDEA

The ZZen application comprises three stages: start, activity, and farewell. During the start stage, ZZen will wake up, introduce itself, greet the child (user), talk about the yoga practice, and invite the user to practice with the robot. The activity stage consists of telling a story with movement instructions as incentives for the user to execute them with the robot, which, in addition to the verbal instructions, will show an image of the expected movement. The last step consists of ZZen's farewell, which thanks the company and says it wants to meet the user again.

The start and farewell stages aim to offer the robot some personality with which the user can identify and create some bond. This possible relationship would be helpful for the user to see a companion in the robot and to feel comfortable and encouraged to practice the activity.

The suggested activity is a yoga practice presented through storytelling. This activity method aims to draw attention and entertain the child during the activity. The chosen story has a space travel background, and the proposed yoga positions are part of the preparation and experience. The story divides into six parts ([1] background, [2] boarding preparation, [3] voyage, [4] landing preparation, [5] meditation, and [6] ending). It suggests four yoga poses ([1] Dragon's Breath, [2] Rocket, [3] Bridge, and [4] Turtle). Subsection 3.3.4 describes the completed application's workflow.

The application development uses a Java SDK provided by ASUS. Subsection 3.3.5 describes the application's architecture, the interaction between the user and the robot, and features like the touchscreen (for generic questions) and the camera for reading the QR code (when asking "yes or no" questions). The robot body's LEDs compose the robot's mood and personality. One collected users' feedback using the System Usability Scale (SUS) (BROOKE, 1996) questionnaire adapted to children (PUTNAM et al., 2020) (JERONIMO et al., 2022), a semi-structured interview and an analysis of test recorded video. Data gathering and analysis methods are described in subsection 3.4.1.

3.3 ZZEN'S DEVELOPMENT

The ZZen application development combined Human-Centered Design (HCD) and Design Science Methodology framework principles (WIERINGA, 2014). The combined design cycle comprises three interactive stages: inspiration (problem investigation), ideation (treatment design), and implementation (treatment validation or evaluation) (WHELER et al., 2021). ZZen's development also used some of the tools proposed by the authors to understand stakeholders' needs and requirements, create application workflow, study safety and privacy issues from the application (to avoid or mitigate them), and evaluate the application idea.

3.3.1 Development stages

ZZen application used an iterative development strategy resulting in several versions (i.e., inspiration, ideation, and implementation). The initial idea was an application in which the Zenbo robot would act as a friend for children. The concept evolved and simplified some aspects to achieve more well-defined and valuable objectives.

3.3.1.1 *Inspiration*

The first step in the design cycle is the inspiration stage. Inspiration can happen in different ways and use multiple strategies. A common ground for inspiration is to observe a real-life situation through many lenses to have a complete view of the problem to which one will develop a solution.

Table 5 – Application classification and features.

Classification	Topics	Features	ZZen's features
Category	General purpose	Content-driven	Companion/Peer instructor
	Play purpose	Serious	Guide mindful yoga practice
	Play rules	Closed rules	ZZen gives instructions, child follow instructions
Genre	Physical and social environments	Indoor and solo	Child and robot in the same local, with space to do some movement
	Physical play dynamics	Full body	Child will use arms, legs, hands, feet, back, and head
	Social play dynamics	Single	One child per time
	General thematic	Learning and training skills	Yoga
	Target audience	Children	Children (6-12 yr.)
Setup	Toy component	Toy device	Social robot
	Toy type	Toy robot	ZenboJr. robot
	Size	Medium playground toy	18.5x18.5x31.5 cm
	Symbolic representation	Characters	-
	Devices and peripherals	-	No other device or peripherals
	Interactivity	Toy-to-player	ZenboJr. robot and child(user)
	Connectivity	AR and I/O sensors	Touchscreen, QR code scanner

Source: Elaborated by author based on tool described by de Albuquerque and Kelner (2019).

The first tool used in ZZen application development was the classification tool (WHELER et al., 2021). It was used from the beginning of the development to understand the present scenario: the robot features, the social robots for kids' literature, and social robots' uses in general.

Using a table (see Table 5) based on the tool described on (de Albuquerque; KELNER, 2019), ZZen would be categorized as a Serious App, on the Edutainment genre, with a Playful Training setup. This classification was used as a start point to our literature review. Table 5 was also useful to define the application features.

3.3.1.2 Ideation

The ideation phase consists of organizing all the ideas, thoughts, and inspirations to develop a single idea. The Covid-19 pandemic context largely impacted this phase. As a result, some ideas and inspiration came from the world scenario in 2020.

From the original idea, the only requirement maintained was that the application be friendly to kids. An ideation session with the Virtual Reality and Multimedia research group members followed a few steps of the brainstorming tool proposed by (WHELER et al., 2021). Taking the idea of a friendly robot and the children's wellness needs during the Covid-19 pandemic, the questions were how the Zenbo robot could be helpful for children and if it could be helpful and fun at the same time. The literature showed that mindfulness techniques were valuable and helpful in dealing with such adverse experiences, and yoga might be a fun activity for kids when respecting their physical and cognitive capabilities.

The next step was defining which data and how the robot would collect them from the users using the data collection planning tool (WHELER et al., 2021). At this point, the ZZen idea has advanced, defining the robot as a yoga instructor for children. Having children's privacy as a primary concern, we avoided collecting personal data such as voice, facial image, and profile information (e.g., full name, e-mail address) or any sensitive data (i.e., unexpected/unplanned personal data collected using a camera or microphones) (ALBUQUERQUE; KELNER, 2019).

Even though the Zenbo robot has some of these features available, ZZen does not process audio and only uses the camera to analyze QR codes locally and instantly, not recording any image or using the cloud or other online tools. The data collection planning tool was handy in verifying the consistency of the application workflow while refining the ideas following privacy by design principles (WHELER et al., 2021).

The ideation process produced several ideas, some detailed using the robot storyboard tool, consisting of a sequence of scenes in a PowerPoint presentation (WHELER et al., 2021). The storyboard also served as a guide for implementing child-robot interaction in the ZZen application. To implement the mindful yoga application content, one used free material guides (COSMICKIDS, 2014) from the Cosmic Kids web platform[2] (COSMICKIDS, a) and consulted related YouTube channel[3] (COSMICKIDS, b) for inspiration. The final application content, a storytelling yoga practice, was constructed by mixing and adapting some activities from the web platform. The implementation phase is fully detailed in section 3.3.1.3.

3.3.1.3 Implementation

The first attempt to implement the ZZen application used the Zenbo Junior Python SDK, Pyzenbo, available by ASUS on Zenbo's official website[4]. However, we found some troubles in including option selection interfaces. Then, we decided to create an Android application for the ZZen idea using the Zenbo Junior Java SDK, also available by ASUS on the same official website. During the implementation phase, we also reviewed the predicted child-robot interactions to guarantee the privacy of the data collection procedure.

3.3.2 ZZen's requirements

The robot's personality significantly impacts its performance for social robot design. The Personality of Robots (POR) Personality of Robots (POR) has not a solid definition in related literature (MOU et al., 2020) (Mou, Shi, Shen, AND Xu, 2019). Generally, compared to human personality, POR can be described as the set of characteristics, behaviors, temperament, emotions, and positions observed consistently in a being over time.

ZZen's POR can benefit from matching the Zenbo personality by ASUS: a happy and expressive child willing to help (ASUS, e). Thus, it must have an upbeat personality (e.g., being pleasant, friendly, enthusiastic about everything, and complimenting people).

[2] https://cosmickids.com/
[3] https://www.youtube.com/c/CosmicKidsYoga
[4] https://zenbo.asus.com/developer/

Table 6 – Summary of ZZen's requirements and Zenbo's features used

Requirement	How was it implemented?	Why is it needed?	Where was it implemented?	Zenbo Junior feature used
Embodiment	Zenbo's body	Cause good first impression; Elicit social behaviors; Engage user attention	Every scene.	All features available.
Emotional display and be fun and well-humored	Facial expression; Specific phrases (and matching non-verbal cues)	To support interaction since humans are essentially emotional being.	Almost every scene.	Head and body movements; Zenbo's facial expressions; Play media sound; Wheel lights.
Social support	Specific phrases (and matching non-verbal cues).	ZZen is to be a companion on social isolation environment.	Reassuring that it is ok to have doubts and giving positive comments after movements.	Head and body movements; Zenbo's facial expressions; Play media sound; Wheel lights.
Perceived good rapport with user *Social Rapport*	Head movements; facial expressions; vocal prosody.	Good rapport improves activity results.	Almost every scene.	Head and body movements; Zenbo's facial expressions; Play media sound;
Empathic behavior *Social Rapport*	Different responses according to user answers.	Increases probability of good perceived rapport.	Greeting scene; Invitation scene.	Selection interface; QR code scanner; Head and body movements; Zenbo's facial expressions; Play media sound; Wheel lights.

Continue

Continuation of Table 6

Requirement	How was it implemented?	Why is it needed?	Where was it implemented?	Zenbo Junior feature used
Elicit desire to play along *Social Rapport*	General ZZen behavior.	ZZen is to encourage physical activity.	Every scene.	Head and body movements; Zenbo's facial expressions; Play media sound; Wheel lights.
Non-verbal communication *Communication Skills*	Body and head movements; facial expressions; wheel lights color and mode; vocalization, intonation on recorded audio.	Non-verbal communication is important as verbal communication to present a desired message.	Every scene	Head and body movements; Zenbo's facial expressions; Play media sound; Wheel lights.
Verbal communication *Communication Skills*	Recorded audio for each sentence.	Support good rapport building; complement non-verbal communication.	Every scene.	Play media sound.

Source: Elaborated by author (2023).

ZZen has other requirements summarized in Table 6 and expanded on subsections below. Table 6 also presents the application's location and the features used to achieve each requirement.

3.3.2.1 Embodiment

One of the most critical characteristics of ZZen is to be friendly and create a peer-like bond with the user. Just as for humans, the robot's first impression highly impacts how an interaction will occur later (MOU et al., 2020), so ZZen's physical appearance must be perceived in a friendly way.

Zenbo's embodiment already offers a friendly appearance. However, the robot does not have arms or legs to physically show users the expected moves, which could benefit the ZZen application. Instead, the Zenbo robot can display instructions to perform physical moves using multimedia content, bypassing this limitation.

3.3.2.2 Emotional displays

One of the project's objectives is that ZZen can bond with users. The robot needs to express an empathic, fun, and well-humored behavior. Emotional displays are critical to human interactions since humans are essentially emotional beings (BREAZEAL; DAUTENHAHN; KANDA, 2016).

Showing one's emotions helps others understand one's internal states (agreement and disagreement to statements heard, for example). It might evoke emotional responses from others (be it mirror or oppose emotion). By behaving humorously, ZZen can stimulate the desire to play along (KULMS; KOPP; KRÄMER, 2014) and, hopefully, evoke good feelings in the users.

3.3.2.3 Social support

Humans are social beings which means that they need social relations to live. One of the facets of the importance of social relationships is the possibility of offering social support, whether through emotional, instrumental, informational or companionship support. Breazeal, Dautenhahn and Kanda (2016) point out that providing social support is an effective way that social robots can help people, either by direct interaction or mediating interaction with other people (BREAZEAL; DAUTENHAHN; KANDA, 2016).

One of ZZen's requirements is to offer social support by supporting children's needs during an adverse event of social isolation, and loneliness is one of their hardships in this scenario. ZZen can offer emotional support by offering empathy, encouragement, and companionship, giving the sense that ZZen and the child belong to the same social environment when performing PA together.

3.3.2.4 *Social rapport*

The ZZen application must encourage the child to bond with the robot. According to a study, a good social rapport between people working together often results in better activity results (BREAZEAL; DAUTENHAHN; KANDA, 2016). The authors claim that patients tend to complete the proposed treatment when they have a good social rapport with the doctor who prescribed it, and students have a better learning curve when they have a good social rapport with their teachers.

In human-human interaction, non-verbal cues, such as mirroring or synchrony of body posture, head movements, facial expressions, and vocal prosody, are some factors that influence social rapport quality (BREAZEAL; DAUTENHAHN; KANDA, 2016). So including non-verbal cues in the ZZen behavior becomes crucial to influence social rapport in human-robot interaction.

3.3.2.5 *Communication skills*

A social robot's communication skill is a significant feature of any social robot. A social robot should communicate naturally and casually if possible. Zenbo offers natural language processing in English and Chinese languages. However, ZZen targets Brazilian children who are Brazilian Portuguese speakers, which imposes a technical limitation to using this feature. This choice implied a child-ZZen communication restriction: the child could listen and understand ZZen verbally, but ZZen would not "listen" to the child.

Verbal communication includes more than just the sentences spoken. Aspects such as volume, speaking speed, pitch, and the amount of speech can positively or negatively impact the message (MOU et al., 2020). All phrases were previously recorded for ZZen's verbal communication, considering the intention and intonation necessary for the application context. ZZen plays the correspondent media at the appropriate time.

Robots' movements are part of a robot expression display. Head and neck motions can show agreement, attention, or other internal robots' states. The body's moves can express extroversion and dominance according to angle, speed, and pattern. The larger, faster, and more frequent moves are, the more extrovert and dominant the robot's personality stands (MOU et al., 2020).

ZZen's non-verbal communication cues include head and body movements, facial expressions, and the wheel lights using different colors and available modes (e.g., breath mode, blinking mode, rainbow mode). Modes vary by color range, blinking speed, and frequency. Those features support three roles of non-verbal communication: regulatory cue (through vocalization); state display: indication of internal state (facial expression, blinking lights); illustrators: gestures that supplement information (body and head movements) (BREAZEAL; DAUTENHAHN; KANDA, 2016).

ZZen design permits mimicking verbal communication with the user by using a turn-taking structure, where the robot speaks and waits for the user to reply. ZZen receives child inputs using the screen option selection and QR code scanning.

3.3.3 ZZen's scripting

The phrases said by Zenbo are significant in constructing the robot's personality and the application's narrative. Initially, the sentences were classified according to their purpose in the general flow when building the first verbal communication script. The goal was to evaluate the need for each sentence in the script. The sentences classify four groups:

- **Robot persona** - sentences used for the construction of the robot's personality,
- **General explanation** - sentences that give an explanation of the application and proposed activity,
- **Story** - sentences that compose the ludic story part of the proposed activity, and
- **Yoga Pose Instructions (YPI)** - sentences required to describe and guide yoga poses movements.

ZZen's phrases were later classified according to the type of robot-child interaction it was supposed to evoke. This classification supported planning verbal interactions, considering the robot's limitations to enable natural language processing in Portuguese, and measuring the user's reactions during data analysis. The proposed classification distributed sentences into: direct interactions, indirect interactions, subjective instructions, direct instructions, and additional sentences. The following table describes each category's goals and provides examples (Table 7).

Direct interactions are those in which, after a question from the robot, the user provides a response input that can change the course of the application. For ZZen, the possible forms of direct interaction were selecting an option on the screen, using a touchscreen, and reading a QR code. In the Greetings scene, for example, the user must choose an option on the robot screen to answer the question "How are you feeling today?". Each of the three available options leads

Table 7 – ZZen's sentences classification according to robot-child interaction.

Category	Definition	Robot-child interaction
Direct interactions	Questions/commands from the robot that expects users' response / input and can change the course of the application.	Selecting an option on the touchscreen or reading a QR code.
Indirect interactions	Verbal interaction that does not require a child's involvement and engagement and does not directly influence the communication flow.	Rhetorical phrases aiming to create the feeling that the robot is talking directly to the user, or to encourage the user to continue the activity.
Subjective instructions	Verbal interaction that expect some reaction from user but not necessarily a physical reaction.	Sentences like "think how you feel" were included as part of the activity's mindfulness respect.
Direct instructions	Motor commands after which the user is expected to do some movement. They were subdivided in two groups: instructions for the yoga movements and other commands that compose the story.	The first group contains all sentences providing step-by-step instructions for the yoga poses, including instructions on breathing correctly during the activity. The second group covers motor commands like "wiggle your fingers and toes." that appeared in storytelling scenes to keep the story rhythm.
Additional sentences	All sentences that do not result in any interaction, but they are essential for constructing a cohesive narrative for the application.	Such as "Hello! I'm ZZen!" and "My body is different from yours so, sometimes, my moves will be a little different from yours."

Source: Elaborated by author (2023).

to a different reaction from ZZen. Another direct interaction occurs in the Invitation scene, where the user must use one of the QR code signs to answer the question, "Do you want to practice yoga with me today?" depending on the answer, the application proceeds to a different communication flow.

Indirect interactions depend on the child's involvement and engagement in the application and do not directly influence the communication flow. ZZen does not implement a natural language processor, so it cannot hear the user's verbal responses. That way, this group of sentences includes some questions that became rhetorical. Some sentences aim to create the feeling that the robot is talking directly to the user, while others encourage the user to continue the activity. At the beginning of the application, there is an example of this interaction when

ZZen asks the user what his name is, and even if the user answers, ZZen does not record the answer. Another example of this interaction is when ZZen says, "Let's go!" at different times. Finally, ZZen constantly praises the user's performance with phrases such as "Very well!" and "Excellent!" to congratulate the user for the effort and encourage the user to continue developing the activity, regardless of users' performance.

Subjective instructions come from subjective commands like "think how you feel." After one of these commands, although some reaction from the user is expected, no motor reaction is expected. The interaction resulting from these instructions is complex because, although some elements in the user's behavior provide some indication of his involvement in these situations, it is not possible, in the majority of cases, to conclude if there was interaction with the robot by the user since it is impossible to know what the user is thinking.

Direct instructions are those in which the robot says motor commands to the user. These instructions compose of two groups: the instructions for the yoga movements and other commands part of the story. The first group contains all sentences providing step-by-step instructions for the four yoga poses: Dragon Breath, Rocket, Bridge, and Turtle, including instructions on the correct way of breathing during the yoga activity. The second group covers motor commands like "close your eyes", and "wiggle your fingers and toes." Those sentences can be found during the storytelling activity, in scenes where yoga poses are not included, but some movement is needed to keep the story rhythm. In these cases, the interaction occurs when the user proposes to execute the robot's commands, even if he cannot complete them or has some difficulty.

Additional sentences are all other sentences spoken by ZZen in the application. They do not result in any interaction, but they are essential for constructing and coherence the application's narrative. They are sentences such as “Hello! I'm ZZen!” and “My body is different from yours so, sometimes, my moves will be a little different from yours.”.

3.3.4 ZZen's workflow

As said before, ZZen application has three stages: start, activity, farewell. Each stage is composed by one or more scenes. Figure 5 shows the stages and the scenes related to each stage. ZZen storytelling follows a core workflow with few pathways that usually lead back to the main flow. Table 8 shows which interactions, and in which scene, user may change the workflow.

Table 8 – Users' interactions that may change ZZen workflow.

Scene	Input options	Output actions	Next
Start - Greetings	▪ Touchscreen selection a.Happy face image b.Neutral face image c.Sad face image	a.Happy expression, speech "Excellent! I'm also happy today!" b.Happy expression, speech "Ok!" c.Sad expression, speench "What a shame! I hope you feel better after our time together!"	a.Presentation scene b.Presentation scene c.Presentation scene
Start - Presentation	▪ QR code scan a.Yes b.No	a.Happy expression, speech "Cool!" b.Happy expression, speech "No problem, I'll explain"	a.Continue Presentation scene b.Continue Presentation scene
Start - Invitation	▪ QR code scan a.Yes b.No	a.Excited expression, speech "Wow!!!" b.Sad expression, speech "Oh, alright..."	a.Activity Directions scene b.Continue Invitation scene
Start - Invitation	▪ QR code scan a.Yes b.No	a.Speech "OK, maybe another day..." b.Speech "Ok, I'll ask again... "	a.Farewell stage b.Starts Invitation scene again
Start - Breathing Technique	▪ QR code scan a.Yes b.No	a.Speech "Now inspire..... and now expire" b.Speech "Ok!"	a.Activity Directions scene b.Activity Directions scene
Activity	▪ Touchscreen selection a.Let's start! b.Leave	a.Happy expression b.Speech "Ok!"	a.Context scene b.Farewell stage

Continued

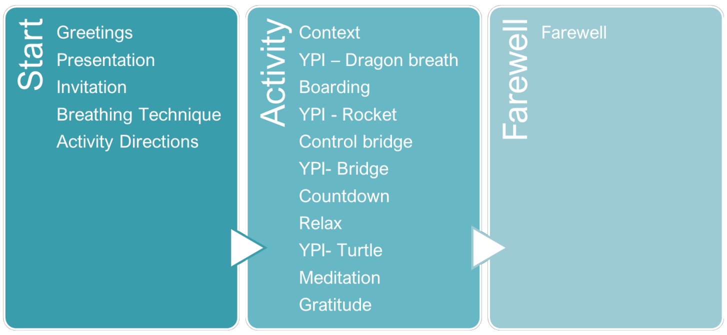
Continuation of Table 8

Scene	Input options	Output actions	Next
Activity - YPI - Dragon Breath	▪ QR code scan a. Yes b. No	a. Direct instructions on Dragon Breath yoga pose. b. Speech "Ok! Let's continue."	a. Continue YPI - Dragon Breath scene b. Continue YPI - Dragon Breath scene
Activity - YPI - Rocket	▪ QR code scan a. Yes b. No	a. Direct instructions on Rocket yoga pose. b. Speech "Ok! Let's continue."	a. Continue YPI - Rocket scene b. Continue YPI - Rocket scene
Activity - YPI - Turtle	▪ QR code scan a. Yes b. No	a. Direct instructions on Turtle yoga pose. b. Speech "Ok! Let's continue."	a. Continue YPI - Turtle scene b. Continue YPI - Turtle scene

Source: Elaborated by author (2023).

The ZZen application starts with a blank screen, so the users can start when ready. Then, ZZen will blink and slowly spin as if it is waking up. When it faces the user again, ZZen will start greeting the user and asking how he/she is doing. ZZen screen displays a selection interface with three image selection options: (1) Happy face; (2) Neutral face; and (3) Sad face.

Figure 5 – ZZen stages and scenes.



Source: Elaborated by author (2023).

The user will choose one of them, and ZZen will respond accordingly. If option (1) Happy face is chosen, ZZen will say it is happy as well; if option (2) Neutral face, ZZen will only place a happy expression and say “Ok!”; if option (3) Sad face, ZZen will show a sad expression and say it is sorry and hope user feels better after playing with it.

Next, ZZen will say it loves practicing yoga and ask if users know what it is. The user will then answer, using the QR code plaque, “yes” or “no.” If the user chooses the “yes” plaque, ZZen will say it is nice, and if the user chooses the “no” plaque, ZZen will say that it is not a problem since it will explain what yoga is. In both cases, after this, ZZen will explain the yoga definition and comment on what ZZen likes about this kind of practice.

Then, ZZen will ask if the user wants to practice yoga with it. Again, the user will answer using the QR code plaques. If the user says “yes,” ZZen will say, “Ok!”. If the user says “no,” ZZen will ask if the user is sure about this—another question for the QR code plaques. If the answer is “yes,” the application will move to the Ending Scene, in which ZZen says goodbye to the user and close the application. If the answer is “no,” ZZen says it will ask again if the user wants to play with it, then the application repeats the invitation question.

If the user chooses to practice yoga, ZZen will explain how the practice will be, meaning it will say the yoga practice predicted includes a story in which both the user and robot are a part. Thus, they should move accordingly to the given instructions. Then, ZZen will explain how to take deep breaths: inspire through the nose and expire through the mouth.

After these simple explanations, ZZen will ask if a user is ready for the practice. Users will choose on an option selection interface between “Let’s start!” or “Leave.” The application will go to the Ending Scene and finish the application if the user chooses the Leave option. ZZen will tell the Spatial Trip story if the user selects the “Let’s start!” option.

The story starts with ZZen saying they are going on a space trip and need to take some deep breaths to focus before their journey. ZZen will then describe the "Dragon Breath" position. Later, ZZen will state that they are mentally ready but need to put on the spatial jumpsuit and find their helmets. Then, ZZen will say they need a spaceship and invite the user to do the "Rocket" pose. Once the Rocket moves are complete, ZZen will look around as if it is looking inside their spaceship and point out that they need a controlling bridge to fly. ZZen invites the user to do the "Bridge" pose at this stage. On the bridge pose, ZZen will start the countdown to the rocket takeoff.

Since the Bridge pose puts much strain on the user’s muscles, ZZen says they can now relax. After a few moments, ZZen says the user might sit down and spin his/her body to look at the stars through the rocket’s windows. Then, ZZen bemoans that the trip is almost at the end and that they must prepare for landing. ZZen asks the user to do the "Turtle" pose to feel safe and protected.

After the Turtle pose, ZZen says they are landing, and the user might lie down for a bit. ZZen guides meditation and says a few positive things about the practice experience. Then, ZZen says the user can open their eyes and sit, so they can greet themselves by bowing to each other. ZZen states that the yoga practice is over.

A few moments later, ZZen will say that it enjoyed the company and hope to meet again, then it will say goodbye, and the application will close.

All tools for direct interaction, when needed, had things written in Portuguese, which means that, for example, the QR code plaque for "Yes" had its corresponding word ("Sim") written on it. Table 9 shows the correspondence between words/sentences in English on this description and in Portuguese used on actual application and test. Similarly, cited verbal sentences in English have their Portuguese correspondence shown in APPENDIX A.

Table 9 – Translated words/sentences used on application.

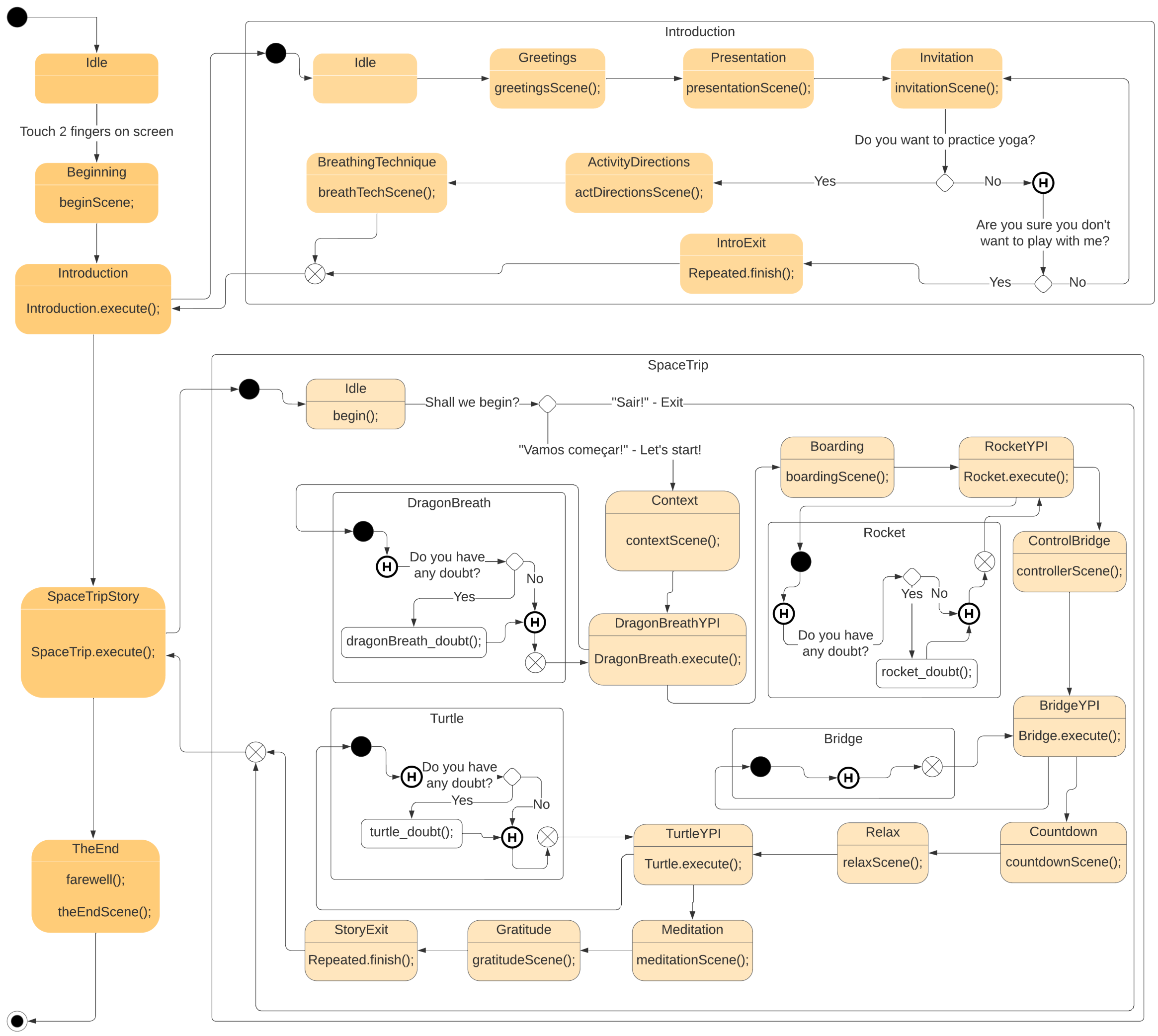
Interaction	English	Portuguese
QR code board	Yes	Sim
QR code board	No	Não
Interface Feel Today - Title	How are you feeling today?	Como você está se sentindo hoje?
Interface before activity - Title	Let's start?	Vamos começar?
Interface before activity - Option 1	Let's start!	Vamos começar!
Interface before activity - Option 2	Leave	Sair

Source: Elaborated by author (2023).

3.3.5 Setup architecture

The Android application for ZZen uses the Zenbo Junior SDK (Java) available by ASUS on the Zenbo Junior official website. Since some features have frequent use, we created a Java class (named Utils) and put the equivalent methods to the features in this class. We organized those methods so that we would only have to add a few parameters when using the methods. The app uses a state machine with four events (Start, Introduction, SpaceTripStory, and TheEnd) (Figure 6) as the main course that works mostly linearly.

Figure 6 – Schematic application architecture.



Source: Elaborated by author (2023).

This first Idle state consists of the white screen waiting for the user to touch (two fingers) to start the "real" application, redirecting the app to the Beginning case state, where ZZen blinks and spins 360° degrees as if it is waking up. It finishes the movement by displaying a lazy expression.

It goes, then, to the third main state: Introduction. This state corresponds to a set of scenes in which ZZen introduces himself, greets the user, introduces yoga, invites the user to practice and gives general instructions about the practice (explaining that the yoga movements will appear in the middle of storytelling and giving instructions on the correct form of breathing during exercise). Since many things are happening in the Introduction case, a class was created (named Introduction, as well) in which each scene was a case of a state machine on the

Introduction class.

The state machine in the Introduction class has seven states: Idle, Greetings, Presentation, Invitation, ActivityDirections, BreathingTechnique, and IntroExit. The Idle case only changes ZZen's expression to the "active" expression, a neutral expression with speaking mouth movements. The Greetings case includes the robot introducing itself and greeting the user, asking how the user feels, opening a selection display on the robot's screen, and the user can choose between three emoticon options. Commenting on the user's answer finishes this case.

Then it starts the Presentation case, in which the robot introduces yoga and asks if the user knows what yoga is, and the user answer using QR code plaques. ZZen will give a different comment according to the user's answer, but then it will continue explaining the yoga definition.

After this, the Invitation case starts with ZZen asking if the user wants to practice yoga, which uses a QR code scan as input for answers. If the user chooses "yes," the application will follow the ActivityDirections case, and if the user chooses the "no" option, ZZen asks if the user is sure he/she does not want to play with it. The user will, again, answer with a QR code plaque. When choosing "yes," the application goes to the IntroExit case, and if the user chooses "no," ZZen says it will ask again, and the Invitation case starts again.

The ActivityDirections case is where ZZen explains that it will tell a story, and the user must pretend to be a character of the story and follow the instructions, making the suggested moves with attention and care, avoiding hurting himself. After these explanations, it starts the BreathingTechinique case, where ZZen explains the importance of consciously slow breathing during exercises and how to do it correctly. After explaining inspiration and exhalation, ZZen asks if the user wants to practice the breathing technique. If the user chooses "yes" QR code plaque, ZZen will give the deep breathing instructions; if the user chooses "no," ZZen will only say "ok."

The last case in this class, IntroExit, is accessed if the user chooses "yes" after being asked if he/she is sure he/she does not want to play with ZZen. This case will direct to the application ending and finish interaction, which ends the Introduction state machine, and the application returns to the main state machine and goes to the SpaceTripStory case.

The fourth main state, SpaceTripStory, is also composed of many scenes and was placed as a new class, named SpaceTrip, with another state machine. It has thirteen cases (Idle, Context, DragonBreathYPI, Boarding, RocketYPI, ControlBridge, BridgeYPI, Countdown, Relax, TurtleYPI, Meditation, Gratitude, and StoryExit).

This Idle case only has a selection screen with two options: "Let's begin" and "Leave." The first option goes to the Context case; the second goes to StoryExit, which works like the IntroExit case (case of the Introduction state machine).

The Context case begins the storytelling by giving the story background and motivating the first yoga move, which is in the next case: DragonBreathYPI. The yoga poses instructions follow the same scheme: instructions are given verbally and with images on the ZZen screen. After explaining how to do it, ZZen asks if the user has any doubts about how to do it. Using the QR code plaques, the user may choose "yes," ZZen will explain again, or "no," and it will start guiding the pose repetitions.

When the DragonBreathYPI case is finished, the application starts the Boarding case, which has many story parts, invoking the user's imagination and some simple movements instruction (raising arms to catch a helmet, for example). In the end, ZZen invites users to make a rocket so they can travel.

The RocketYPI case includes the yoga poses instructions for the rocket pose and the question if the user has any doubt about how to make the pose. After the guided repetitions, the application goes to the ControlBridge case, where ZZen looks amazed by the rocket interior and calls the user to make a control bridge for travelling.

The application starts the BridgeYPI case, which follows the same instructions scheme as the others. However, it does not include the repetitions since ZZen will challenge the user, in the Countdown case, to make the Countdown with the bridge pose repetitions.

When finished the Countdown is, the application starts the Relax case, in which ZZen says the user can lie down and relax a bit after the bridge challenge. While relaxing, ZZen asks the user to pay attention to his breath and feelings, helping the user to be mindful of himself. Some moments later, ZZen says they are already in space and can sit to watch stars, then ZZen says it is time to go back to Earth. ZZen invites the user to do the turtle pose to prepare for landing.

The TurtlePose case follows the same scheme as the other yoga pose instructions. After finishing this, the application moves to the Meditation case, where ZZen guides a mindful meditation, giving the user help in thinking about the playful and relaxing moments lived together.

The last case on the SpaceTrip state machine is the Gratitude case, where ZZen thanks the user for practicing yoga with it, ending this state machine, and the application returns to the main state machine, where the SpaceTripStory case ends as well, and the application goes to the fifth main case: TheEnd.

The end case has two parts. The first is where ZZen says goodbye to the user and that it would like to meet him/her again, and the second is where it turns the LEDs lights and screens off and ends the application.

3.4 EVALUATION PROTOCOL

The evaluation process comprises four steps: pre-session arrangements, the test session, post-session arrangements, and data analysis. Each scheduled test session received a code number to keep testers' anonymity, so all data gathered was marked under the session code.

3.4.1 Data analysis

The study made a qualitative evaluation combined with some quantitative data. Also, some basic profile information was asked to understand the data better.

We used a basic profile questionnaire to characterize the testers' samples. A parent questionnaire was attached to the consent term in which we asked for adults related to the child (father, mother or other), age, profession, and education level.

The child profile questionnaire asked for age, gender, experience with robots, child's yoga knowledge, and child's yoga experience. The answered profile received the session code on the automatic results spreadsheet based on the date and hour the form was filled to preserve the child's anonymity. The analysis consisted of crossing profiles, quantitative and qualitative data of each session, comparing data from individual sessions with each other, and extracting patterns and modes from all gathered data.

3.4.1.1 Quantitative data

We used the SUS questionnaire to measure users' feedback on the ZZen application (BROOKE, 1996). Since there was a relatively large age group, three versions of the SUS questionnaire were used. They are:

- The regular SUS questionnaire for parents, containing 10 statements ((BROOKE, 1996)) plus 3 extra statements related to fun from the SUS-kids ((PUTNAM et al., 2020)) adapting the term "application" to "social robot", a 5-point Likert-scale for each statement, and all sentences were translated to Brazilian Portuguese (tester's native language).

- Two adapted versions for underage participants containing 13 statements and varying sentences according to their age group (6-8, 9-11) (PUTNAM et al., 2020), also adapting the term "application" to "social robot," the 5-point Likert-scale to a 5-point Emoji-Likert scale (JERONIMO et al., 2022), and all sentences were translated to Brazilian Portuguese (tester's native language).

Table 10 shows an example of how a sentence was adapted in each case. And Appendix B shows all 13 statements and adaptations. It also shows Emoji-Likert scale used on used questionnaires.

Table 10 – Example of SUS and SUS-Kids statement 4 adapted to present work.

Reference	Target audience's age	Statement
SUS from (BROOKE, 1996)	Adults	I think that I would need the support of a technical person to be able to use this system.
SUS-kids from (PUTNAM et al., 2020)	9-11 y.o.	I would need help from an adult to continue to play [app].
SUS-kids from (PUTNAM et al., 2020)	7-8 y.o.	I would need help to play [app] more.
SUS-kids adapted for social robots from (JERONIMO et al., 2022)	9-11 y.o.	I would need help from an adult to continue to play with the robots.
Presente work	9-11 y.o.	Eu precisaria de ajuda de um adulto para continuar brincando com o ZZen.
Presente work	7-8 y.o.	Eu iria precisar de ajuda para brincar mais com o ZZen.

Source: Elaborated by author (2023).

3.4.1.2 Qualitative data

The Google Form used for the SUS questionnaire included a few open-ended questions, related to expectations and general opinions on the Zenbo robot and the ZZen application. Beyond this, a semi-structured interview was conducted at the end of the session to get insight into child and adult perceptions and opinions on the ZZen application.

More qualitative data on the user's attitude toward the robot were extracted from the recorded video and compared to expected behavior (see Table 7), and from observational notes made during the test session to access.

3.4.2 Test sessions

The following subsections describe how the test sessions were planned and data gathered.

3.4.2.1 Pre-session arrangments

A psychiatrist and a speech therapist (who are not part of the research group) helped recruit sending messages to patients or patients' parents who were guardians of 6 to 12 years old children. Recruitment occurred using an instant messaging platform (Whatsapp). After they accepted to participate, their phone contact was passed to the principal researcher, who would privately message them to schedule the test session. When they were at the test location, prior to or after the session, all participants (child and guardian) were offered some snacks (drumstick (coxinha in Portuguese) and soda).

Participants' parents provided written consent for children's participation in this study and completed a simple profile form. Before the session started, parents were asked if they wanted to be present in the session room and if they could also participate in research by answering questionnaires and interviews afterward.

After scheduling the meeting with participants, it was sent to them via e-mail or instant message platform, a consent form and two profile questionnaires (one for the child and the other for the parent/responsible for the child). The parents were asked to respond to these materials before the session meeting.

The consent form included the parent's authorization to their child's participation in the research, to record the test session on video, audio and image, and to non-identifiable image publication. The adult's profile questionnaire includes data on relation to the child (father, mother or other), age, profession, and education level. The child's profile questionnaire asked for the child's experience with robots, age, gender, and yoga knowledge and experience.

3.4.2.2 Session structure

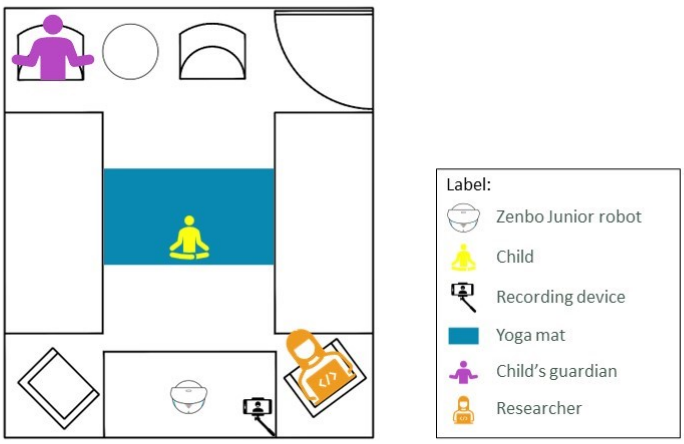
The test session briefly explained the project's objectives and introduced the ZenboJr robot. Parents could choose to stay through the session, participate in it, supervise it, or not. After the brief welcome and project explanation, the researcher introduced the ZZen application to the child. The application has between 16- and 20- minutes duration. During the demonstration, the researcher recorded the child's reactions on video for later analysis.

Then the child and parent (if he/she was present during the demonstration) were asked to answer the SUS questionnaire adapted to social robots (SUS-kids). The child had an age-adapted questionnaire based on (PUTNAM et al., 2020).

The session happened in different places, depending on parent and child availability and convenience. The criteria for the location were that it had enough space for the robot and child to be at least a meter apart, and the child must lie on the floor (able to lie down in terms of space and hygiene).

During the session, we used one Zenbo robot, a video recording camera, and an audio recording dispositive. The audio recording device was used closer to the child so as not to miss the things said in a low voice, which the camera would not be able to capture since the camera was away from the child.

Figure 7 – Test session schematic setup, based on a clinic room where most test sessions occurred.



Source: Elaborated by author (2023).

The room was organized so that the camera, the robot, and the child were arranged straight (Figure 3.6). The camera was put behind the robot, facing the child, and it was placed on support so it would be higher than the robot in a way that would not interfere with the recorded video. The support was a half meter away from the robot, so the robot would not hit the support when moving. The child stayed approximately one meter away from and facing the robot, except when the child needed to select an option on the robot's screen. The suggested distance was enough to see the robot screen and was safe for the child and robot to move during the yoga practice. The parent (if they choose to be present) would stay next to the camera. The researcher was also present during the session (positioned behind the camera).

When all was set, the researcher would start the ZZen application on the robot. The child should interact with the robot and follow the robot's lead. After ending the application, the child (and parent, if present) was (were) asked to answer the SUS-kids questionnaire presented on a Google Form on a computer. The researcher supervised the child to guarantee the conclusion of all questions. Then, the researcher would conduct a semi-structured interview.

3.4.2.3 Post-session arrangements

After the test session, the researcher uploaded in an online folder the recorded video, a copy of the filled profile and questionnaire, and a copy of the informed consent form, assigning them a unique participant's code. A file with the researcher's notes and comments about the session was created and added to the corresponding folder. Later, the researcher prepared a manual transcript for each session, including what the user and researcher said during the session and visual observations of the user's behavior.

A single spreadsheet file (Google Sheets) was created, with four tabs: one for Consent and Parent Profile, one for Children Profile, one for Parent SUS questionnaire answers, and one for Children SUS questionnaire answers. Google Forms saved all answers automatically in the corresponding spreadsheet for further analysis.

4 RESULTS AND DISCUSSION

This chapter describes the quantitative and qualitative outcomes of the user testing setup. The sample profile is described in detail, including age, gender, school year, knowledge about yoga and previous experiences with robots.

As mentioned in the methodology, we used the System Usability Statement (SUS) as the quantitative approach to evaluate parents and children's user experience. The SUS and SUS-kids scores were systematized and are presented in tables and graphs in this chapter.

The qualitative approach consisted of comparing user behavior with expected behavior in each scene, cataloging general user's reactions and commentaries during application test, and user's responses to open-ended questions and semi-structured interview after interaction with robot.

4.1 SAMPLE PROFILE

The user test was performed with 15 children ranging from 6-11 years old (8 females, M_{age} = 8.21 years, SD = 1.805 years)[1]. All participants had no hearing problems and no vision issues, but the sample was quite diverse in age, gender, and school year characteristics, as shown in Figure 8 and Figure 9.

Figure 8 – Children's age and gender.

Age	6	7	8	9	10	11	Total
Female	2	0	1	2	2	1	8
Male	1	3	1	0	0	2	7
Total	3	3	2	2	2	3	15

Source: Elaborated by author (2023).

One participant experienced issues filling in the profile questionnaire and evaluating the SUS-kids sentences using the Emoji-Likert scale. The participant seemed to need help comprehending the SUS-kids statements, and we opted to discard their responses. According to the parents, the participant presented a diagnosis of Autism Spectrum Disorder (ASD) and hyperfocus on technology subjects (e.g., mobile phones and robots were their favorite subjects).

[1] M_{age} = Mean age of children participating on the experiment
SD = Standard Deviation for participating children's age

Figure 9 – Children's school year.

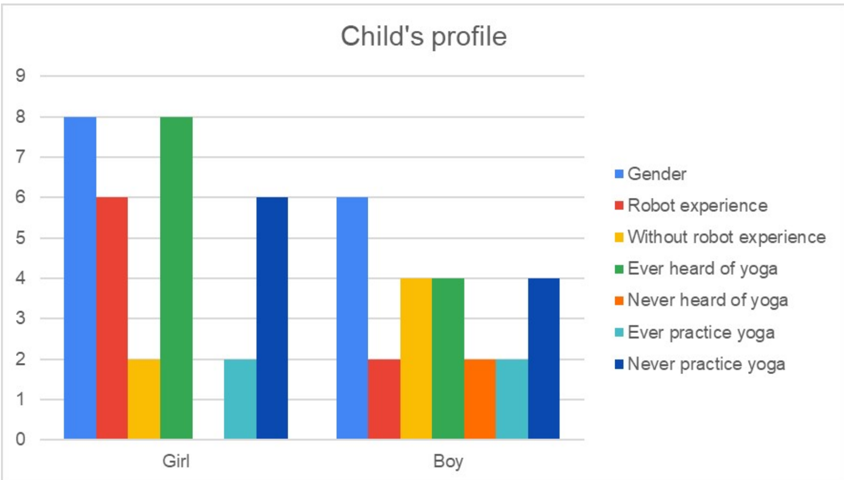
School grade	1st year	2nd year	3rd year	4th year	5th year	6th year	Total
Female	2	0	2	0	3	1	8
Male	2	2	1	0	0	2	7
Total	4	2	3	0	3	3	15

Source: Elaborated by author (2023).

The participant was eager to talk about the robot and the application, and their interview data was included during the qualitative analysis.

Some questions answered by the children assessed their knowledge and experience with robots or robotics kits and yoga. The goal was to analyze whether there would be any significant difference in the answers according to the children's previous experience. Most children (13) said they had already heard about yoga, but only five said they practiced it occasionally (i.e., one time or a few times) (Figure 10). Eight girls have heard about yoga, but only two have practiced it. Four boys said they had heard about yoga, but only two practiced at least once, and two said they had not heard of it.

Figure 10 – Child's experience with yoga and robots according to gender.

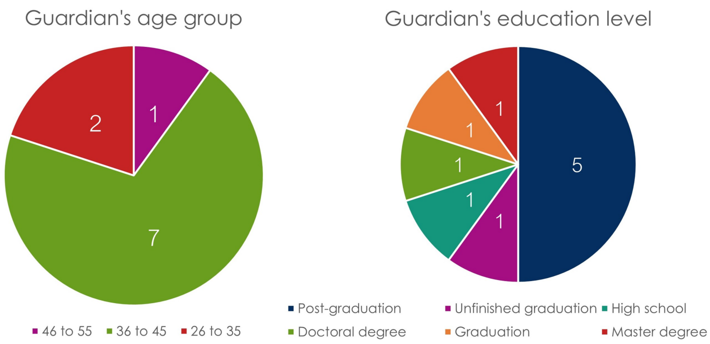


Source: Elaborated by author (2023).

Six girls and two boys said they had already experienced or interacted with robots. Among five who participated in school robotics projects, two said they owned robotic toys, and one participant experienced them once (at a mall exhibition). Two girls and four boys said they only experienced robots through the TV or the Internet.

Participants' parents gave written consent for children's participation in this study and completed a simple profile form. Of 10 parents who filled out forms (some participant children were siblings), there were three males and seven females. One participant was between 46 and 55 years old, seven between 36 and 45, and two between 26 and 35. Five had post-secondary education, one with a doctoral degree, one with a master's degree, one graduated, one undergraduate, and one with a high school education level (Figure 11). Two were stay-at-home mothers, one dentist, two physicians, one teacher, one journalist, one military fireman, one bio medic, and one government employee.

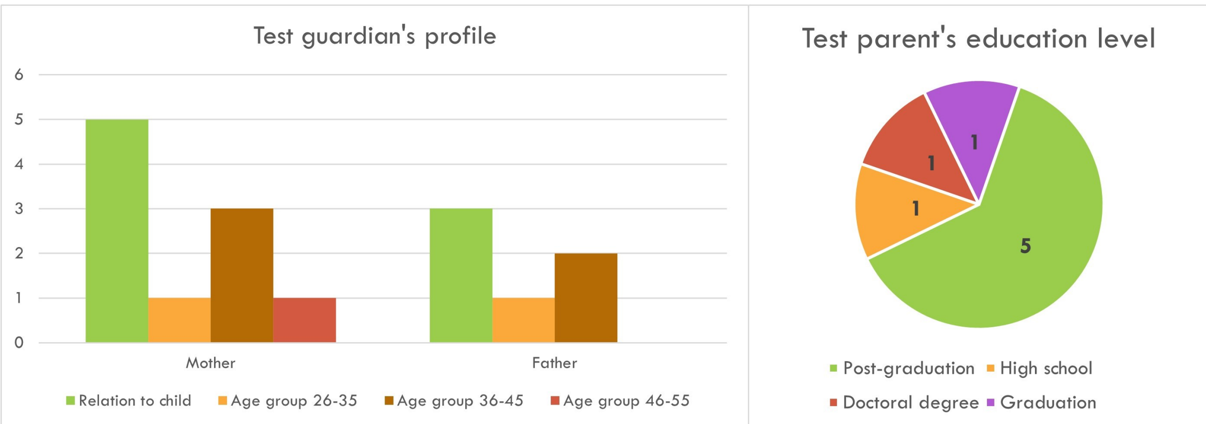
Figure 11 – Guardian's profile.



Source: Elaborated by author (2023).

Eight (8) parents (five mothers and three fathers) opted to participate during the session and agreed to answer the questionnaire and interview. Their profile is detailed in Figure 12. The other parents prefer to refrain from participating in the session.

Figure 12 – Profile of guardians who were present in test session and agreed to participate answering questionnaire and interview.

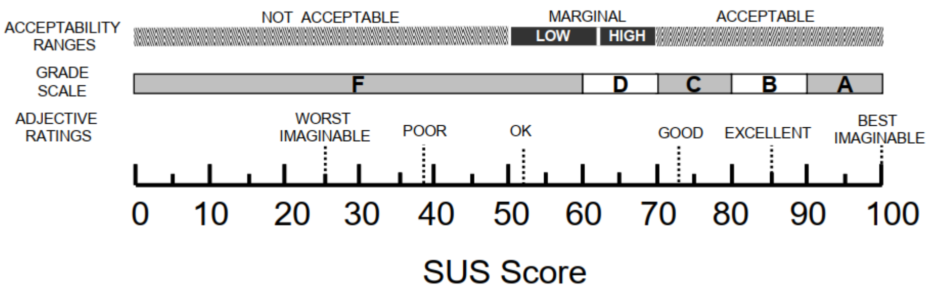


Source: Elaborated by author (2023).

4.2 QUANTITATIVE DATA

The SUS mean score for the children's sample is 75.71. Using Bagnor *et al.* (2009) SUS comparison scale (see Figure 13, (BANGOR; KORTUM; MILLER, 2009)), ZZen application would be considered good and acceptable system. When considering children's genre, girls would have the same adjective rate and acceptability range, but boys would place ZZen ok/good and marginal high scales.

Figure 13 – A comparison of the adjective ratings acceptability scores, and school grading scales, in relation to the average SUS score



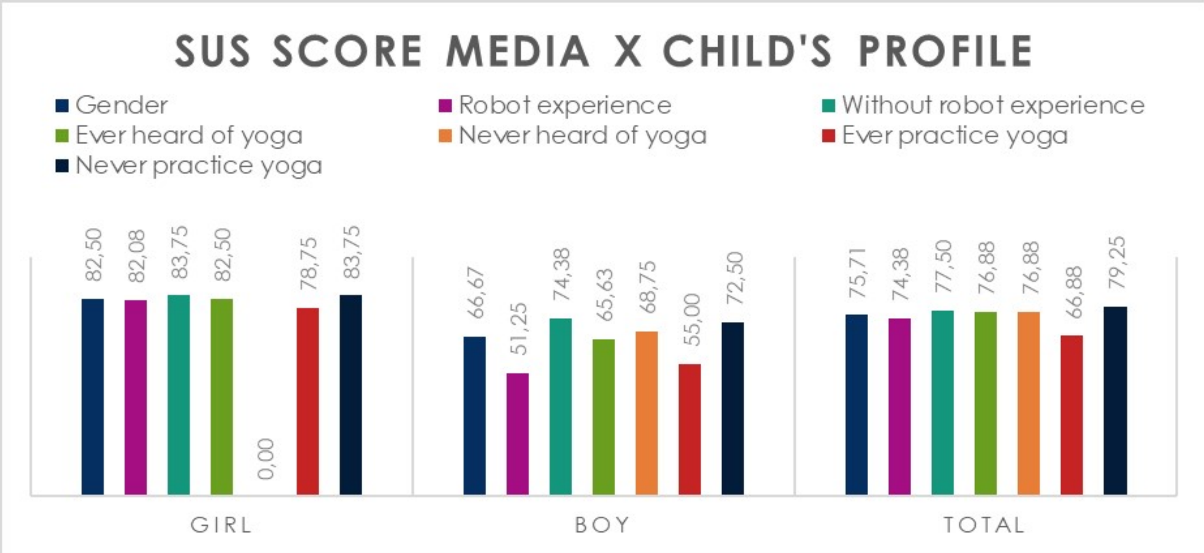
Source: (BANGOR; KORTUM; MILLER, 2009)

Figure 14 shows SUS score mean according to gender and children's previous knowledge and experience with robots/robotic kits and yoga. When comparing the total SUS score mean (from all fourteen participant children) with the SUS score means according to children's experience, there is not much variation between them. Concerning the experience with robots SUS score mean varies by 3.12 points (74.38 - 77.50); zero points of variation in regards of SUS score mean of children who heard or never heard of yoga (both mean were 76.88), and regarding yoga previous practicing yoga experience there was a variation of 12.37 (66.88 - 79.25).

Girls' SUS mean scores did not vary much according to their experience with robots or with yoga: SUS mean score from girls with robotics experience was 82.08 and girls without robotics experience 83.75; and SUS mean score from girls with yoga practice experience was 78.75 and girls that never practiced it obtained 83.75 score. All girls stated they had already heard about yoga, so the “SUS score mean” for girls that never heard of it was plotted as zero in Figure 14.

Boys' SUS mean scores had a higher variation according to their experience. Boys with robotics experience obtained 51.25 SUS scores, and boys without robotics experience 74.38.

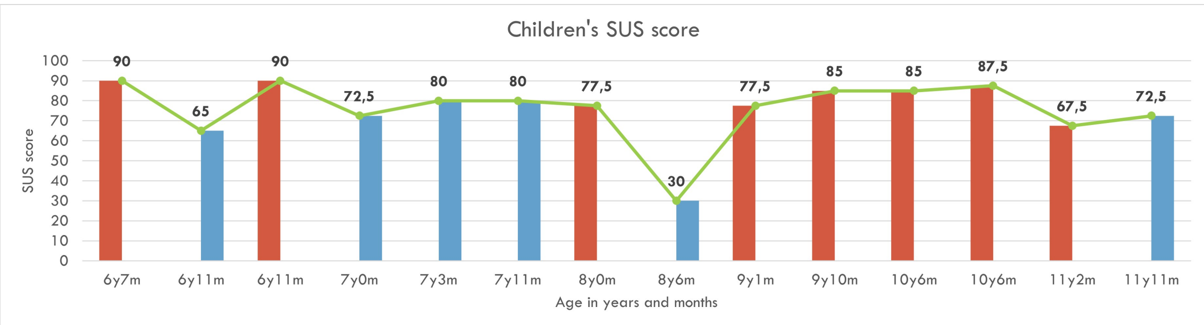
Figure 14 – SUS score mean according to child's experience with robots and yoga.



Source: Elaborated by author (2023).

The SUS mean score from boys with yoga practice experience was 55.00, and boys that never practiced it obtained a 72.50 score. Boys that stated they had already heard about yoga had a 65.63 SUS score, and the SUS score mean for boys that never heard of it was 68.75.

Figure 15 – Child's SUS score by age and gender.



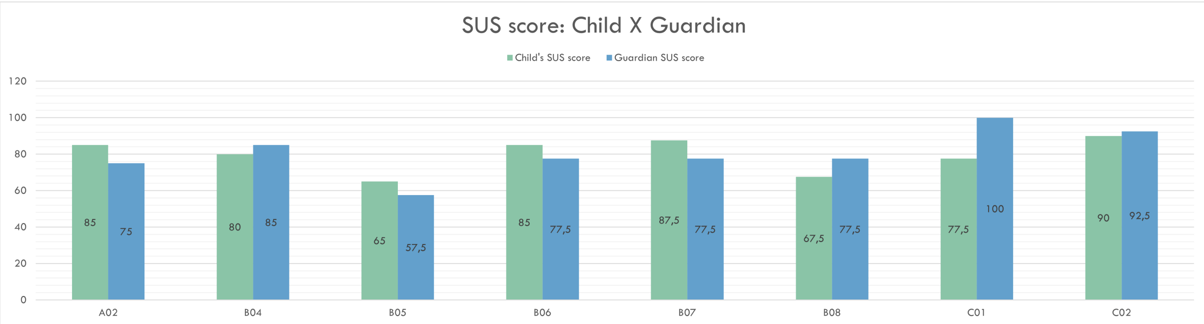
Source: Elaborated by author (2023).

Children's SUS scores were plotted in Figure 15 according to the child's age (considering their age in both years and months), so they are arranged in age ascending order. Generally, girls scored higher than boys, except in the 11 years old group. Most scores are between 65 and 90. Only one is outside this range, and it is the lowest score (30), which was from an eight-year-old boy who was not interested in practicing yoga, which might have affected his perception of the role of application. During the interview he stated that if he had tested on a different day, he probably would have enjoyed practicing yoga and would have scored differently than he did on the test session day.

Disregarding the extreme case (30 on SUS score) due to specific questions from this session (described above), the highest and the lowest scores are from the same age group, six years old children and children from 7 to 10 years old scored closely (from 72.5 to 87.5 on SUS score), which probably indicates that the application is better suited for this age group instead of 6 to 12 as estimated before.

Eight parents were present and agreed on also participating in the research answering the questionnaire and interview. Guardian's SUS score varies from 57.5 to 100; the SUS score mean was 80,31. The highest and lowest scores were from guardians in the youngest age group (26 to 35 years old), but they had different highest education levels. Parent who scored lowest is a stay-at-home parent with a high school education level, and parent who scored highest is a biomedical with a doctoral degree. Four participant parents scored higher than their child, meaning half of the parent's sample (Figure 16).

Figure 16 – Comparing child's and guardian's SUS score.



Source: Elaborated by author (2023).

Table 11 shows children's SUS score means according to their parent's higher education than the general child's SUS score mean. Data gathered shows no clear relation between how children scored and the guardian's education level, meaning that children didn't scored higher when guardian's education level was higher nor children scored lower when guardian's education level was lower.

Putnam et al. (2020) conducted a Principal Component Analysis (PCA) with Varimax rotation. Their analysis indicated that the individual 13 scores of their kids-adapted SUS (SUS-Kids) can be classified into four components. Component 1 comprises statements 1, 5, 9, 11, 12, and 13; component 2 has statements 2, 3, 6 and 7; component 3 only has statement 8; and component 4 with statements 4 and 10.

Observing Putnam et al. (2020) PCA classification, we could find the common subject in each component statement. Component 1, composed of statements 1, 5, 9, 11, 12, and 13,

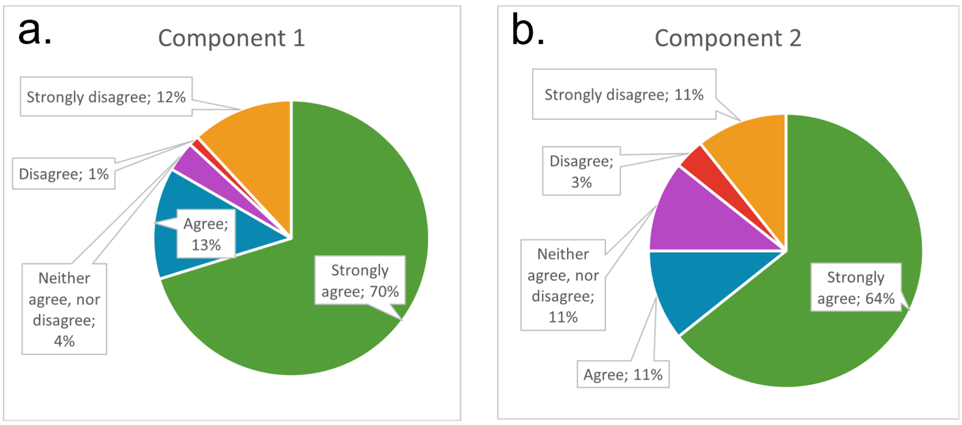
Table 11 – Child's SUS score mean according to guardians' education level compared to child's SUS score mean.

Parent higher education level	Child's SUS score mean (according to parent's higher education level)	Deviation to Child's SUS score mean
All	75.71	0
Doctoral degree	77.5	1.26
Master's degree	51.25	17.30
Post-graduation	85	6.57
Graduation	67.50	5.81
High school	68.75	4.92

Source: Elaborated by author (2023).

is related to pleasantness and personal confidence; component 2 has statements 2, 3, 6 and 7 and is related to general usability aspects; component 3 with only statement 8 is related to comfort or convenience; and, lastly, component 4 with statements 4 and 10 are related to requiring assistance or previous knowledge to use the system (PUTNAM et al., 2020).

Figure 17 – Children's answers to statements that composed a. Component 1 and b. Component 2 from Putnam's PCA.

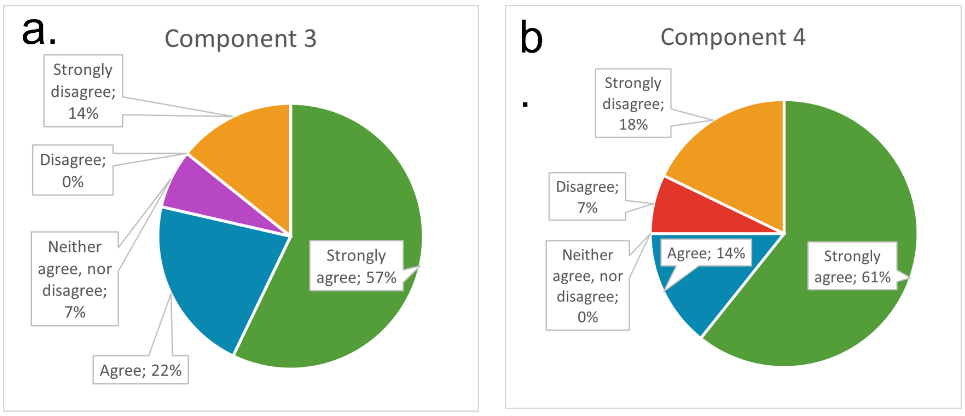


Source: Elaborated by author (2023).

The SUS questionnaire has some negative statements, which means that for a perfect score, the user must choose "completely agree" on half statements (positive statements) and "completely disagree" on the other half (negative statements). In order to calculate the mean for Putnam's components, the scores from the negative sentences were inverted: 5 instead of 1 for "completely disagree", 4 instead of 2 for "disagree", and so on. So, it was possible to have the mean score for Putnam's components obtaining mean score of 4,28 for component 1;

4,14 for component 2; 4,07 for component 3; and 3,92 for component 4. Figure 17 and Figure 18 show how children scored on each component (considering the reverse for the negative sentences).

Figure 18 – Children's answers to statements that composed a. Component 3 and b. Component 4 from Putnam's PCA.



Source: Elaborated by author (2023).

Component 4 has the lowest mean score, and it is related to the user's need to ask for help from someone with more knowledge (statement 4) or to learn new things before interacting with the robot (statement 10). The highest score mean was from component 1, which is related to general enjoyment using the robot's application.

4.3 QUALITATIVE DATA

This section describes children's performance in the proposed activity using data from recorded video and observational notes made during the test session. Children's behavior and facial expressions were used to analyze their engagement in PA proposed and whether they were able to picture themselves in the activity story, interacting with imaginary elements. This section also relates the feelings of children and parents and aspects of guiding PAs to ensure that children follow instructions to perform correctly.

4.3.1 Physical activity performance vs. Robot instructions

From a general perspective, all children followed the application without significant difficulties. Most children could perform yoga poses and movements with different degrees of completion. Some children showed some difficulty in following the yoga movements instructions, especially the bridge pose, and some showed a few doubts while performing the turtle pose.

Figure 19 – Child performing the dragon breath movement.

Source: Screenshot from a test session recorded video (AUTHOR, 2023).

The dragon breath pose was used to give the child the first relaxation moment, where they could start focusing on the present activity. Most children followed the first instruction, putting the hand on the belly, inhaling, and opening the arms when exhaling with the mouth open. ZZen would guide two repetitions of this movement. Most children stayed in the initial position (Figure 19 a.) and did deep breaths, but when exhaling, some forgot to open their arms (Figure 19 b.).

Figure 20 – Child performing the rocket pose.

Source: Screenshot from a test session recorded video (AUTHOR, 2023).

Children showed little difficulty performing and understanding instructions for the rocket pose (Figure 20). However, when it came to the repetitions (i.e., raising the arms while inspiring and lowering them when exhaling), most participants would simply take deep breaths in the rocket position.

The bridge pose (Figure 21) seemed to be the most challenging for children, although they quickly understood the PA instructions. The difficulty increased during repetitions. For instance, in the Countdown scene, ZZen guided them to move from the straight bridge pose -

Figure 21 b. - to a curved bridge pose - Figure 21 c., some kids claimed their arms felt tired. Most participants looked focused when performing these repetitions, but some would laugh while trying to do the movements.

Figure 21 – Child performing the bridge movement.

Source: Screenshot from a test session recorded video (AUTHOR, 2023).

Finally, the turtle pose (Figure 22) seemed hard to understand. The final pose put the child facing the floor, so ZZen would show the image of the final pose before giving the movement instructions. Some children would mimic the image without listening to the instructions and felt confused. In the end, most children were able to perform this movement.

Figure 22 – Child performing the turtle pose.

Source: Screenshot from a test session recorded video (AUTHOR, 2023).

Children seemed generally comfortable with the ZZen app's direct instruction, but the movements' complexity impacted their understanding. For instance, simple and straightforward commands like "stand up" and "open your arms" were followed quickly. However, more complex instructions such as "When exhaling, open your arms quickly and release the air at once," or "Let's place our hands in the middle of the belly, and leave the elbows open, pointing out." often caused confusion on how they should perform the movements.

The representative images helped them to execute the movements fully or partially. Still, direct commands for the Relax and Meditation scenes (e.g., "While we're resting, let's take some deep breaths," "Let's wiggle our fingers and toes, watch their movement and the feeling of doing it," and "Let's close our eyes,") were partially followed or not followed by most of the children. A possible explanation is that those are low physical effort scenes, and children might have (consciously or not) used the moment to rest and listen to the robot.

4.3.2 Non-verbal vs. Verbal communication

Despite verbal communication limitations, children developed a social rapport with the robot and would interact spontaneously and humorously. Figure 23 shows one child listening to the beginning of the application. Children would generally talk and gesture to the robot, even when they knew it could not identify this interaction. Figure 24 a. shows one girl giving thumbs up after being asked if she would like to do the activity with ZZen. In another scenario, a participant expressed their wish for a robot psychologist, describing it as someone who could hear them without judgment and that they could share daily questions and doubts and, eventually, get some answers.

Figure 23 – Child facing the robot.

Source: Screenshot from a test session recorded video (AUTHOR, 2023).

Throughout the storyline, the robot asks rhetorical questions to mimic a dialogue with the user, aiming to reduce the impact of the one-sided monologue. Most children would respond excitedly (and positively) to these rhetorical questions. However, a set of 'rhetorical' questions intended to express the robot's surprise/confusion during a demonstration (e.g., "How are we not ready? What is missing?") evoked unexpected responses. Several children seemed curious to answer the "What is missing?" question. Some would question themselves and make creative assumptions (e.g., "shoes?" "a gift"). Those questions were crucial in building the narrative and creating, maintaining or increasing the child's engagement and involvement in the story.

ZZen's storyline contained fantastical elements (e.g., "the spatial suit" and "rocket's window") aimed to stimulate children to perform PA by making them feel part of the story and enabling them to use imagination and creativity. Some children quickly immersed themselves in the imaginary scenario, and others took a while, but soon after, they seemed to understand that picturing was part of the activity. Some participants even looked for physical elements in the room to complement the story told. For instance, when the robot suggested they look for the helmet to complete the space travel suit, a child asked their parent where the helmet was.

Subjective instructions and sentences that were part of expected indirect interaction could only create a personal interaction. The user's part of the interaction corresponds to the child's state of mental and psychic involvement in the proposed interaction and activity, which makes it challenging to measure. When the robot suggests that children assess their present moment and feelings, they may or may not do what it asks. Observing and analyzing the child's expressions and behaviors during the session is not a confident measurement to infer their engagement level during the interaction. Based on the recorded videos, most children participated actively during the experiment, which leads us to assume that subjective interaction occurred when necessary and without difficulties.

Figure 24 – Children interacting with robot. a. Child doing gestures; b. Child touching robot's screen to answer question; c. Child showing QR code plaque.

Source: Screenshot from a test session recorded video (AUTHOR, 2023).

The children seemed satisfied with the possibility of directly interacting with the robot via touchscreen and QR code scan (Figure 24 b. and c.). However, several expressed that they would like to interact through natural verbal language (for example, one said, "I wish it could hear me"). Some looked frustrated with the fact that the robot was not able to hear them (one said, "It would be better if I could answer other things other than "Yes or No" if the robot could understand what I said and not rely on these plaques for it to understand me").

4.4 DISCUSSION AND STUDY LIMITATIONS

The first research question (RQ1) regarded whether children from 6 to 12 would perceive the social robot as a companion when using the ZZen application. The qualitative analysis of the children's behavior during the robot interaction suggests that most felt comfortable with the robot and perceived it as a social being, making it possible to infer that they considered the ZZen application a yoga practice companion. However, as the quantitative evaluation method assessed the application usability, not perception, more data is still necessary to investigate how they perceived it in a controlled setting. Other experimental setups can include assessing perception changes over time (e.g., long-term or timed-bonded interactions).

The second research question (RQ2) sought to determine if the social robot Zenbo could be a tool for practicing mindfulness. The ZZen application supported children practicing mindfulness through yoga movements and breathing exercises. In the user evaluation session, children engaged in the mindfulness practice guided by the robot and seemed to enjoy themselves during and after PA. The ZZen application was limited to a single application, and future development should incorporate other practices to further evaluate the use of robots for mindfulness to a full extent.

4.4.1 Physical activity constraints

ZZen's application was carefully designed to stimulate PA, but still had some limitations and restrictions. The first limitation concerns the content relevance and adequacy: the yoga practice script was formulated following a script provided by an expert, considering that the primary researcher is not a yoga specialist. Still, the ZZen application has successfully guided children when performing PA.

An essential aspect of guiding PAs is ensuring those following instructions perform correctly to avoid injuries. Children could follow the robot's instructions in the user testing but had difficulty performing some movements. The reasons for not performing PA movements may vary per child, including their cognitive development, physical capacity, or instructions not being objective or age-appropriate. Another limitation is that the robot model without limbs could not physically demonstrate the movements, which could have supported children to mimic them. The ability to display images on the robot's screen was suitable for providing visual instruction. However, since the images were static, some children needed help moving from the initial pose to the ending pose, despite the help from verbal instruction.

Another study limitation is that participants experienced the application in a single-user session. There is insufficient evidence to confirm whether robot companionship can motivate children to practice PA in a long-term setting. Still, the application features, such as encouraging speech and observing children's disposition during the robot-guided PA, suggest that the robot plays a factor in their overall engagement. For instance, an eleven-year-old boy was not particularly interested in engaging in PA at the beginning of the session but changed his attitude while following the robot's instructions.

4.4.2 Robot application constraints

Zenbo is a commercially available robot and only has minimal performance fails. The limitations described below are mostly related to application requirements and the robot's available features, and a few are related to the robot's improvement. Zenbo has a rounded body with a neck and head attached to it. It does not have other body parts such as arms, hands, legs, feet, or tails. Its body is very fit for many possible social applications. It looks cute, which helps create a trustworthy environment.

However, the ZZen application aimed to provide PA instructions, and it would be more useful if the robot could perform physical movements in addition to showing images of them. Although Zenbo is very reliable regarding its movements, it has a few restrictions. Its head only spins to one axis, providing up and down moves, but it cannot turn its head right and left. Such a limitation is a significant restriction in reproducing common social gestures like shaking the head in denial and other behaviours. For instance, the robot must turn its entire body in one direction to look up left or right.

An issue occurred when using the robot on irregular surfaces (e.g., a table or on the floor). Issues increased when the robot performed spin movements. Sometimes the robot's wheel would get hooked on the floor cement, limiting rotational movements or slipping on a surface ripple and rotating more than expected. Although those are not limitations of the robot design, these wrongful movements might have affected the coherence of ZZen's behaviour when providing PA instructions.

Another contextual limitation was the available languages for the natural language processing feature (English, Chinese and Japanese). Unfortunately, Zenbo could not interact verbally with children fluent in Brazilian Portuguese. Due to speech processing limitations, the researcher pre-recorded all robot's sentences, restricting interaction responses and not allowing script changes, resulting in fewer direct interactions. The application has an interaction mean time of 20 minutes. Direct interactions comprised nine binary selections on the display interface and seven QR code plaques to scan. However, most interactions are subjective (e.g., the robot gives directions, and the user follows). It is unclear from the current data how limitations in speech processing may have affected children's participation in PA.

4.4.3 User session restrictions

The sample size is small, including 15 children and eight parents, and stratified regarding age, sex at birth, and school grade. Still, due to sample size limitation, results should be considered as trends rather than conclusive statements. Another factor impacting the sample stratification was parental participation. Not all parents or guardians engaged during the user testing sessions. Besides, some kids seemed uncomfortable or shy with their parent's presence, which might have affected their engagement and enjoyment during PA.

Another limitation was the session duration and location conditions. Sessions lasted about 30-40 minutes, covering introduction/set-up (3-4 min), robot interaction (16-20 min), and user feedback (8-10 minutes). During the feedback, participants had to complete a questionnaire and respond to a short interview. The evaluation scenario could have affected the spontaneity of their responses. Regarding the session locations, most sessions occurred in the same clinic room, and four were in an open space. The environmental conditions from the open space added noise (rain and traffic rumble), affecting the development of the session since, at these times, it was impossible to hear the robot. The researcher repeated the robot's phrases aloud to get around adversities.

The researcher video-recorded the sessions to transcript verbal comments and capture spontaneous interactions and expressions during robot interaction. Participants did not share their thoughts out loud, which could have helped capture information from the recordings. Another limitation was that the selected usability questionnaire did not focus on the user's perception of the robot's features, such as anthropomorphism, animacy, likability, perceived intelligence, and perceived safety. The interviews should have included these aspects more formally, and a more structured approach should be part of future work.

Unexpected events and technical difficulties also interfered with some sessions. For instance, a sibling interrupted a participant twice, seeking to interact with the robot. Another session was interrupted because the robot stopped working due to a low battery. Other technical difficulties included malfunctioning the recording device and no memory disk to record entire sessions. The notebook battery also went off in one session before a child completed their profile questionnaire, interrupting them momentarily. Difficulties occurred mainly during sequential sessions, with little time to check battery status, memory and general conditions of devices and other tools, due to the extended use of electronics (the robot and video camera).

5 CONCLUSION

The research evaluated how a social robot can support children in PA and mindfulness activities to relieve tensions and benefit mental and physical health in social isolation. The study happened in Brazil during the COVID-19 pandemic, where the rules of social isolation impacted schools' closure for an extended period, seeking to mitigate the spread of the disease among children and families. Social isolation is a proven mitigation measure in endemics and pandemics, but not without a negative impact on society, affecting key areas such as the economy, public health system, and individuals' mental health (BROOKS et al., 2020).

The related literature shows strong evidence that children may develop mental health issues due to social isolation, such as anxiety, depression, and post-traumatic disorder symptoms (JIAO et al., 2020)(BROOKS et al., 2020). Social isolation can also impact children with autoimmune diseases isolated in hospitals or their homes, those undergoing cancer treatment, and other terminal or immunocompromising illnesses. Studies on the mental health of children undergoing treatment for serious illnesses indicate that many have symptoms of depression and anxiety (ALEMI et al., 2016).

The present study targeted healthy children who experienced social isolation due to the pandemic. The study developed a social robot application named ZZen, turning the Zenbo Junior robot from ASUS into an instructor companion for yoga practice. Yoga is a practice that mixes meditation, relaxation techniques, and PA and can adapt to the physical conditions of the practitioner—also promoting physical and mental health (LACK et al., 2020). During the COVID-19 pandemic, many people have joined meditation and yoga programs as part of their personal care and daily activities. In one of its pamphlets on how to deal with the pandemic, the World Health Organization recommended the practice of breathing exercises, meditation and yoga as measures to mitigate the tensions generated by social isolation.

Fifteen children experienced the ZZen application in person during 30-40 min user testing sessions, promoting 16 to 20 minutes of child-robot interaction with the application. Children filled in a post-session questionnaire, the SUS-kids, an adapted usability scale for children, varying sentences by age group. The researcher translated the sentences into Brazilian Portuguese. After the questionnaire, children participated in short semi-structured interviews. Eight of the parents/guardians present during the sessions agreed to participate in the research. They also answered the standard SUS questionnaire and the interview at the end of the test session.

The average SUS-kids score of 14 children was 75.71, higher than acceptable (N>70), and the average standard SUS score for parents/guardians was 80.31. Therefore, the application was well accepted by both samples, the children and their guardians. In addition to the SUS-kids score, some children expressed verbal approval, stating that they loved the interaction, wanting to have a robot of the type at home and asking to retake the test on another day. One child said that if this robot and app were available at home, she would do yoga often.

An additional quantitative analysis using the Principal Component Analysis (PCA) suggested by Putnam et al. (2020) grouped the 13 SUS-kids statements into four components: 1.(statements 1, 5, 9, 11, 12, 13); 2.(statements 2, 3, 6 and 7); 3.(statement 8); 4.(statements 4 and 10). The highest score mean was from component 1. (4.28), which can be related to experiencing enjoyment when using the robot's application (e.g., 70% of children strongly agreed that it was a pleasant time). Component 4. has the lowest mean score (3.92), which comprises statements about the user's perceived need for help/assistance from an expert/someone knowledgeable to execute tasks or learn new things before interacting with the robot.

Parents/guardians also expressed verbal approval. Some said they would be willing to purchase the robot and application within a reasonable price range. They perceived the potential benefits of having the robot as an incentive for children engaging in PA. Two parents who participated in the user tests claimed it would have been great "to have one of these at home during the pandemic." They shared difficult experiences during social isolation, where their daughters stayed home, spending much time with electronics like TV, tablets, and video games.

The present research successfully achieved its primary goal of using a social robot to encourage and guide children during PA and mindfulness activities. A secondary goal was to evaluate whether children would perceive the social robot as a social being and experience companionship. The children seemed delighted with the robot; some hugged it affectionately, and many perceived it as a friend. Still, the robot model, Zenbo, offered a series of limitations to the application performance, such as not having limbs (arms or legs) to demonstrate physical movements and relying on the LCD screen to present visual instructions. Other limitations to the study results might be related to the novelty factor due to user tests consisting of a single test session. As part of future work, a long-term study can evaluate whether children would maintain interest in the robot and application after more than one session.

5.1 FUTURE WORKS

The ZZen project achieved its core goals, and further research can achieve more complete results. First, a systematic literature review on robots promoting physical and mindfulness activities can summarize the benefits and challenges guiding other researchers in this field, such as supporting more robust application requirements for implementing other user test scenarios.

Second, a long-term assessment can also support more conclusive results and overcome the impact of a novelty factor during a single test session. A long-term scenario should account for changes in the application content since the single test application was limited to a 16-20 minutes storytelling timeline and a set of PA movements based on yoga practice. Besides, the session location should include the participant's home and a mix of moderated and unmoderated scenarios.

On the one hand, the storytelling method to guide the yoga activity was proven effective in drawing children's attention and entertaining them during a single session. It would be vital to offer more than one story to evaluate an application in multiple sessions, considering that repeating the same story can become tedious for a child, impacting their long-term interest.

On the other hand, the limited number of PA movements could also become tedious during a long-term evaluation, and application content should include a more extensive set of mindfulness and PA tutorials, including progressive levels and adapting to children's age and psychomotor capabilities.

Finally, the application should improve accessibility features, and user test sessions should include participants with more diverse backgrounds and psychomotor capabilities, such as children with disabilities and neurodivergent individuals.

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APPENDIX A – SENTENCES FOR ZZEN APPLICATION

Table 12 – Script sentences for ZZen in Portuguese and English.

Stages	Sentence in Portuguese	Sentence in English
	Introduction	
Introduction - Greetings	Olá! Eu sou ZZen!	Hello! I'm ZZen
Introduction - Greetings	E você? Como se chama?	And you? What is your name?
Introduction - Greetings	Como você está se sentindo hoje?	How are you feeling today?
Introduction - Greetings	Não precisa ter pressa para me responder...	No need to rush to answer me...
Introduction - Greetings	Pense com calma...	Think calmly...
Introduction - Greetings	É muito importante saber como estamos nos sentindo.	It is very important to know how we are feeling.
Introduction - Feel Today	Muito bem. . . E como você está se sentindo hoje?	Very well. . . And how are you felling today?
Introduction - Feel Today - Interface Title	Como você está se sentindo hoje?	How are you feeling today?
Introduction - Feel Today - After choice "Happy Face"	Ótimo! Eu também estou feliz hoje!	Excellent! I'm also happy today!
Introduction - Feel Today - After choice "Neutral Face"	OK!	OK!
Introduction - Feel Today - After choice "Sad Face"	Que pena! Eu espero que você se sinta melhor depois de nosso tempo juntos!	What a shame! I hope you feel better after our time together!
Introduction - Presentation	Agora eu vou te contar um segredo:	I am a robot passionate about practicing yoga!
Introduction - Presentation	Você sabe o que é yoga?	Do you know what yoga is?

Continued

Continuation of Table 12

Stages	Sentence in Portuguese	Sentence in English
Introduction - Presentation - After answer QR code "YES"	Legal!	Cool!
Introduction - Presentation - After answer QR code "NO"	Não tem problema, eu vou te explicar!	No problem, I'll explain!
Introduction - Presentation	A yoga é uma prática que serve para alongar e fortificar o corpo, e que também serve para exercitar a mente.	The yoga is a practice that serves to stretch and strengthen the body, and that also serves to exercise the mind.
Introduction - Presentation	É um exercício divertido e relaxante, é por isso que eu adoro praticar yoga!	It's a fun and relaxing exercise, that is why I love to practice yoga!
Introduction - Invitation	Você quer praticar yoga comigo hoje?	Do you want to practice yoga with me today?
Introduction - Invitation - After answer QR code "YES"	OBA!!!	Wow!!!
Introduction - Invitation - After answer QR code "YES"	Goes to Introduction - Activity Directions	
Introduction - Invitation - After answer QR code "NO"	Ah, tudo bem...	Oh, alright...
Introduction - Invitation - After answer QR code "NO" - Ask Again	Você tem certeza de que não quer brincar comigo hoje?	Are you sure you don't want to play with me today?
Introduction - Invitation - Ask Again - After answer QR code "YES"	OK, quem sabe um outro dia...	OK, maybe another day...

Continued

Continuation of Table 12

Stages	Sentence in Portuguese	Sentence in English
Introduction - Invitation - Ask Again - After answer QR code "YES"	Goes to Ending	
Introduction - Invitation - Ask Again - After answer QR code "NO"	OK, eu vou perguntar de novo...	Ok, I'll ask again...
Introduction - Invitation - Ask Again - After answer QR code "NO"	Goes to Introduction - Invitation	
Introduction - Activity Directions	Para a prática de hoje, eu vou contar uma história, uma aventura, e nós vamos participar dela, imaginando as cenas e nos movimentando de acordo com as instruções.	For today's practice, I'm going to tell you a story, an adventure, and we will participate in it, imagining the scenes and moving around according to the instructions.
Introduction - Activity Directions	Mas, ATENÇÃO: É bom sentir seus músculos, mas eles não precisam ficar achucados ou doloridos. Então, não exagere!	But pay ATTENTION: It's good to feel your muscles, but they don't have to be bruised or sore. So, don't overdo it!
Introduction - Activity Directions	O meu corpo é diferente do seu então, algumas vezes, meus movimentos vão ser um pouco diferentes dos seus. Mas isso não impede que a gente se divirta muito juntos.	My body is different from yours so, sometimes, my moves will be a little different from yours. But that doesn't stop us from having a lot of fun together.
Introduction - Breathing Technique	Para uma boa prática de yoga, devemos estar bem atentos a nossa respiração e fazê-la de forma consciente.	For a good yoga practice, we must be very attentive to our breathing and do it consciously.
Introduction - Breathing Technique	Ao INSPIRAR, você deve puxar o ar só pelo nariz, com a boca fechada até sentir seu pulmão cheio de ar.	When INSPIRING, you should only take in air through your nose, with your mouth closed until you feel your lung full of air.
Introduction - Breathing Technique	E para EXPIRAR, você deve soltar o ar pela boca até esvaziar o peito.	And to EXHALE, you must release the air through your mouth until your chest is empty.

Continued

Continuation of Table 12

Stages	Sentence in Portuguese	Sentence in English
Introduction - Breathing Technique	Vamos treinar uma vez?	Shall we train once?
Introduction - Breathing Technique - After answer QR code "YES"	Agora inspira..... e agora expira	Now inspire..... and now expire
Introduction - Breathing Technique - After answer QR code "NO"	OK!	OK!
	Activity	
Activity - Interface - Title	Vamos começar?	Let's start?
Activity - Interface - Option 1 button	Vamos começar!	Let's start!
Activity - Interface - After choice Option 1 button	Goes to Space Trip Story	
Activity - Interface - After choice Option 2 button	Sair	Leave
Activity - Interface - After choice - Option 2 button	Goes to Ending	
Space Trip Story - Context	Hoje, na nossa aventura, nós vamos fazer uma viagem espacial!	Today, on our adventure, we're going to take a space trip!
Space Trip Story - Context	Vamos viajar pelo espaço e ver as estrelas bem ao nosso lado.	Let's travel through space and see the stars right next to us.
Space Trip Story - Context	Antes de embarcar nessa história, vamos nos concentrar, juntar muita animação e energia para participar desta aventura.	Before embarking on this story, let's focus, gather a lot of excitement and energy to participate in this adventure.

Continued

Continuation of Table 12

Stages	Sentence in Portuguese	Sentence in English
Space Trip Story - Context	Para isso, vamos começar com a prática de fôlego do dragão.	For that, let's start with the dragon breath practice.
Space Trip Story - Dragon Breath	Para fazer o fôlego do dragão, vamos sentar no chão e cruzar as pernas.	To make the dragon's breath, let's sit on the floor and cross our legs.
Space Trip Story - Dragon Breath	Vamos colocar as mãos no meio da barriga, e deixar os cotovelos abertos, apontando para fora.	Let's put our hands in the middle of the belly, and keep your elbows open, pointing out.
Space Trip Story - Dragon Breath	Quando for a hora de inspirar, aproveite para deixar as costas retinhas;	When it's time to inspire, take the opportunity to keep your back straight;
Space Trip Story - Dragon Breath	E na hora de expirar, abra os braços rapidamente e solte o ar todo de uma vez, como se fosse um dragão soltando fogo.	And when it expires, open your arms quickly and release all the air at once, like a dragon breathing fire.
Space Trip Story - Dragon Breath	E na hora de expirar, abra os braços rapidamente e solte o ar todo de uma vez, como se fosse um dragão soltando fogo.	And when it expires, open your arms quickly and release all the air at once, like a dragon breathing fire.
Space Trip Story - Dragon Breath - Any Doubt	Você ficou com alguma dúvida?	Did you have any doubts?
Space Trip Story - Dragon Breath - Doubt "YES"	Vamos sentar no chão e cruzar as pernas.	Let's sit on the floor and cross our legs.
Space Trip Story - Dragon Breath - Doubt "YES"	Vamos colocar as mãos no meio da barriga, e deixar os cotovelos abertos, apontando para fora	Let's put our hands in the middle of the belly, and let the elbows open, suck out
Space Trip Story - Dragon Breath - Doubt "YES"	E na hora de expirar, abra os braços rapidamente e solte o ar de uma vez.	And when exhaling, open your arms quickly and release the air at once.
Space Trip Story - Dragon Breath - Doubt "NO"	Ok!	Ok!
Space Trip Story - Dragon Breath	Nossa! Esse dragão pareceu um pouco cansado...	That dragon looked a little tired...
Space Trip Story - Dragon Breath	Vamos fazer mais uma vez!	Let's do it one more time!
Space Trip Story - Dragon Breath	Coloca as mãos na barriga, cotovelos para fora, as costas retinhas	Put your hands on your belly, with elbows out and back straight

Continued

Continuation of Table 12

Stages	Sentence in Portuguese	Sentence in English
Space Trip Story - Dragon Breath	Agora sim, eu senti um calor de fogo de dragão!	Now I felt a dragon fire heat!
Space Trip Story - Boarding	Excelente! Agora que já estamos bem-preparados por dentro, precisamos vestir nossa roupa especial: um macacão espacial!	Great! Now that we're well-prepared inside, we need to wear our special outfit: a spacesuit!
Space Trip Story - Boarding	Fica em pé, segura a roupa na sua frente, coloca as pernas dentro do macacão	Stand up, hold the clothe in front of you, put your legs inside the spacesuit.
Space Trip Story - Boarding	Ótimo! Agora só falta o capacete para completar nossa roupa de viagem espacial.	Excellent! Now all we need is the helmet to complete our space travel outfit.
Space Trip Story - Boarding	Mas, onde será que ele está?	But where is it?
Space Trip Story - Boarding	Precisamos procurar o nosso capacete!!!	We need to look for our helmet!!!
Space Trip Story - Boarding	Com as pernas abertas na mesma largura dos ombros, gire o tronco de um lado a outro, procurando...	With your legs spread shoulder-width apart, rotate your torso from side to side, looking for...
Space Trip Story - Boarding	Ah!!! Eu achei!	Oh!!! I found it!
Space Trip Story - Boarding	Ele está lá em cima... levante as mãos bem para o alto e tente alcançá-lo.	He's up there... raise your hands high in the air and try to reach for it.
Space Trip Story - Boarding	Muito bem!	Very well!
Space Trip Story - Boarding	Agora vamos verificar se o macacão está fechado e o capacete está ajustado.	Now let's check if the spacesuit is closed and the helmet is fitted.
Space Trip Story - Boarding	Passe a mão na barriga para verificar o macacão e esfregue as orelhas e depois o queixo para confirmar que o capacete está bem preso!	Run your hand over your belly to check the spacesuit and rub the ears and then the chin to confirm that the helmet is securely attached!
Space Trip Story - Boarding	Tcharam! estamos prontos!!!	Tadaa! We are ready!
Space Trip Story - Boarding	Não?!	No?!
Space Trip Story - Boarding	Como não estamos prontos?	How are we not ready?

Continued

Continuation of Table 12

Stages	Sentence in Portuguese	Sentence in English
Space Trip Story - Boarding	O que está faltando?	What is missing?
Space Trip Story - Boarding	Ah, claro! Como eu fui esquecer...	Oh, of course! How could i forget...
Space Trip Story - Boarding	Nós precisamos de um foguete!	We need a rocket!
Space Trip Story - Boarding	Vamos fazer um?!	Let's make one?
Space Trip Story - Rocket Pose	Para fazer o foguete, primeiro vamos ficar em pé.	To make the rocket, first let's stand.
Space Trip Story - Rocket Pose	Agora, vamos fazer a base do foguete que é bem larga.	Now, let's make the base of the rocket which is very wide.
Space Trip Story - Rocket Pose	Afaste os pés o tanto que você conseguir, com cuidado para não perder o equilíbrio e não sentir dor.	Spread your feet as far as you can, carefully not to lose balance and not feel pain.
Space Trip Story - Rocket Pose	Vamos, agora, fazer a ponta do foguete.	Now, let's make the rocket tip.
Space Trip Story - Rocket Pose	Primeiro vamos abrir os braços para os lados.	First let's open the arms to the sides.
Space Trip Story - Rocket Pose	Agora, imagina que existe uma cordinha puxando cada braço para um lado	Now imagine that there is a string pulling each arm to one side
Space Trip Story - Rocket Pose	Vamos inspirar fundo e esticar os braços como se a cordinha estivesse puxando ainda mais cada braço e vamos expirar mantendo esta posição.	Let's take a deep breath and stretch our arms as if the string was pulling each arm even more and we are going to expire holding this position.
Space Trip Story - Rocket Pose	Em seguida, vamos inspirar imaginando que a cordinha está, devagarinho, puxando nossos braços para cima, levantando... até que as palmas das mãos se encontrem lá no alto, bem acima da nossa cabeça!	Then, let's inspire, imagining that the string is slowly pulling our arms up, raising it up.... until the palms of the hands meet high above our heads!
Space Trip Story - Rocket Pose	E expirar abaixando os braços.	And expire lowering your arms.
Space Trip Story - Rocket Pose - Any Doubt	Você ficou com alguma dúvida?	Did you have any doubts?

Continued

Continuation of Table 12

Stages	Sentence in Portuguese	Sentence in English
Space Trip Story - Rocket Pose - Any Doubt "YES"	Ok... Eu posso falar novamente...	Ok... I can explain again...
Space Trip Story - Rocket Pose - Doubt "YES"	Inspira levantando, lentamente, os braços até que as mãos se encontrem, bem acima da sua cabeça	Inspire slowly raising your arms until your hands meet just above your head
Space Trip Story - Rocket Pose - Doubt "YES"	E expira abaixando os braços lentamente, até que repousem sobre suas pernas	And expire lowering your arms slowly, until they rest on your legs
Space Trip Story - Rocket Pose - Doubt "NO"	Legal!	Ok!
Space Trip Story - Rocket Pose	Deixe os braços abertos, na altura dos ombros	Keep your arms open at shoulder height
Space Trip Story - Rocket Pose	Inspira levantando os braços,	Inspire raising your arms,
Space Trip Story - Rocket Pose	E expira abaixando os braços.	And expire lowering your arms.
Space Trip Story - Rocket Pose	Vamos fazer mais uma vez.	Let's do it one more time.
Space Trip Story - Rocket Pose	Agora inspira..... e agora expira	Now inspire..... and now expire
Space Trip Story - Control Bridge	Agora sim podemos embarcar para nossa viagem!	Now we can embark on our trip!
Space Trip Story - Control Bridge	UAU! Que lindo dentro do foguete!	WOW! How beautiful is inside the rocket!
Space Trip Story - Control Bridge	Nós vamos precisar de uma ponte de controle para voar então vamos fazer uma ponte?	We're going to need a control bridge to fly, so let's make a bridge?
Space Trip Story - Bridge Pose	Primeiro, sente no chão com as pernas esticadas.	First, sit on the floor with your legs straight
Space Trip Story - Bridge Pose	Depois coloque os braços para trás, e apoie as mãos no chão	Then, put your arms back, and place your hands on the floor
Space Trip Story - Bridge Pose	Agora, dobre os joelhos e deixe os pés bem apoiados no chão.	Now, bend your knees and keep your feet flat on the floor
Space Trip Story - Bridge Pose	Confira se você está sentado no chão com cinco apoios: as duas mãos, os dois pés e o bumbum.	Make sure you're sitting on the floor with five supports: both hands, both feet and your butt.

Continued

Continuation of Table 12

Stages	Sentence in Portuguese	Sentence in English
Space Trip Story - Bridge Pose	Agora preste atenção:	Now pay attention:
Space Trip Story - Bridge Pose	Quando inspirar, levante o bumbum do chão, e você vai ficar na posição de ponte reta, parecendo uma mesa.	When you inspire, lift your butt off the floor, and you'll be in a straight bridge position, looking like a table.
Space Trip Story - Bridge Pose	E depois você vai expirar mantendo essa posição.	And then you will expire holding this position.
Space Trip Story - Bridge Pose	Na próxima vez de inspirar, você vai arquear as costas, isto é, vai levantar mais as costas, para formar uma ponte curva.	The next time you inspire, you'll arch your back, that is, you'll lift your back more to form a curved bridge.
Space Trip Story - Bridge Pose	E quando for expirar volte para a posição de ponte reta.	And when you expire come back to the straight bridge position.
Space Trip Story - Bridge Pose	Em resumo: primeiro, inspira, faz a ponte reta e expira mantendo. Depois inspira, faz ponte curva, expira faz ponte reta	In summary: first, inspire making the straight bridge position and expire keeping it. Then inspire, making the curved bridge, expire making straight bridge position
Space Trip Story - Bridge Pose	Então vamos lá!	So, let's go!
Space Trip Story - Bridge Pose	Inspira, e fica na posição de ponte reta e expira mantendo a posição	Inspire and stay in the straight bridge position and expire holding this position
Space Trip Story - Bridge Pose	Agora, INSPIRA, curvando as costas, e fazendo uma ponte bem redondinha.	Now inspire, bending you back and making a very round bridge.
Space Trip Story - Bridge Pose	E agora, EXPIRE, voltando à posição de ponte reta	And now, expire, returning to the straight bridge position
Space Trip Story - Bridge Pose	Muito bem! Agora sente no chão, mas deixe os braços e pernas como estão.	Very good! Now sit down on the floor but leave your arms and legs as they are.
Space Trip Story - Countdown	Está na hora da decolagem!	It's takeoff time!
Space Trip Story - Countdown	Vamos fazer a contagem regressiva mexendo na ponte de controle.	Let's make the countdown by moving the control bridge.
Space Trip Story - Countdown	Na hora de inspirar fica na posição de ponte curva e na hora de expirar, volta para posição de ponte reta.	When inspire, stay in the curved bridge positions and when expire, return to the straight bridge position.

Continued

Continuation of Table 12

Stages	Sentence in Portuguese	Sentence in English
Space Trip Story - Countdown	Prepara, fica na posição inicial, de ponte reta.	Get ready, stay in the starting position, the straight bridge
Space Trip Story - Countdown	E vamos começar! 5...	And let's begin! 5...
Space Trip Story - Countdown	Inspira 4	Inspire 4
Space Trip Story - Countdown	Expira 3	Expire 3
Space Trip Story - Countdown	Inspira 2	Inspire 2
Space Trip Story - Countdown	Expira 1	Expire 1
Space Trip Story - Countdown	***BOOM***	***BOOM***
Space Trip Story - Relax	Agora você pode se deitar no chão e descansar um pouco.	Now you can lie down on the floor and get some rest.
Space Trip Story - Relax	Enquanto estamos descansando, vamos fazer algumas respirações profundas, prestando atenção no movimento que o nosso corpo está fazendo cada vez que o ar entra e sai	While we are resting, let's take a few deep breaths, paying attention to the movement our body is making each time the air come in and out.
Space Trip Story - Relax	Inspira... Sente o ar entrando	Inspire... Feel the air coming in
Space Trip Story - Relax	Expira... Vê como a barriga murcha	Expire... See how the belly withers
Space Trip Story - Relax	Vamos balançar os dedos das mãos e dos pés, observe o movimento deles e a sensação de fazer isso... muito bom!	Let's wiggle our fingers and toes, watch their movement and the feeling of doing this... very good!
Space Trip Story - Relax	Já estamos voando a algum tempo...	We've been flying for a while...
Space Trip Story - Relax	Acho que já conseguimos ver as estrelas!	I think we can already see the stars!
Space Trip Story - Relax	Vamos sentar e espiar pela janela.	Let's sit down and look out the window.
Space Trip Story - Relax	Quantas estrelas! É tudo muito bonito por aqui...	How many stars! It's all very beautiful around here...

Continued

Continuation of Table 12

Stages	Sentence in Portuguese	Sentence in English
Space Trip Story - Relax	Noossaaa!!! O tempo passou muito rápido, já está quase chegando a hora de voltar para a Terra.	Wooww!!! Time has gone by so fast, it's almost time to go back to earth.
Space Trip Story - Relax	Vamos começar a nos preparar para a aterrissagem.	Let's start getting ready for landing.
Space Trip Story - Turtle pose	Com a posição da tartaruga, nós vamos ficar seguros e relaxados.	With the turtle position, we will be safe and relaxed.
Space Trip Story - Turtle pose	Essa é a posição final, mas quando chegar nela, você não estará me vendo, por isso, estou te mostrando agora.	This is the final position, but when you get to it, you won't be seeing me, so I'm showing you now.
Space Trip Story - Turtle pose	Primeiro, vamos ficar ajoelhados, com os dedões dos pés encostados, e separar um pouco os joelhos para que eles fiquem com a mesma largura dos quadris.	First, let's get down on our knees, with our big toes together, and separate your knees a little so that they are the same width as your hips.
Space Trip Story - Turtle pose	Depois, sente nos tornozelos.	Then sit on your ankles.
Space Trip Story - Turtle pose	Quando for inspirar, deixe as costas retas e na hora de expirar, dobre o corpo para frente e coloque as mãos no chão, na sua frente	When inspire, keep your back straight and when expire, bend your body forward and place your hands on the floor in front of you
Space Trip Story - Turtle pose	Encoste a testa no chão e faça suas mãos irem andando para frente, se afastando cada vez mais da sua cabeça	Put your forehead on the floor and make your hands go forward, moving further and further away from your head
Space Trip Story - Turtle pose	Depois, vamos inspirar fundo mais uma vez, e ao expirar, lentamente levar os braços para trás, para que repousem ao lado do corpo	Then, let's take a deep breath in again, and as you expire, slowly bring your arms back so that they rest at your sides
Space Trip Story - Turtle pose	Esta é a posição final da tartaruga.	This is the final turtle pose.
Space Trip Story - Turtle pose - Any Doubt	Você ficou com alguma dúvida?	Did you have any doubts?
Space Trip Story - Turtle pose - Any Doubt "YES"	Ok... Eu posso falar novamente...	Ok... I can explain again...

Continued

Continuation of Table 12

Stages	Sentence in Portuguese	Sentence in English
Space Trip Story - Turtle pose - Doubt "YES"	Você vai ficar na posição inicial, sentado sobre os tornozelos, com os dedões dos pés encostados,	You will be in the starting position, sitting on your ankles, with your toes touching,
Space Trip Story - Turtle pose - Doubt "YES"	Depois, inspira fundo deixe as costas retas e expira, curvando o tronco	Then, inhale deeply leave your back straight and exhale, curving the torso
Space Trip Story - Turtle pose - Doubt "YES"	Encoste a testa no chão e faça suas mãos irem andando para frente,	Put your forehead on the floor and make your hands walk forward,
Space Trip Story - Turtle pose - Doubt "YES"	Depois, vamos inspirar fundo mais uma vez, e ao expirar, lentamente levar os braços para trás, para que repousem ao lado do corpo	Then, let's take a deep breath once more, and as we exhale, slowly bring our arms back so that they rest at our sides.
Space Trip Story - Turtle pose - Doubt "NO"	Legal!	Ok!
Space Trip Story - Turtle pose	Agora vamos começar	Now let's start
Space Trip Story - Turtle pose	Verifique se está na posição inicial	Make sure you are in the starting position
Space Trip Story - Turtle pose	Sentado sobre os tornozelos, com as costas retas	Sitting on your ankles, with your back straight
Space Trip Story - Turtle pose	Inspira fundo	Inspire deep
Space Trip Story - Turtle pose	E expira, curvando o tronco e colocando as mãos no chão, à frente do corpo.	And expire, bending your torso and placing your hands on the floor, in front of your body.
Space Trip Story - Turtle pose	Inspira mais uma vez e expira levando os braços para trás	Inspire once more and expire bringing your arms back
Space Trip Story - Turtle pose	Agora inspira..... e agora expira	Now inspire..... and now expire
Space Trip Story - Turtle pose	Vamos respirar fundo mais uma vez	Let's take a deep breath one more time
Space Trip Story - Turtle pose	Agora inspira..... e agora expira	Now inspire..... and now expire
Space Trip Story - Meditation	Agora, vamos encontrar uma posição bem confortável.	Now, let's find a really comfortable position.
Space Trip Story - Meditation	Pode ser deitado ou sentado, o importante é que possamos ficar bem relaxados.	Can be lying down or sitting down, the important thing is that we can be very relaxed.

Continued

Continuation of Table 12

Stages	Sentence in Portuguese	Sentence in English
Space Trip Story - Meditation	Vamos fechar os olhos e relembrar com calma tudo que vivenciamos	Let's close our eyes and calmly remember everything we've experienced
Space Trip Story - Meditation	Eu estou muito feliz por ter feito essa aventura com você.	I'm so glad i took this adventure with you.
Space Trip Story - Meditation	Todos esses movimentos e posições foram bem divertidos.	All these moves and positions were a lot of fun.
Space Trip Story - Meditation	Eu estou até me sentindo um pouco mais leve.	I'm even feeling a little lighter.
Space Trip Story - Meditation	Você consegue identificar como está se sentindo?	Can you identify how you are feeling?
Space Trip Story - Meditation	Não precisa me dizer nada, apenas pense um pouco sobre a nossa aventura hoje.	You don't have to tell me anything, just think a little about our adventure today.
Space Trip Story - Meditation	Tente lembrar como estava se sentindo antes e perceber como você está agora.	Try to remember how you were feeling before and realize how you are now.
Space Trip Story - Meditation	Depois da prática de hoje, eu sei que vou continuar meu dia mais leve e feliz.	After today's practice, I know I will continue my day lighter and happier.
Space Trip Story - Meditation	Vou guardar com carinho a nossa atividade de hoje.	I will cherish our activity today.
Space Trip Story - Meditation	É hora de abrir os olhos, sem pressa. Muito bem!	It's time to open your eyes, no rush. Very good!
Space Trip Story - Gratitude	Agora podemos nos sentar, com as pernas cruzadas e nos cumprimentarmos, inclinando o tronco para frente.	Now we can sit cross-legged and greet each other, leaning forward
Space Trip Story - Gratitude	Muito obrigado pela companhia na prática de hoje!	Thank you so much for joining us in today's practice!
Space Trip Story - Gratitude	E assim termina a nossa aventura hoje.	And so, ends our adventure today.
	Ending	
Ending - Farewell	Eu gostei muito do nosso tempo juntos!	I really enjoyed our time together!
Ending - Farewell	Nos vemos na próxima prática!	See you at the next practice!

Source: Elaborated by author (2023).

APPENDIX B – SUS-KIDS ADAPTED FOR ZZEN APPLICATION.

Table below shows SUS questionnaire adapted for social robot applications and for children assessment, according to age, using a Emoji-Likert scale. For each statement, there is the statement adapted for social robots by de Souza Jeronimo (2022) and translation that also used Putnam *et al.* (2020) as reference for age accordance (JERONIMO et al., 2022)(PUTNAM et al., 2020).

Table 13 – SUS questionnaire adapted for ZZen and for children's age, using a Emoji-Likert scale.

Target	Statement number	Statement
Ref	1	If I had these robots, I think that I would like to play with them a lot.
7-8 y. o.	1	Eu gostaria de brincar mais com o ZZen.
9-11 y. o.	1	Se eu tivesse esse robô em casa, eu gostaria de brincar muito com o ZZen.

Discordo completamente	Discordo	Não concordo NEM discordo	Concordo	Concordo completamente

Target	Statement number	Statement
Ref	2	I was confused many times about how to play with the robots.
7-8 y. o.	2	Foi complicado brincar com o ZZen.
9-11 y. o.	2	Eu fiquei confuso muitas vezes enquanto brincava com o ZZen.

Discordo completamente	Discordo	Não concordo NEM discordo	Concordo	Concordo completamente

Target	Statement number	Statement
Ref	3	I think these robots would be easy to use.
7-8 y. o.	3	Eu achei fácil brincar com o ZZen.

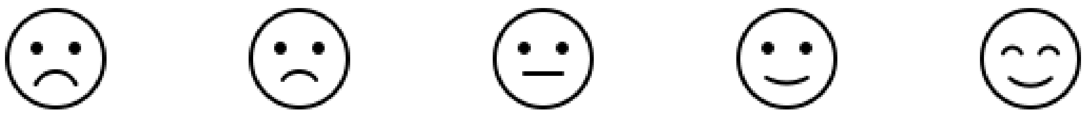
Continued

Continuation of Table 13

Target	Statement number	Statement
9-11 y. o.	3	Eu achei fácil brincar com o ZZen.

Discordo completamente	Discordo	Não concordo NEM discordo	Concordo	Concordo completamente

Target	Statement number	Statement
Ref	4	I would need help from an adult to continue to play with the robots.
7-8 y. o.	4	Eu iria precisar de ajuda para brincar mais com o ZZen.
9-11 y. o.	4	Eu precisaria de ajuda de um adulto para continuar brincando com o ZZen.



Discordo completamente	Discordo	Não concordo NEM discordo	Concordo	Concordo completamente

Target	Statement number	Statement
Ref	5	I always felt like I would know what to do next when I watched those robots.
7-8 y. o.	5	Eu sabia o que devia fazer enquanto brincava com o ZZen.
9-11 y. o.	5	Eu senti que sempre sabia o que deveria fazer enquanto brincava com o ZZen.

Discordo completamente	Discordo	Não concordo NEM discordo	Concordo	Concordo completamente

Target	Statement number	Statement
Ref	6	Some of the things I had to do when playing did not make sense.
7-8 y. o.	6	Algumas coisas em ZZen são confusas.
9-11 y. o.	6	Algumas coisas que precisei fazer enquanto brincava, não faziam sentido.

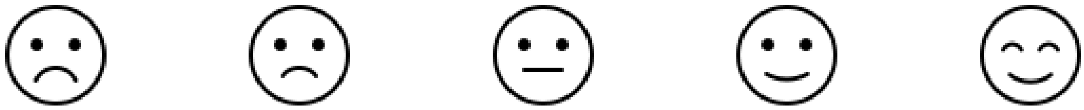
Continued

Continuation of Table 13

Target	**Statement number**	**Statement**		

Discordo completamente	Discordo	Não concordo NEM discordo	Concordo	Concordo completamente

Target	Statement number	Statement
Ref	7	I think most of my friends could learn to play with those robots very quickly.
7-8 y. o.	7	Seria fácil para meus amigos aprender a brincar com o ZZen.
9-11 y. o.	7	Eu acho que a maioria dos meus amigos aprenderiam a brincar com o ZZen muito rápido.



Discordo completamente	Discordo	Não concordo NEM discordo	Concordo	Concordo completamente

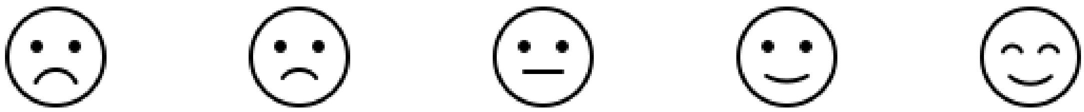
Target	Statement number	Statement
Ref	8	Some of the things I had to do while playing sounded kind of weird.
7-8 y. o.	8	Eu precisei fazer coisas estranhas para brincar com o ZZen.
9-11 y. o.	8	Algumas coisas que eu precisei fazer enquanto brincava foram esquisitas.

Discordo completamente	Discordo	Não concordo NEM discordo	Concordo	Concordo completamente

Target	Statement number	Statement
Ref	9	I would feel confident when I was playing with the robots.
7-8 y. o.	9	Eu fiquei orgulhoso de como eu brinquei com o ZZen.
9-11 y. o.	9	Eu estava confiante enquanto estava brincando com o ZZen.

Continued

Continuation of Table 13

Target	Statement number	Statement		
				
Discordo completamente	Discordo	Não concordo NEM discordo	Concordo	Concordo completamente
Ref	10	I would have to learn a lot of things before playing well with the robots.		
7-8 y. o.	10	Precisa aprender muita coisa para brincar com o ZZen.		
9-11 y. o.	10	Eu precisei aprender um monte de coisas antes de brincar com direito com o ZZen.		
				
Discordo completamente	Discordo	Não concordo NEM discordo	Concordo	Concordo completamente
Ref	11	I would really enjoy playing with the robots.		
7-8 y. o.	11	Brincar com o ZZen foi divertido.		
9-11 y. o.	11	Eu me diverti bastante brincando com o ZZen.		
				
Discordo completamente	Discordo	Não concordo NEM discordo	Concordo	Concordo completamente
Ref	12	If we had more time, I would keep playing.		
7-8 y. o.	12	Se desse tempo, eu continuaria brincando com o ZZen.		
9-11 y. o.	12	e tivéssemos mais tempo, eu continuaria brincando com o ZZen.		

Continued

Continuation of Table 13

Target	Statement number	Statement

Discordo completamente	Discordo	Não concordo NEM discordo	Concordo	Concordo completamente

Target	Statement number	Statement
Ref	13	I plan on telling my friends about these robots.
7-8 y. o.	13	Eu vou contar aos meus amigos sobre o ZZen.
9-11 y. o.	13	Eu pretendo contar aos meus amigos sobre o ZZen.

Discordo completamente	Discordo	Não concordo NEM discordo	Concordo	Concordo completamente

Source: Elaborated by author (2023).

APPENDIX C – USER'S TEST SESSION SUMMARY

Fifteen children and eight guardians participated in the test sessions. All session happened in Recife, Pernambuco, Brazil, during 2022 June. Each session received a code to guarantee participants confidenciality. Each section below describes one user test session for ZZen application.

C.1 SESSION A01

Participants: Child (6 year-old) and mother (36-45 years)

Researcher notes: There was a disagreement in the scheduling of the experiment, and the child was not present, but the mother agreed to perform the test, interacting directly with the robot. She liked the application idea, gave an average SUS score (70), and enjoyed playing with the robot. Due to scheduling difficulties, we could not schedule another session for her daughter. As a mother and medical doctor, the tester said this was a great application to have at home. She was confident that her daughter would love it.

SUS score: Mother's SUS score was 70.

C.2 SESSION A02

Participants: Child (9 year-old) and mother (36-45 years)

Researcher notes: They were both curious about the robot. The girl was extremely excited on personally seeing a robot and being able to touch it. She came bouncing into the room, and was very happy and satisfied after the session, leaving the room bouncing again and asking if she could bring some friends and have another meeting with the robot. She said she wanted to have the robot at home and share the application with friends. She admitted that she probably would practice yoga frequently using this application. Mother agreed with the daughter about the application and said that the robot and application were things that she would like to have at home for her child.

SUS score: The girl gave 85 SUS score for ZZen, and her mother scored 75 for it.

C.3 SESSION B01

Participants: Child (7 year-old)

Researcher notes: Child was a little shy in the beginning, but very excited about the experience. He was accompanied by an aunt, but she chose to not be present during the session experiment. During the test, there was a very heavy rain, which made a lot of noise, disturbing the hearing. To get around this difficulty, the researcher had to repeat a few sentences. Despite this, the boy loved the interaction and wanted to repeat the experience.

SUS score: His SUS score for ZZen was 80.

C.4 BACKGROUD ON SESSIONS B02 AND B03

Boys from B02 and B03 sessions were brothers who were accompanied by their mother, a stay-at-home parent. She chose to not be present during either session. Before both sessions, the experiment was explained, and the robot shown to mother. She admits that she found it interesting but was not interested in seeing it functioning.

C.5 SESSION B02

Participants: Child (11 year-old)

Researcher notes: B02 session had an eleven-year-old boy with ASD. He is very passionate about technology and had many questions about the Zenbo robot, including its features and specifications. Sometimes he would be confused about ZZen instruction, looking at it with a very thoughtful expression. If the instruction was followed by an image on the ZZen display, the boy would say something like "oh, that's what he wants" and would try his best to achieve the final position. The bridge position gave an interesting result: he made the bridge facing down instead of facing up (which makes a different yoga pose but shows the boy's effort in trying to perform the activity).

SUS score: His SUS score for the application was discharged since he marked "completely agree" for all statements without reading (or waiting to listen for researcher to read for him) any and saying that he loved ZZen.

C.6 SESSION B03

Participants: Child (7 year-old)

Researcher notes: It was heavily raining during this session and there was a lot of noise from the rain and the traffic. During some moments it was impossible to hear the robot, so researchers repeated some sentences. The boy was very excited and anxious before starting the interaction with the robot and tried to sneak peek when his brother (from session B02) was testing. Due to his excitement, he seemed to be a little distracted during the session. The boy, even though he was still learning to read, tried to be quick with interactions, so he got it wrong when asked if he was ready to start yoga (the display for this question showed two options. The "Leave" option was a single word that started with the same letter as "yes" in Portuguese (see on Table 3.4). This resulted in termination of the application without yoga practice. He was very sad and upset about it. When presented with the possibility to start again, he was very happy. In the second round, he always confirmed with the researcher if he was choosing the corrected answer. For example, he would say "I want to say 'yes', is this the right panel to say 'yes'?".

SUS score: He scored 72.5 on SUS.

C.7 SESSION B04

Participants: Child (7 year-old) and mother (46-55 years)

Researcher notes: During the introduction part of the robot application, the mother was actively looking at the robot and showing some different facial expressions following the robot's movements and/or speech. After some time, she looked a little bored and reached for her mobile and during the rest of the session was dividing attention between robot and personal mobile. Besides this, she gave ZZen a high SUS score.

The boy was a little shy when meeting the researcher and the robot but was getting excited while the experiment was explained. He was remembering some school activity where he did some yoga movements and was very curious to see how the robot would instruct him. He was not openly showing his emotions and thoughts but sometimes would smile or frown at the robot, expressing his enjoyment, fun, confusion, or frustration. Mainly he was able to perform all guided moves with little struggles. His SUS score was a little lower than his mother.

SUS score: Child's SUS score was 80, mother's SUS score was 85

C.8 SESSION B05

Participants: Child (6 year-old) and mother (26-35 years)

Researcher notes: The boy came with both parents to session B05. When asked if they wanted to be present at the session, the mother thought it would be better to be present due the boy's electric behavior. She admits she would worry that the boy would misbehave if he was alone. Then father asked if he could be present as well, because he was curious and would like to see the robot on the move. So, it was decided that both would be present during the experiment. Besides mother's worries, the boy was mainly shy in the test room, especially during the first minutes of interaction with the robot. He would frequently look at mother before interacting (touching screen or showing QR code plaque) with the robot. When the yoga activity started, he was more confident in himself and seemed happy, showing smiles, to perform the activity. Although the boy was able to read, parents said that he was still in the learning process and wasn't fluently reading completed sentences. So, the questionnaire was read to him, but even with the sentences adapted to his age, the boy had some difficulties in understanding what each SUS was expressing. Many times, the mother would rephrase the statement and then the boy would understand and give his score. Later, only the mother responded to the questionnaire. The boy had the second lowest SUS score between the children (65) and the mother had the lowest (57,5) between guardians. Besides that, both parents were wonderstruck with the robot and liked the application but thought that its use was not very simple. They were not very familiar with yoga, but thought it was a good activity for kids.

SUS score: Boy's SUS score was 65 and mother's 57.5

C.9 BACKGROUD ON SESSIONS B06 AND B07

Children from B06 and B07 sessions were ten-year-old twin girls. They were accompanied by their father. Girls decided between themselves who would go first. Girl from B07 asked her sister to go first because she was unsure of herself and preferred that her sister went first, they said that this was their usual behavior facing some unknown situation. During the first session, the other twin girl waited in a different room.

C.10 SESSION B06

Participants: Child (10 year-old) and father (36-45 years).

Researcher notes: Girl from B06 had no major problems when interacting with ZZen. She seemed to enjoy herself. She was a little confused on the Turtle pose instructions but performed the movement adapting the verbal instructions to what was expected based on the image displayed.

Father answered the SUS questionnaire after B06 session (the first for his daughters) and said that even if he was not performing the movements, he was doing the deep breaths with the robot, and felt more relaxed after the session. He also said that this application would be very useful during the COVID-19 home confinement, and, as a medical doctor, he could see that, if expanded and adapted to some specific scenarios, it could be a great tool for medical treatments, like depression treatments. His SUS score was 77.5 and he said, while answering the questionnaire, that he would "completely agree" with some statements if the application was more adaptable and more accessible.

SUS score: Girl's SUS score was 85 and father's 77.5.

C.11 SESSION B07

Participants: Child (10 year-old) and father (36-45 years)

Researcher notes: When session B07 was going to start, the girl asked if father could be present just like he was at her sister's session. B07 session began then without any other problems, but during the Dragon Breath pose instruction, the robot discharged. Father and girl agreed to wait a few minutes for the robot to recharge. After half an hour, the test was restarted from the beginning of the application.

Then the twin (who had already performed in the B06 session) asked if she could be there as well, ensuring that she would be very quiet and would not interfere in her sister's performance. So, session B07 happened with the presence of father and sister, although the sister wasn't facing her twin and was using her mobile during the entire session. Girl from B07 seemed to enjoy herself. When facing some struggle, she would laugh at herself and try again. Although unfortunate that the test had to restart, researchers believe it didn't affect the result, especially because B07's girl gave a higher SUS score than B06's girl, showing that the girl from B07 enjoyed the application regardless of the presented issue (robot discharged).

SUS score: Girl SUS score was 87.5 and father's 77.5.

C.12 SESSION B08

Participants: Child (11 year-old) and father (36-45 years).

Researcher notes: Father was very enthusiastic and curious to see the robot in use regardless of the application. The girl, who showed signs of maturity beyond what was expected for her age, was very interested in the robot itself and its possible uses and practices and, before starting the application, she made a few questions on some of her ideas for the robot use and their feasibility. After explaining some of the robot's features, the application was initiated.

When the robot asked if she wanted to practice yoga she said "no" because she would like to see what it would do. When the application ended, she asked if she could start the application again in order to see the different path after answering "yes" to the invitation question. She said that she would like to see how the robot would guide a yoga practice and if she could perform under its instructions.

Later, she said that she liked the application, but she was not a fan of yoga so would not be practicing even if she had the robot at home. Her father, who genuinely showed that he liked the application, commented that he thought it would be nice if there was one of those with children during home confinement. In the end, the father seemed to have liked the application more than his daughter had, which is confirmed with their SUS score.

SUS score: 67.5 for the girl, 77.5 for her father

C.13 SESSION C01

Participants: Child (9 year-old) and father (26-35 years)

Researcher notes: Girl was accompanied by both parents. She was a little shy in the beginning and would constantly look at her father or her mother for approval. But when the yoga activity started, she was more confident and performed everything in an easy way and seemed content with herself. She answered the questionnaire by herself but asked researchers to write her answers for the open questions on the questionnaire. She didn't talk much. Besides both parents being present, only the father answered the questionnaire. But both parents gave many comments on the application. They both liked the application and while commenting they were almost brainstorming on how the application could be improved. Among their suggestions, they thought that more stories and other activities, like dance (instructed or free performed), or other music related activity for example.

SUS score: Girl's SUS score 77.5 and father's 100

C.14 BACKGROUD ON SESSIONS C02, C03 AND C04

A guardian aged came with three girls: her daughter and her two nieces. When choosing the test order, the youngest of the girls, besides being super excited, asked to be the last. They decided that the first one would be the girl who was with her mother, then the oldest girl and later the younger. Besides being cousins from C02 girl, children from C03 and C04 were sisters.

C.15 SESSION C02

Participants: Child (7 year-old) and mother (36-45 years)

Researcher notes: The girl didn't talk too much, but seemed to enjoy herself during the interaction, especially during the yoga activity when she was able to perform all four moves without difficulties. After answering the questionnaire and brief interview, she seemed more at easy and, while her mother was filling her questionnaire, the girl started talking to researcher and told that some movements were similar to some things she usually does on her ballet class and showed some other pose she knew: a different way to do the bridge and the candle pose. The mother said that she liked the application but didn't seem very excited about it.

SUS score: Girl SUS score was 90, and mother's SUS score was 92.5.

C.16 SESSION C03

Participants: Child (8 year-old)

Researcher notes: Girl was alone during the session and was a little nervous at the beginning. Later she enjoyed her time interacting with the robot. At several moments she seemed to be insecure with herself and asked several questions to the researcher during the robot's interaction. At the end of the meeting, the researcher explained that she couldn't answer during the experiment, because the test purpose was to check if the robot was clear enough, and if she had some doubts, it was an application's problem that should later be accessed by the researcher. The girl said that she often thought that she understood things differently than others, but she thought she understood the robot well enough.

SUS score: She gave ZZen 77.5 SUS score.

C.17 SESSION C04

Participants: Child (6 year-old)

Researcher notes: The girl who was very anxious before starting. She was alone during the session, and a little insecure. She looked a few times at her sandals, and the researcher said she could take them off, but she refused saying that it was hard to put them on again. After the researcher assured her that later she would be helped to put them on again, she relaxed, and said she was ready to start interacting with the robot. She performed everything with minor difficulties. In the end, she seemed happy to have played with the robot which can be corroborated with her high SUS score.

SUS score: Girl SUS mean score was 90.

C.18 SESSION C05

Participants: Child (11 year-old)

Researcher notes: Session C05 was done with the oldest sibling. Right away he came into the room and seemed to be very interested in the robot and immediately said "hi" trying to talk to the robot, but he wasn't very interested in practicing yoga. Despite the lack of interest in practicing yoga, he followed the entire flow of application. He seemed to find it a little silly sometimes, especially when the experiment required more imagination ("hold the jumpsuit in front of you and slide your legs inside it", for example). He said that found the application interesting, that he could use his imagination a lot, but he thought younger children would probably find it more interesting. When asked what other applications Zenbo could do, he said it could be a psychologist robot. A robot that you had at home and could tell all your secrets with the confidence that no one would ever know about them.

SUS score: He gave ZZen an average SUS score (72.5).

C.19 BACKGROUD ON SESSIONS C05 AND C06

Boys from C05 and C06 are brothers and arrive at the test site accompanied by an aunt who chooses to not be present during the test sessions.

C.20 SESSION C06

Participants: Child (8 year-old)

Researcher notes: The boy was super excited to interact with the robot. As the researcher explained the application that would be tested, he got a little disappointed and kept changing the subject. He expected something like a "chatbot". He wanted to talk and ask questions to learn many subjects with the robot. He was frustrated that the robot didn't understand his verbal responses and needed the QR codes panel. During yoga practice, he didn't follow any of the instructions and even claimed he was bored, walked around the room a lot and started to play with a Pilates ball. At the end of session, he said he was diagnosed with "eagle vision" (a diagnosis related to ADHD, hypersensitivity of vision and hearing, or attention deficit disorder).

SUS score: His SUS score for ZZen (30) was the lowest between children and guardians. Besides this, during the interview, he said that he liked the robot, and the application wasn't bad per se, but it was not what he expected, and admitted this might have influenced his answer to SUS.