STUDY OF EFFICIENCY OF APPLIED BEHAVIORAL ANALYSIS-BASED (ABA) ROBOTIC SYSTEM IN EARLY INTERVENTION TRAINING OF AUTISM SPECTRUM DISORDER (ASD) CHILDREN

BY

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A dissertation submitted in fulfilment of the requirement for the degree of Master of Science in Engineering

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MAY 2023

ABSTRACT

Autism Spectrum Disorder (ASD) in children can be observed by difficulties with social, executive dysfunction, communication and sensory issues. Although there are various well-established interventions for ASD children, most of them are done manually by human therapists and parents which require attention to details and time-consuming. The objective of this research is to develop Human-Robot Interaction (HRI) platform using partial application of Applied Behavioral Analysis (ABA) techniques for early intervention programmes of ASD children. The ABA techniques were then converted to Finite State Machine (FSM) and were programmed in Python 3 (Linux environment) to enable future researchers for HRI to implement the correct technique in lesser time. This framework is then evaluated on ASDC. Four interaction modules with predictable and consistent teaching structures were developed. For implementing the robot modules in this work, the FSM approach were used during the integration of all three components of interaction modules: (a)learning content (developed with ABA therapist); (b)rigid teaching structures; (c)robot's response. Interaction modules, proof-of-concept and final framework validation were done by experienced ABA therapist. The modules were converted to FA where it enables future researchers to iterate the correct method more effectively and to lessen the time-consumed in developing HRI for ASDC. Efficiency of the system were tested with 20 ASD children recruited from IDEAS. 95% of the subjects managed to finish the modules. From the 19 subjects, 53% subjects showed excitement over meeting the robot, and the remaining 47% showed no expression. While they showed indifference over meeting the robot, their interest started to peak once reinforcement (video reward - cartoons) were shown on the monitor. Out of the 19 subjects, only 16% showed excitement throughout the session while the others started to get restless by the end of the goodbye module. The last subject (9 years old boy, male) was not able to finish the modules as he showed clear signs of irritability. While the subjects showed varying levels of emotions during the interaction, and some were not able to finish the modules, the preliminary results obtained can contribute to better understand factors that might help determine sub-groups of children with ASD for whom robots could be particularly useful, and the structure they need. In summary, two objectives involving development of HRI framework for ASDC were fully achieved while a mixed results on effectiveness of the system were obtained when evaluating efficiency of the system.

خلاصة البحث

اضطراب طيف التوحد هو اضطراب نمو عصبي منتشر يتميز بصعوبات في الأداء الاجتماعي والتواصلي ، والمصالح المقيدة ، والسلوك المتكرر ، والعجز الحسي. على الرغم من وجود العديد من التدخلات الراسخة لأطفال اضطراب طيف التوحد ، إلا أن معظمها يتم يدويا بواسطة المعالجين البشريين والآباء الذين يحتاجون إلى الاهتمام بالتفاصيل ويستغرقون وقتا طويلا. الهدف من هذا البحث هو تطوير منصة التفاعل بين الإنسان والروبوت باستخدام التطبيق الجزئي لتقنيات التحليل السلوكي التطبيقي لبرامج التدخل المبكر لأطفال التوحد. ثم تم تحويل تقنيات أبا إلى آلة الدولة المحدودة (ولايات ميكرونيزيا الموحدة) وتمت برمجتها في بيثون 3 (بيئة لينكس) لتمكين الباحثين في المستقبل ل هري لتنفيذ التقنية الصحيحة في وقت أقل. ثم يتم تقييم هذا الإطار على أسدك. تم تطوير أربع وحدات تفاعل مع هياكل تعليمية متسقة ويمكن التنبؤ بها. لتنفيذ وحدات الروبوت في هذا العمل ، تم استخدام نهج ولايات ميكرونيزيا الموحدة خلال دمج جميع المكونات الثلاثة لوحدات التفاعل: (أ)محتوى التعلم (تم تطويره مع معالج أبا) ؛ (ب)هياكل التدريس الصارمة ؛ (ج)استجابة الروبوت. وحدات التفاعل ، إثبات صحة المفهوم والتحقق من صحة الإطار النهائي تم القيام به من قبل المعالج أبا من ذوي الخبرة. تم تحويل الوحدات إلى اتحاد كرة القدم حيث تمكن الباحثين في المستقبل من تكرار الطريقة الصحيحة بشكل أكثر فعالية وتقليل الوقت المستغرق في تطوير معهد حقوق الإنسان ل أسدك. تم اختبار كفاءة النظام مع تجنيد 20 طفلا من التوحد من الأفكار. تمكن 95 ٪ من الأشخاص من إنهاء الوحدات. من بين 19 شخصا ، أظهر 53 ٪ من الأشخاص الإثارة عند مقابلة الروبوت ، ولم يظهر 47 ٪ الباقون أي تعبير. بينما أظهروا عدم مبالاة بشأن مقابلة الروبوت ، بدأ اهتمامهم في الذروة بمجرد عرض التعزيز (مكافأة الفيديو – الرسوم المتحركة) على الشاشة.

من بين 19 موضوعا ، أظهر 16 ٪ فقط الإثارة طوال الجلسة بينما بدأ الآخرون يشعرون بالقلق بنهاية وحدة الوداع. لم يتمكن الموضوع الأخير (صبي يبلغ من العمر 9 سنوات ، ذكر) من إنهاء الوحدات حيث أظهر علامات واضحة على التهيج. بينما أظهر المشاركون مستويات متفاوتة من المشاعر أثناء التفاعل ، ولم يتمكن البعض من إنهاء الوحدات ، يمكن أن تساهم النتائج الأولية التي تم الحصول عليها في فهم أفضل للعوامل التي قد تساعد في تحديد المجموعات الفرعية للأطفال المصابين بالتوحد الذين يمكن أن تكون الروبوتات مفيدة لهم بشكل خاص ، والبنية التي يحتاجون إليها. وباختصار ، تم تحقيق هدفين ينطويان على وضع إطار لمعهد حقوق الإنسان للتعاون فيما بين البلدان النامية بالكامل ، بينما تم الحصول على نتائج مختلطة بشأن فعالية النظام عند تقييم كفاءة النظام.

APPROVAL PAGE

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DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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ACKNOWLEDGEMENTS

All glory is due to Allah, the Almighty, whose Grace and Mercies have been with me throughout the duration of my programme. Although, it has been tasking, His Mercies and Blessings on me ease the herculean task of completing this thesis.

I am most indebted to by supervisor, Dr Hazlina Md. Yusof, whose kindness and understanding have facilitated the successful completion of my work. I am also grateful to my co-supervisor(s), Prof. Dr. Shahrul Naim Sidek and Dr. Aimi Shazwani Ghazali, whose comments and suggestions contributed to the outcome of this work. It is by Allah's mercy that I was able to take this project to completion.

Abundant thanks to my dear "Bio-Mechatronics" labmates, who has been my company - at a time where everyone is isolated, thank you for giving me company. Always remembered, my company in the lab, Ifrah Shahdad and many thanks to all of Ruqayyah's sisters who had been giving me moral support throughout the research. Special thanks to Farah Sakiinah for being my partner in crime for pushing through together until the end. I will remember our friendship for years to come.

I want to thank my family who gave me love and support every single day of this journey. Thank you for always believing and supporting me in whatever I do, however odd it may seem at times.

Lastly, to Nur Qisti - thank you for being the one who listened and supported me tirelessly, at one of the most difficult and critical phase of my research, at a time where I needed support most. Thank you for reminding me of my purpose. Thank you for always giving me the motivation to move forward.

This thesis is dedicated to Saif, Dylan and Raul.

The output from this research is fully designed, developed and written with the three of you in mind - from the times spent with you.

Thank you for teaching me more than what I could ever taught you.

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LIST OF ABBREVIATIONS

A	autonomous
ABA	Applied Behavioral Analysis
ADOS-2	Autism Diagnostic Observation Schedule – Second Edition
ASD	Autism Spectrum Disorder
ASDC	ASD children
BOT-2	Bruininks-Oseretsky Test of Motor Proficiency, Second Edition
CI	correct imitation
CS	cross-sectional study
CSC	cross-sectional study with control
EC	eligibility criteria
EG	eye gaze
ESCS	Early Social-Communication Scales
HRI	Human-Robot Interaction
IC	inclusion criteria
IQ	intelligence quotient
ID	intellectual disability
IJA	initiation of joint attention
JA	joint attention
LEAP	Learning Experiences and Alternative Program for Preschoolers
LTM	Least-To-Most
LS	longitudinal study
LSC	longitudinal study with control
M	manually (data taken on the spot by researchers)
MSEL	Mullen Scales of Early Learning
MTL	Most-To-Least
PDD-NOS	Pervasive Developmental Disorder-Not Otherwise Specified
PEP-30	Psychoeducational Profile, Third Edition
PL	Prompt levels required
QI	quality of interaction
R	real-time data
RD	research design
RJA	responding to joint attention
SAR	Socially Assistive Robots
TD	typically developing
TDC	typically developing children
TEACCH	Treatment And Education of Autistic and Children
TH	target hit
V	video data analysis
W	WoZ
WISC	Wechsler Intelligence Scale for Children
WoZ	Wizard-of-Oz

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Autism Spectrum Disorder (ASD) in children can be observed by difficulties with social, executive dysfunction, communication and sensory issues (Maenner et al., 2020). ASD children (ASDC) experience delay in developmental milestones compared to other typically developing (TD) children. Currently, there is no known medical cure for ASD. The main method for interventions is focused on therapy and behavioral modifications. To help ASDC catch up to their supposed developmental milestones and increase their independence, intensive therapy becomes a necessity. Applied Behavior Analysis (ABA) and therapies based on its principles are the most well researched and commonly used in earlier studies (Yu et al., 2020). Such therapies are usually carried out in early intervention centres or schools that cater special needs students. An earlier work revealed that intense practice or hours of therapy can help the ASDC to catch up faster (Grynszpan et al., 2014).

Robots for rehabilitation purposes have gradually gained popularity and are redefining the current clinical strategies. Robot-assisted rehabilitations are known to be more accurate and systematic compared to conventional therapies. Robots are capable of delivering intense and long duration repetitive sessions without the constant presence of a therapist. Thus, robot-aided therapies possess a bright potential to be utilized as therapist's assistant. Furthermore, evidence collected from the past decade has proven on ASDC's keenness with robots (Kim et al., 2012; Mazon et al., 2019). Thus, there are no doubts that it is an effective platform to reduce the therapist's burden and keep ASDC engaged during the therapy session.

More importantly, ASDC shows clear attraction to technology and pays more attention to robots than human therapists. To date, HRI has been employed for several uses: assisting in the diagnostic process, improving eye contact and enhancing teaching process. Although there are many researchers currently working on the use of HRI for ASC, most of them are more focused on the robot's capability and hardware itself. There are also studies which claimed to follow ABA only applied certain aspects of therapy like reinforcement (Simut et al., 2016) or prompt levels (Warren et al., 2015). In this research proposes on building framework adapted from ABA's core technique and adapt it via robotic means. The framework is validated by ABA therapists and the efficiency of the developed framework was analyzed based on child's response towards the robot.

1.2 PROBLEM STATEMENT

Evidence-based practice (EBP) for ASDC such as Applied Behavioral Analysis (ABA) therapy can be very costly. This therapy can go up to RM 15000 each month for a child. This raises questions on the attainability of quality therapy for ASD children in the lower-income group. This may cause for the group being unable to go for quality education. Without support, they may be halted from reaching their full potential.

Changing therapist constantly can decrease learning process' effectiveness as it is also known that ASDC responds best with someone they are highly familiar with. ASDC has low tolerance to changes, this issue can affect the child's focus. New therapists will need to spend time building rapport and gaining trust from ASD children which can vary in the length of time. The use of robots can help overcome this issue as robots can be replicated and are consistent in terms of appearance and behaviors.

HRI researchers for ASDC are also currently taking time to develop the framework as this is transdisciplinary research and requires perspectives from both the clinical and the engineering side. This research aims to lessen this issue by building a framework that can be re-used and iterated by future researchers by building a Finite State Machine (FSM) based modules that can be used as a template, to enable correct technique to be used easily.

1.3 RESEARCH OBJECTIVES

Based on the problem statements, the **main goal** of this research is to develop a framework of Human-Robot Interaction (HRI) based on Applied Behavioral Analysis (ABA) technique for ASD children. To fulfil the main goal, this research has been streamed into **three research objectives (RO):**

i. To **investigate** the characteristics of robots effective for human-robot interaction (HRI) session in ASD children (RO1).

ii. To **develop and integrate** framework for HRI session based on ABA technique into Finite State Machine (FSM) method for robot's control. (RO2).

iii. To **evaluate** efficiency of the HRI framework on ASD children by **verifying and validating** the developed framework from ABA therapists and ASDC's engagement to robot (RO3).

1.4 RESEARCH METHODOLOGY

In order to fulfill the research objectives, quantitative methods were used to address this research and different phases were planned. This research has been divided into 4 phases and are discussed as follows:

The initial phase focuses on satisfying Research Objective 1 (RO1). This phase focuses on a comprehensive literature survey on existing literatures of HRI-based intervention for ASD children. Various published research findings in areas related to robot's technology, robot's application for ASD children and educator's view on the use of HRI for education were systematically reviewed. Emphasize were given more on studies claiming to apply ABA technique in their research as this is the focus of this project. Based on articles reviewed, essential information on developing modules of interactions, the experimental setups and procedures, ethical conducts and existing HRI-based platform for ASD children were extracted. The advantages and downsides of relevant data from current literatures were thoroughly studied to highlight and identify the research gap, and to recommend further improvements from current framework.

ABA therapists were interviewed to assist in developing modules of interaction and to advice on possible implementation, as best as we can, the core techniques of ABA into a robotic platform. Research objectives, problem statements, research scopes and methodology were also formulated in this phase.

The second phase was to achieve Research Objective 2 (RO2) whereby it established the overall process. This phase constitutes the framework development for HRI the session. Development was based on literature survey and feedback from ABA therapists. Amendments were done accordingly following the feedback. The developed framework was then embedded to the robotic platform in ROS environment.

The third phase was designed to meet Research Objective 3 (RO3). A set of questionnaires were administered to ABA therapists for framework validation purposes. The validated framework was then finalised and tested with TD and ASD children. The outcome measures include: child's response towards robot, proxemics behaviour and module completion.

The final phase involves fulfilling Research Objective 3 (RO3) as well. This phase involves the evaluation on the efficiency of the HRI platform on TD and ASD children A flowchart is used to summarize the steps and action taken throughout the different phases of this research. The flowchart may be referred to in Figure 1.1.

1.5 RESEARCH SCOPE

There are three groups of ASD children, severe, intermediate, and mild. However, the teaching modules and technique will be developed to suit only two groups which are the intermediate and mild groups. This is due to the limitation of our robot. Children who are severely affected are more susceptible to tantrums/behavioral issues that our robot are not programmed to handle in this research.

There are several limitations in this study. ABA's comprehensive program comprises of many areas. Therefore, this research is highly focusing on early intervention for mild and intermediate and mild ASDC. Although ABA's comprehensive program contains various modules for mild to severe ASDC, our project will only apply techniques based on the early learner's program and ABA's core technique.

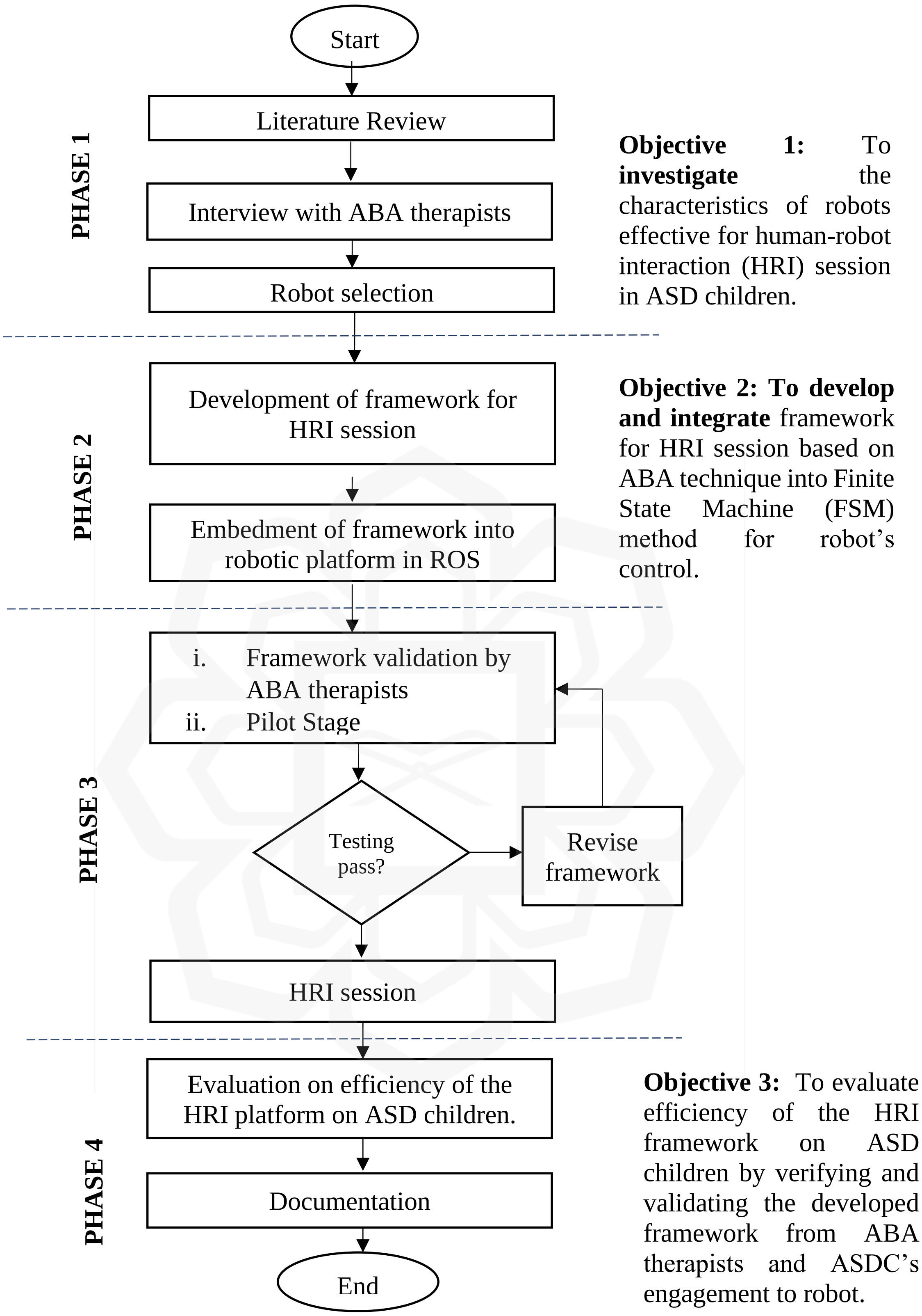

Figure 1.1 Flowchart of research methodology

1.6 THESIS ORGANIZATION

This thesis is organized into five chapters, chapter one presents an introduction to the present work which comprises of current research foundations and concepts. This chapter discusses the introduction, problem statement, objectives, methodology and research scope.

Chapter two provides an extensive literature review on previous research that are relevant to this topic. Some of the highlighted points are behaviors of ASD children, robot design and features, and modules of interaction that are effective for early intervention.

Chapter three elaborated in depth the framework development. Elements of the framework: (a) module of interaction; (b) subjects; (c) robots; and (d) outcome measures are thoroughly described.

Chapter four discusses the outcomes of this project. The results obtained and performance of the HRI platform is also discussed in this chapter.

Chapter five presents the conclusions drawn from the research. It discusses the achievement of objectives, limitations and recommendations for future works that can be extended from this research.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

The current prevalence data estimates that one out of 68 newborns each year has ASD (Maenner et al., 2020). Currently, medical cure are yet known for ASD. Various methods of interventions, mainly for behavioral were developed. ABA and therapies based on its principles are the most well-researched and commonly used (Geoffrey Louie et al., 2020). Such therapy is usually carried out in early intervention centers or schools that cater to special needs students. Interestingly, skills of ASDC can be improved by taking advantage of Human-Robot Interaction (HRI). Robots are predictable, repetitive systematically understood by ASDC (Mazon et al., 2019). Thus, this literature review addresses the following questions: (1) *What are the characteristics of robots effective for HRI-session in ASDC? (2) How did existing research adapt ABA technique to HRI? (3) How are the effectiveness of HRI evaluated?* (4) *Which technique from ABA can be adapted into HRI?*

2.1.1 Human-Robot Interaction

HRI is a study of interaction dynamics of humans with robots (Dautenhahn, 2007). HRI were recognized as a prospect on autism research (Shamsuddin et al., 2014). HRI can be illustrated as the user's behaviors the role of the robots during the therapy session as in Figure 2.1. According to Shamsuddin (2014), components of HRI include: early intervention curriculum, ABA technique and robot capabilities. The goal of HRI for ASDC involves encouraging imitative behaviors useful for social interaction, as a mediator for turn-taking, extract and enhancing joint attention between ASDC and another human.

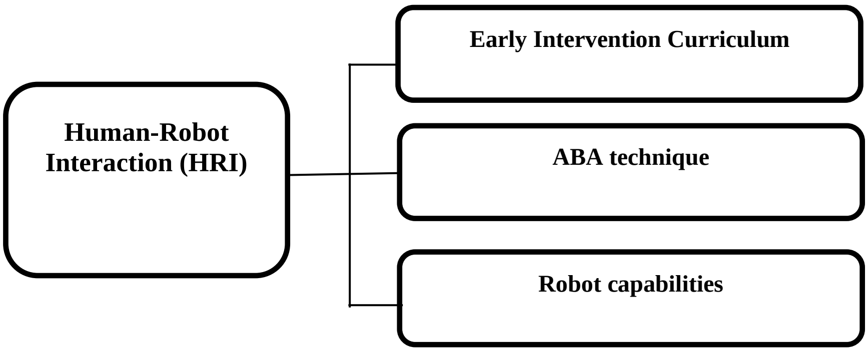

Figure 2.1 The three major components of the interaction (Shamsuddin et al., 2014)

2.2 LITERATURE REVIEW PROCEDURE

For this research, literature comparison was done using five reliable database which is IEEE, PubMed, ERIC, Scopus and Springer Link. All search were restricted to English articles with publication year limited only to research done from the past 10 years (from 2011 to 2021). For each database, different strategies in executing the search string were adapted due to each database's individual characteristics. For PubMed and IEEEXplore database, searches were performed without filtering, searching the entire text. Searches were done by filtering titles and abstracts for ERIC, Scopus and SpringerLink databases. Search string or keywords used were: (autism spectrum disorder AND robotic platform). The search string used were: (ASD OR autism) AND (HRI OR robots OR "socially assistive robots" OR SAR). Articles selected are limited to ones with (autism OR ASD) present during abstract and title screening. Next, only articles from reliable peer-reviewed journals were selected. Articles that obligated to the requirements listed were downloaded and important information were imported into a separate Microsoft Excel (.csv) database. This includes the complete bibliographic data: title, authors, literature abstract, source (database, journal name, index and etc.). This process resulted in 1,125 English articles.

For the process, articles that studied Human-Computer Interaction (HCI), (Haokip et al., 2017; Jyoti & Lahiri, 2020), computer vision (Coco et al., 2017; Masmoudi et al., 2019; Zhang et al., 2018), information communications technology (ICT) (Galán-Mena et al., 2016; Grossard et al., 2018), and general assistive devices (Hashim & Yussof, 2018; Hong et al., 2016; Moktar et al., 2014) for ASDC whose focus lies exclusively on technologies not related to robotics were excluded and labelled as assistive technologies (AT). Figure 2.2 presents data obtained from this process. 128 articles were removed due to duplication and limitation by our institution on full-text access, another 292 articles focusing solely on clinical/psychology aspect with no relation engineering were also removed. Other basis of removal includes: focus on AT (146 articles), review papers (25 articles). Only 535 articles proceeded to the screening stage. Benitti (2012) were referred to for screening and eligibility criteria. The articles were further categorized to different study are: social, communication, imitation and joint attention analyzation purposes.

2.2.1 Screening Process

All abstract and introduction were screened using these criteria for inclusion (IC):

IC-1: Research focus must be limited to autism and robotics. Research with focus on multiple mental/developmental disabilities were excluded (e.g., ADHD or Down syndrome).

IC-2: Research must evaluate efficiency of robotic system in improving skills in ASD children.

IC-3: One group of the test subjects must fully constitute ASD children.

IC-4: Robot model used for the study must be declared.

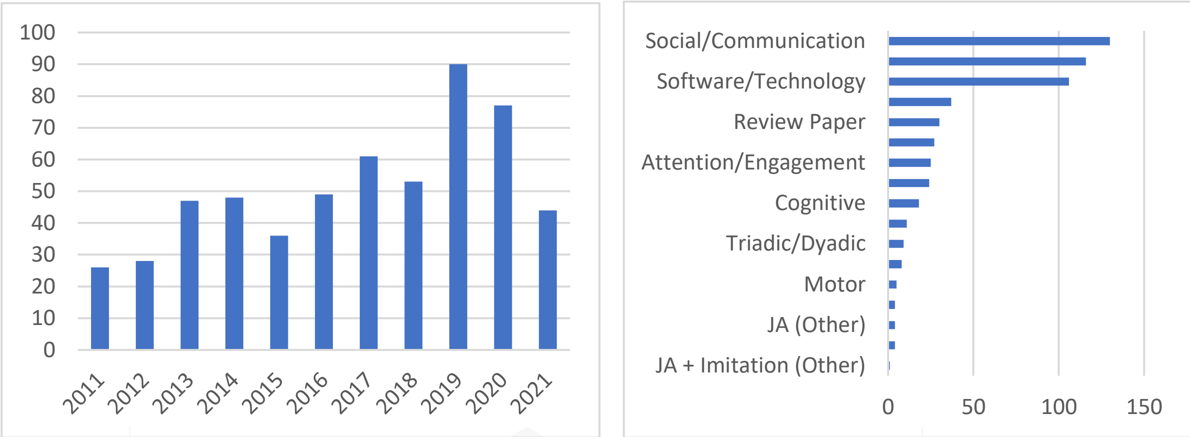

Figure 2.2 Number of research per year, and categorized based on study area

2.2.2 Eligibility Process

After defining the inclusion criteria, eligibility of the studies was then designed to align with objectives of this research. Two exclusion criteria (EC-n) were used to further eliminate articles that are not relevant to this research: (EC-1) Studies that exclusively focus on the robot's technology and did provide enough data on the robot's function for therapy were excluded, (EC-2) Studies with no original experiment (surveys, reviews, commentaries) and are not exhaustive with the reporting (insufficient data on experiment) were also excluded.

EC-1 were used to exclude studies with focus that is more on the hardware and technology of the robot only instead of working on integrating robotic and ASD studies. These two rules were designed as evidence collected from the past decade are sufficient enough in proving efficacy of robotic studies with HRI (Andreia P. Costa et al., 2018; W.-C. So, Wong, Lam, Lam, et al., 2018; Z. Warren et al., 2015; Z. Zheng et al., 2014). Studies from the past ten years has proven that ASDC are intrigued and fascinated with robot and new technologies. As studies executed in this discipline is being done rapidly, papers that may not reflect current technologies were not included (any articles published prior to 2011).

Articles with only preliminary results published during conference, and a more comprehensive results published on the same study in a journal paper, the journal paper will be included and the conference proceeding will be ignored (E. T. Bekele et al., 2013; Esubalew Bekele et al., 2014; Z Zheng et al., 2013). Data included in this literature search were extracted from eligible articles with reliable data to best of our knowledge during the course of the study.

2.2.3 Extraction of Data

Once identified, studies relevant to this research were screened and crucial data from each study were extracted. These relevant data were recorded: (a) test subject's information (total samples, physical age, mental/developmental assessment method), (b) robot designed/used, (c) design of experiment, (d) overview of system, and (e) research outcome.

2.3 DATA EXTRACTION METHOD

This sub-section further discusses on the process of data extraction. Research data and its' rationale will be explained further in the next sub-sections. During the process of data extraction, Begum et al. (2016) were referred to for structured guidelines. Method on establishing robot-mediated therapies to qualify it for evidence-based practice (EBP) were referred to by Kim (2012). These guidelines were proposed by clinical researchers to qualify robotic intervention for ASD children to be qualified for EBP. However, as there is a wide range of topics and factors covered by the clinical disciplines in relation to autism, adopting all of their proposed guidelines is currently not possible. Odom (2010) defined EBP is as an intervention practice with high quality research that were tested and found effective. Therefore, for this literature search, relevant data that has demonstrated a meaningful and comprehensive application of HRI for ASD children in a reliable method that could increase the likelihood of current HRI-based therapy to be included for EBP were analyzed in depth. Each data extracted and its' rationale (as per Table 2.1) is elaborated further in this sub-section. The elaboration for further understanding of the data extracted are explained in the following sub-sections.

2.3.1 Intervention

Specific clinical goal of the study/intervention

Main purpose of therapy for ASD children is to assist ASD children for a better life/independence in their future, carefully designed therapeutic goals are needed to fulfill this general therapy purpose for ASD children. Some important aspects that can be considered during the design process by HRI-based researchers include: communication, social, maladaptive behavior reduction or elimination behaviors that affects their daily lives, and academic skills. For this literature study, the main objective is to improve imitation or joint attention (JA) skills. Studies with focus in these two skills is crucial. Imitation is the prerequisite of cooperative behavior as stated by Meltzoff (2015) and Trevarthen (2010) where it plays a fundamental aspect in coordinated acts development as it provides child with mutual connectedness and social experiences.

2.3.2 Participants

Criteria of test subjects in the study

After defining goals of intervention, criteria of inclusion for participants shall be determined carefully. This criteria were defined as it presents a short but accurate information demographics of participants. The total sample size were recorded along with their average age range and are followed by mental or developmental assessment score and the tools/method used. Research that included both ASD children and typically developing children (TD) were also included. Experiments with TD were usually included to either be experimented on for proof-of-concept (Moghadas &

Moradi, 2019; Paillacho Chiluiza et al., 2021; Ramirez-Duque et al., 2018) or for comparison of response/reaction upon meeting the robot (Salvatore Maria Anzalone et al., 2014; E. T. Bekele et al., 2013; Cao et al., 2020; Hirokazu Kumazaki et al., 2018; Xavier et al., 2019).

This is an important step as crucial data on efficiency can only be calculated and counted as reliable if they meet the criteria defined by clinical team as closely as possible. For example, when teaching ASD child a specific skill, researchers must carefully determine the level of mastery the child is currently at, to ensure that modules developed will be able to help the child move further along instead of just teaching the child what they already know, or in worst case scenario, teaching a skill that is too advanced for the child. All participant must also begin with the same baseline score so that each data can be considered reliable. A study that includes ASD children with different severity level into one single intervention is Conti et al. (2018). One important note to remember is that no ASD children is the same, therefore, different children will have different needs to attend to. In order to ensure ASD children obtains the most effective treatment, ASD children needs to be grouped to their respective severity level (mild, intermediate, severe). This is because different severity level needs different focus/treatment. Every approach used during intervention must consider ASD children's baseline skills and deficits as they are crucial variables that can determine intervention outcomes (Zachor & Ben Itzchak, 2010). A detailed demographic (physical age, gender, severity level) and diagnostic data of subjects must also be clearly defined (Aromataris et al., 2015).

2.3.3 Robotic Platform Overview

Type of robot used and complete feature of the overall system

The robotic platform and any external hardware utilized were recorded as it is believed that all the technologies used must be described with replicable precision in order to help future researchers improve the current study and move the research further. Documenting detailed features of the robotic platform, system, hardware and software utilized during implementation of the intervention is a crucial aspect in research (sensors, algorithm for robot control, user interface, software used) to increase its' reproducibility. This aspect in research is crucial as this can help future researchers to iterate and improve outcomes of this study and further move the research in this discipline forward. It can also enable outcomes of this research to be tested and gain feedback from a wider population.

Robotic Platform. The robotic platform utilized in each HRI studies were recorded to explore the different types of robot available and to investigate robot features most effective for ASD children.

Overview of system. This data is further categorized into two other sub-types to identify robot's motor control and data acquisition method for the HRI session. For robot's motor control, most researchers will program the robot to work either autonomously (A) or manually using the Wizard-of-Oz (W) method. For data acquisition method, data acquisition method were summarized into three separate method: real-time data acquisition (R), post-intervention video analyzation (V) or manual data acquisition (M).

2.3.4 Outcome evaluation

Specific ASD skills acquisition implemented by HRI

This data presents the study's dependent variable where dependent variables are defined by the quantities of behavior assumed to be improved/modified (or increased, in terms of skill acquisition and interfering behaviors reduction) by the independent variable (i.e., the robotic platform) (Begum et al., 2016). The variable must be defined clearly by the researcher and it must also be linked strongly to the outcome evaluation of the robotic intervention in order to help gauge efficiency of designed experiment.

2.3.5 Design of Experiment

Design of experiment

This column presents the research's design of experiment. Most research are divided into two separate designs: cross-sectional (CS) or longitudinal study (LS). CS are research that makes comparisons at a single point in time (single session intervention) and LS make comparisons over time (multiple sessions with the same test subjects where data over time will be analyzed). Research consisting of control groups can be identified as such: longitudinal study control (LSC), or cross-sectional control (CSC).

Another crucial aspect to consider for any HRI-based intervention is the total interventions for ASD children (Weitlauf et al., 2014). For any clinical research, it usually involves a multi-session intervention as it is considered a long process, as changing behavior using intervention requires time and patience, this is especially true for ASD children. However, for studies in the discipline of HRI domain, most research are designed to be cross-sectional where ASD children will only go through one single intervention with the robot for a very limited time. By referring to Table 2.1, it can be seen that the trend is slowly changing. Most research designed in early 2011 mostly utilized the cross-sectional method, and as the year and technology progress, most research are starting to move to longitudinal-type of experiment. One possible cause for this could be because of the increasing awareness that ASD children requires rigorous practice and repetition of acquired skill to enhance and retain ASD children's skill mastery (Linstead et al., 2017). Retention of acquired skills can be enhanced and supported by multiple intervention sessions, strengthening the skills acquired and at the same time, any social interaction that can help strengthen bond between ASD children and the instructor/teacher/mediator must be supported to enhance skill generalization. Skill generalization is where the ASD children learn to practice the skill acquired with different people and at different place.

2.4 ROBOTS FOR ASD CHILDREN

As stated previously, the use robotic platform for ASD children is not intended to completely take the therapist's place, instead, the goal here is to utilize robotic platform as a mediator, or as assistant for therapist (S. Costa, 2014; Simut et al., 2016). From research done in the previous ten years, there are multiple types of robot application done by researchers in the field. Foundational developmental skills in children, such as behaviour imitation (I), joint attention (JA) between two people, social interaction (S) and other (O) developmental skills are one of the many example of skills that can be improved by robot's mediation. For HRI-based interventions, while some studies designed and built their own robot prototype (Dunst et al., 2013; Kajopoulos et al., 2015), many studies are moving to use commercial robots in the market. This step is an excellent money-saving and time-saving method.

Robotics is considered to be a time-consuming process. During the design and development process, researchers will spend countless hours of just designing, troubleshooting, programming and doing development works. These steps are expected to deliver a reliable, robust product. Clinical work on the other side is expected to be more focused on the therapy delivery method. Countless hours are used to spend on planning careful intervention session. Multiple trials and rigorous statistical analysis were also done in order to ensure and effective therapy. HRI studies that includes ASD children integrates both clinical and robotic theories, this is why a commercial robot is usually utilized in order to reduce the time spent in developing a robotic platform. This allows researchers from the engineering field to immediately apply and program methods or feedback gained from the clinical perspectives while at the same, improve the state-of-art technology to move forward (E. Kim et al., 2012). Besides, current technology, or programming method for the laypeople such as the drag-and-drop programming method allows educators to plan lesson plans and easily program the robot themselves, as most commercial robot these days also include graphical programming method. This type of programming can be easily understood by the teachers or therapists. In summary, commercial robots are more advantageous in terms of cost, delivery, robustness, and a lower failure rate can also be guaranteed as most commercial robots has gone through rigorous testing before being marketed to the public. This can also be seen in Table 2.1, where 80.9% of the studies used NAO, a commercially available robot manufactured by Aldebaran Robotics as their robotic platform of choice.

2.4.1 Educators' Opinion on HRI

Robot's application for ASD children varies with each research. Earlier studies discovered that humanoid's human-like features are considered bonus points as employing these robots as therapists' assistant during ASD children's therapy increased their attention (Alcorn et al., 2019b). These attributes are particularly useful during social learning acquisition and for generalization purposes. This human-like features aids ASD children in associating robots with humans. Another participant also mentioned that the robot features enable it to resemble a real human boy, thus helping provide a real-life example for ASD children. These feedbacks further help support current findings that during intervention task by robots, a significant time were spent by TD children looking at the mediator's face (the robot utilized). Therefore, robots that most resemble human should be used by a robot-mediated activity.

Meltzoff (2015) suggested that an entity that behaves more "like me" is more likely to be imitated. However, some educators also mentioned that too much interaction with a humanoid robot may make attention to teachers to be deviated in some way. counter this issue, a method as outlined in Fridin (2014) outlined a method that can be used to overcome said issue. Guidelines were designed in order to prevent the children from emotionally attaching themselves to the robot, by carefully underlining its limitations and comply with the ethical requirements.

Table 2.1 Research studied during literature review

Reference	**Participants (Average age)**				**Robot**	**Research Design**	**System Overview**					**Outcome Measures**			
							Control		**Data-taking**						
	Total	**R**	**C**	**IQ (average)**			**A**	**W**	**R**	**V**	**M**	**EG**	**TH**	**PL**	**CI**
Bekele et al. (2014)	**ASD:**6 (4.70)	6		MSEL: 71.65	NAO	CS	x		x			x	x	x	

	TD:6 (4.40)	6		SCQ: 3.8											
Zheng et al. (2014)	**ASD:** 5 (3.93)	5		ASD: 70.60	NAO	CSC	x		x			x			x
	TD: 5 (3.88)	5		TD: not stated											
Conti et al. (2015)	3 (11.3)	3		not stated	NAO	CS		x				x			x
Warren et al. (2015)	6 (3.46)	7		MSEL: 73.67	NAO	LS		x		x		x	x	x	
Kajapoulos et al. (2015)	7 (4.60)	7		Not stated	CuDDler	CS		x			x	stances of RJA or IJA were calculated according to ESCS coding sheet.			
Carlson et al. (2018)	20 (5.30)	10	10	Not stated	CuDDler	LSC		X			X				
Warren et al. (2018)	**ASD:** 8 (3.83)	8		ASD (MSEL): 64.75	NAO	CSC	x		x			x			x
	TD: 8 (3.61)	8		TD: Not stated											
Kumazaki et al. (2018)	**ASD:**28 R-(6.09) C- (4.39)	16	12	K-ABC= R-97.75, C-99.83	CommU	LSC		x		x			x		
	TD:38 R-(5.88) C-(6.03)	17	21	R-108.59, C-103.10											
Chevalier (2017)	20 (9.12)	20		WISC-IQ: 61.52 Stanford-Binet: 51.18	NAO	CS		X		x		x			x
Chevalier et al. (2017)	12 (7.00)	12		not stated	NAO	LS		x		x		x			x
Conti et al. (2018)	6 (8.69)	6		Leiter IQ: 36.33	NAO	LS		x		x		x			x
Zheng et al. (2018)	14 (2.78)	14		54.71	NAO	LS	X		x			X	X	x	

Ali et al. (2019)	12 (7.95)	12		CARS: 27.96	NAO	LS	x		x			X	X	x	
So et al. (2018)	**ASD:**30 R-(5.10) C-(5.65)	15	15	ASD (PEP-3: 4.7, BOT-2: 95.2)	NAO	LSC		x		x					x
	TD:15 (5.31)	15		TD: (PEP-3: 5.41, BOT-2: 112.13)											
Cao et al. (2020)	ASD: 27 (3.86)	27		BSID-II-NL: 33.07	NAO	CS		X		x		x	X	x	
	TD: 40 (3.33)	40		BSID-II-NL: 36.30											
Zheng et al. (2020)	23 R-(2.55) C-(2.54)	12	11	R- 61.90 C- 56.00	NAO	LSC	x		x			x	X	x	
Ali et al. (2020)	8 (7.48)	8		CARS: 26.63	NAO	LS	x		x			x	X	x	

2.5 TEST SUBJECT SELECTION

A crucial first step to identify children with ASD is through diagnostic method. There is various diagnostic tool that can be used. These mental/developmental assessments must be executed by a clinical psychologists or long-term practitioner certified. Most research utilized the Pervasive Developmental Disorder-Not Otherwise Specified (PDD-NOS) (Mesibov, 1997) and also the Autism Diagnostic Observation Schedule (ADOS) (Lord et al., 1989) in order to diagnose children suspected with ASD. This is a crucial step before designing any therapy sessions, as interventions claiming to conduct studies for ASD must verify and ensure that every test subject has their own respective and accurate diagnosis/confirmation for ASD. This is because there are multiple mental/developmental disabilities (i.e Global Developmental Delay, Asperger's, ADHD).

Besides getting the proper and accurately administered diagnosis, the mental/developmental score/age or severity level of ASD children must also be taken into consideration. As the term ASD may already foreshadow, autism is disorder with a wide spectrum, which means that every child is different, meaning that the skills or deficits for each child may not be the same (i.e., level of severity, mental/developmental age and physical age gap). Intervention sessions has a higher probability to be effective when all of the interaction modules developed, and the robot's features/behaviors are designed to suit the child's needs (mental, developmental age/severity) (Conti et al., 2018). As ASD children can be categorized into a very wide spectrum, from mild to severe, specific criteria of inclusion (e.g., IQ cutoff > 75) were set by most research. Different severity level requires different types of interactions between child and robot. For example, ASD children on the severe end, with severe aggression issues are more suitable for a non-physical interaction while children that exhibits mild symptoms may be more tolerant of a more physical social interactions and discussions.

For further understanding on the importance of this issue, to Figure 2.3 can be referred to. Figure 2.3 shows the scoring example of Vineland developmental assessment report (Sparrow et al., 2016). This figure presents the domain in which the child will need support with, and the domain where the child has strength in. Adaptive behavior can help aid ASD children to function with society in their everyday lives, it is a collection of social, conceptual, and practical skills that can usually be learned by anyone, the only difference is that ASD children may need more support than their TD counterparts. Therapy for ASD children mostly focus on aiding ASD children to perform and adapt well to society. These mental/developmental assessments by practitioners or clinical professionals are usually done annually or as needed. Taking into account that each ASD children differs in needs or deficits, some may show significant progress annually while some may not improve at all. This can be seen in Figure 2.3, this shows that while some children perform well in one domain, the other will be struggling. What therapist usually does is to focus on is strengthening the child's strength, while simultaneously improving on their weaknesses. For example, if an ASD child is needs help in socializing but excel in their fine motor skills, the therapy be designed in a way that will shift to increasing practice in socialization, and while the child will still be trained in fine motor skills, the frequency of practice learning session for a skill that the child already excel in will be decreased. This is why it is crucial to record each ASD children's baseline score and their current mental/developmental scoring because as previously stated, no each child is the same, and every child will have different needs to be met. Meaningful conclusions are unlikely to be made if the ASD child's current mental/developmental age is not diagnosed the intervention.

Diagnostic tools utilized to gauge the severity level, mental age or developmental age can be referred to in Table 2.1. The most widely used diagnostic tool in order to assess the Quotient of Intelligence (IQ) level or mental scoring in ASD children is the Wechsler Intelligence Scale Children (WISC) (W.-C. So, Wong, Lam, Cheng, et al., 2018; W. C. So et al., 2016). For certain cases, The Stanford–Binet Intelligence Scale (Fourth Edition) were also utilized as some participant are not able to finish the WISC sub-tests. Next, Mullen Scales Early Learning (MSEL) can also be utilized. Overall score of the child's cognitive ability can be provided by this test. So et al. (2018) utilized the Psychoeducational Profile, Third Edition (PEP-30) to measure the subjects' communication and language skills while motor skills can be assessed with the Bruininks-Oseretsky Test of Motor Proficiency (BOT™-2). Kim et al. (2015) utiized Leiter International Performance Scale (Leiter-3) while H. Kumazaki et al. (2018) utilized the Kaufman Assessment Battery for Children (K-ABC). Bayley Scales of Infant Development (BSID-II-NL) were used by Cao et al. (2020) to calculate the mental age score. Based on data extracted, it is believed that every HRI-based study that includes ASD children must also closely work with professionals/practitioners that has experience in working with ASD children as ASD is a complex disorder. Therefore, to move the studies focusing in this field into the right destination, feedback and guidance from them must be considered.

Instead of categorizing subjects based on their respective mental age (IQ score, severity level), Chevalier et al. (2017) categorized the subject according to their sensory preferences. Conti et al. (2018) categorized subjects into three different category: mild, moderate and severe ASD. This research is a good example on the importance of designing experiments based on severity level. Two subjects with subtle disability in intellect (ID) were unable to finish tasks and follow instructions as they were having difficulty advanced stimuli given. Thus, from this research it believed that a crucial criterion during research participant selection is the mental age. Neglecting this step can result in the data for the study questionable and turn the study efficiency unreliable. Although research in the HRI discipline are applying robots as the main object used for teaching, it must also be made sure that the robots are employed using the proper techniques and are adapting the practitioner's method as much as possible. A richer understanding of HRI-based intervention's potential impact and use can be gained by recruiting more participants from a wider spectrum. Baseline characteristics such as scoring from the communication, socialization, adaptive behaviors, and intellectual domains of the subjects must be obtained first, and can be aided by using help from the clinical side to administer relevant diagnostic tools. These information must be recorded before designing any intervention plans as the changes in skills post-intervention can be predicted using these information.

ABC	Standard Score (SS)	90% Confidence Interval	Percentile Rank	SS Minus Mean SS*	Strength or Weakness**	Base Rate
Adaptive Behavior Composite	66	61 - 71	1			
Domains						
Communication	65	58 - 72	1	-6.5	Weakness	>25%
Daily Living Skills	79	72 - 86	8	7.5	Strength	<=25%
Socialization	57	49 - 65	<1	-14.5	Weakness	<=5%
Motor Skills	85	75 - 95	16	13.5	Strength	<=10%

Figure 2.3 Example of VABS-3 scoring. Extracted from (Sparrow et al., 2016)

2.6 OUTCOME MEASURES FOR HRI

The human-robot interaction (HRI) framework consists of three main focus, that is: robotic platforms, test subjects, and modules of interaction. Each framework development focuses on specific outcome measures. These measures include ASD children's behaviour, attention, response, eye contact and engagement. To analyze HRI's efficiency in intervention sessions, behavioral indicators from ASD children such as duration of eye gaze (Conti et al., 2018; Wing Chee So et al., 2018) and self-initiated interaction towards robots were usually recorded. These data acquisition are usually recorded either in real-time or video analysis post-intervention are usually done. Fluctuating moods from ASD children can make the performance measurement difficult to be done solely by the robotic platform.

The most widely used method during data acquisition is post-session video analyzation, where researchers code for intended behaviors of the subject after the intervention using video recorded. Behaviors intended includes: frequency of eye gaze (Chevalier et al., 2017; Conti et al., 2015), correct imitation of gesture (Chevalier et al., 2017; W. C. So et al., 2016), self-initiation to researcher or robot (Chevalier et al., 2017), target hit (subjects showing correct response in a specific time) (S. Costa, 2014), and level of prompt (E. Warren et al., 2015). Aside using video analysis, Carlson et al. (2018), Fachantidis et al. (2020) and Kajopoulos et al. (2015) manually recorded data during the intervention. Two researchers recorded two differing data sets which is interaction quality (QI) and subjects' involvement during interaction. Carlson (2018) recorded IJA and RJA scored by referring to the guidelines obtained in Early Social-Communication Scales (ESCS). By using independent diagnostics such as ESCS, Carlson et al. (2018) suggests that their results are independent and relatively robust. The Screening Tool for Autism in Toddlers and Young Children (STAT) were utilized by Zheng (2020) to measure baseline of index key in early social communication skills,.

Some studies also analyzed data offline by using the data recorded in real-time. These research embedded sensors onto the robotic platform and calibrated external hardware to record data in real-time (E. Bekele et al., 2014; Zheng et al., 2020; Zheng et al., 2018). Behaviors recorded by the platform are gaze duration to robot administrator (E. Bekele et al., 2014; Zheng et al., 2020; Zheng et al., 2018), target hit (subject responds to instructions by HRI within provided time) (Zheng et al., 2020; Zheng et al., 2018), body gesture (Anzalone et al., 2019), and levels of prompt used to get correct response/target hit (E. Bekele et al., 2014; Zheng et al., 2020; Zheng et al., 2018). Bekele (2011) used a head tracker to detect ASD children's RJA. The child were observed to be uncomfortable wearing the device making this research unsustainable in the long run. The study were then improved and the WoZ method were adapted. Bekele (2014) and Zheng (2020) built a novel JA robotic platform that solves several existing limitations such as the need to use physical technologies such as body-worn sensors, nonautonomous robot operation such as WoZ that requires human involvement.

Kumazaki (2018) and Zheng (2020) provided a calculated time window for children to respond to instructions (3-7 seconds) from the robot. This practice is called the time delay method. This method is widely used by ABA therapists where there is a time frame or window between giving child an instruction and giving prompt to help them follow the instruction (Kurt & Tekin-Iftar, 2008). Bekele (2014) and Zheng (2020) used prompt hierarchy as a learning method. This method is used to instill independence and avoid children from being too dependent on prompts. This is to ensure that child truly understood the instructions given while also giving assurance to the child that they will be assisted should they trouble in comprehending the instruction. Two types of prompts are used by therapists, that is: the Least-To-Most (LTM) method and the Most-To-Least (MTL) strategy. LTM means that instructors will start with the minimum amount of prompts, and will then observe the child's response, and vice versa. If the child is observed to have difficulty in understanding the instructions given, prompts will be increased uniformly as needed. The lesser the amount of prompts used, the more the child considered successful as it shows that the child has true understanding of the instruction (Cengher et al., 2016). ASD children are more likely to perform the desired behavior when the mediator/instructor is clear and consistent with their actions. This is why a time delay that is consistent and the correct hierarchy of prompt must be used in during the interaction with ASD children. This is highly achievable by application of robots. During the conventional therapy with therapists in a normal therapy session, the therapy has a high possibility to be influenced by human error, that can be caused by the therapist. While most studies are focusing on behavioral response from ASDC such eye gaze and facial expression, this project aims to measure another important behavioral response, which is proxemics behavior.

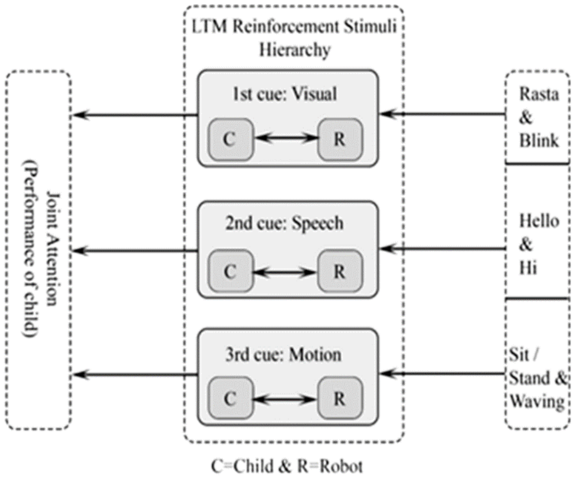

Figure 2.4 Figure extracted from (Ali et al., 2020) on reinforcement hierarchy

2.7 APPLIED BEHAVIOR ANALYSIS (ABA)

ABA operates using the theory that consequence can affect behaviour. In clinical practices, assessments is the first step taken determine suitable goals for each ASD children. A large number of tools can be used such as the Verbal Behavior Milestones Assessment & Placement Program (Sundberg, 2008) and Vineland Adaptive Behavior Scale (Salekin et al., 2018). Next step includes development of intervention modules which clearly define the procedures, goals, instruction, prompt levels, rewards/reinforcements, and child's performance.

2.7.1 Teaching Technique (Discrete Trial Training)

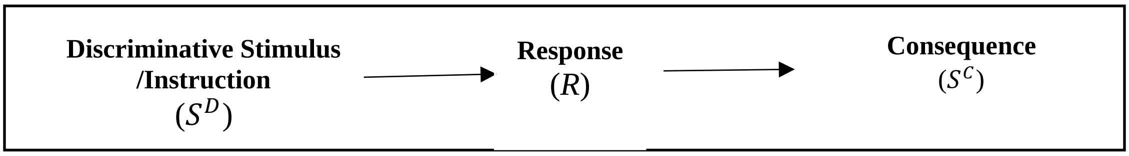

Figure 2.5 Components of DTT

Discrete Trial Teaching (DTT) are utilized for skill acquisition. Discrete trials is a three-part teaching unit and is a sequence of behaviour used to for effective learning in ASD children. It can help make teaching skills clearer, as the structure can subtly let the child understand expected behaviors. DTT can also help maintain consistency and progress evaluation simpler (Lear, 2000). Operant conditioning states that a gesture/behavior that results in something that is favored (rewards) will be repeated. Wolf (1967) states that behavior that can result in something liked (reinforcement) will be repeated. Reinforcements is a crucial tool that are widely used in any ABA interventions. Reinforcers can be used very frequently to provide motivation. Figure 2.5 presents DTT sequence and its' respective component.

2.7.2 Prompting Techniques

Prompting is a technique used to help an individual perform desired behavior by using added stimuli (prompts). It provides learners with assistance, which can help increase probability of desired behaviour occurring. Successful response of expected behavior elicits positive reinforcement, reinforcing learning.

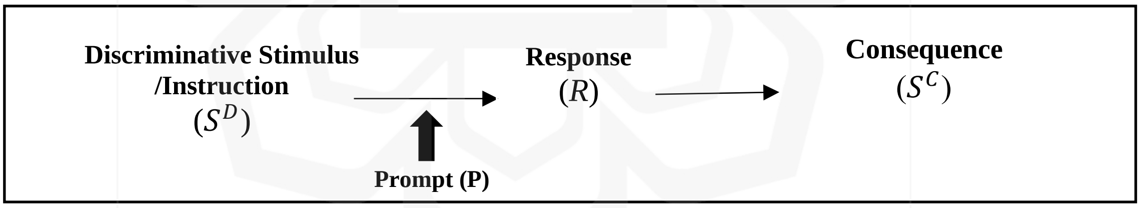

Figure 2.6 Prompt Sequence

2.7.3 ABA application in current HRI studies

Literature was reviewed to identify studies combining ABA and HRI applications. A few common techniques were frequently used by researchers in the past. These are reinforcement/reward (R), prompt levels (PL) and discrete-trial teaching (DTT). All these three components were explained elaborately in Section 3.2. The techniques are summarized in Table 2.2.

Table 2.2 ABA-based HRI intervention

References	Robot	ABA Technique Applied		
		R	PL	DTT
Bekele et al. (2016)	NAO			
Dickstein-Fischer and Fischer (2014)	PABI			
Anzalone et al. (2014)	NAO			
Shamsuddin et al.(2012)	NAO			
Begum et al. (2015)	NAO			
Tariq et al. (2016)	NAO			
Palestra et al. (2016)	KASPAR			
Salvador et al. (2016)	KASPAR			
Ishak et al. (2019)	ReRO			
Louie et al. (2020)	NAO			

All studies summarized in Table 2.2 applied the reinforcement technique. The reward can be implemented using social praises such as (“Awesome job!”, “Amazing!”) or music reward using tones preferred by child can also be used. Levels of prompt are also core techniques of ABA. Should the ASD child answers in an incorrect manner, the robot will prompt the child to re-try and provide hint/the child will be physically prompted by the therapist. DTT can help ASD child learn effectively as it is a structured teaching technique which is highly favorable by children on the spectrum. However, simply following the behavioral sequence (DTT) is not enough. An effective DTT must be followed using the correct technique. This includes differential rewards/reinforcement, correct intonation in different situations and timing. In order to adapt ABA technique as closely as possible, advice from ABA therapists must be implemented.

Louie (2020) is a promising study that applied core techniques of ABA during HRI session. However, there are a few drawbacks in this study. Firstly, although the DTT was applied correctly, the same reinforcement should not be given to the child for all prompt levels. It can only be applied when the child does a desired behaviour so that he or she are able to differentiate between the targeted behavior, and the less desired behavior. Applying differential reinforcement technique can help to fix the issue. Enthusiastic reinforcement, gesture and praise should only be given if the child does the desired behaviour in the first trial. Using a robot with no emotional expression is also a less desirable characteristic. Therapists interview stated that emotional expression is an important aspect in ABA. Emotional expression, as well as tone should vary according to child's response. During therapy, a correct answer (without prompt) from ASDC will be met with the most enthusiastic or often, exaggerated response from the therapist in terms of tone and expression to help the child learn targeted behavior. Figure 2.7 illustrates the sequence used by (Geoffrey Louie et al., 2020).

2.8 SELECTION OF ROBOT

For HRI-based research, although some research designed, developed and built their own robots as prototype, most studies are starting to utilize commercialized robots currently in the market (Hawks et al., 2013; Wykowska et al., 2015). This method is an excellent time-saving and money-saving mechanisms.

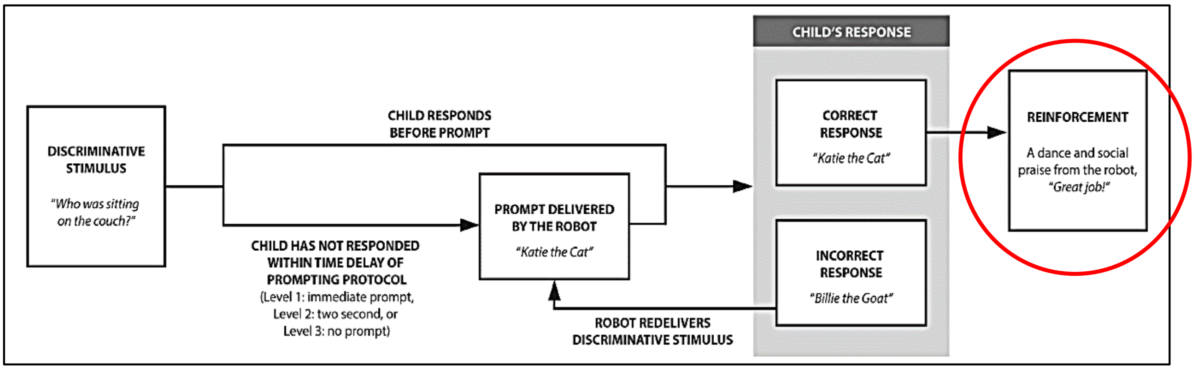

Figure 2.7 Child were given the same reinforcement for all prompt levels

Studies in HRI which involves ASD children combines both the clinical professionals and the robotic teams, therefore, using a commercial robot is a better choice to save time and cost. Using a commercial robot also allows for parents, clinicians and teachers to easily buy and customize the robot for their own needs at the time as robots are easily available commercially. In summary, commercial robots are more advantageous in terms of price and their robustness. Characteristics of robots for the applications of HRI can be referred to in Table 2.3.

Table 2.3 List of current robots and the skills targeted

References	**Characteristics of Robot**
Srinivasan et al. (2015)	A robot must be able to talk or play music. Children prefer to follow the rhythm of music over simply imitating the robot.
Brown et al. (2016)	Three teachers proposed robot-mediated activities. Potential barriers to application includes technical factors, where there is a need for simple, versatile, fast, and easy robot controls.
Duquette et al. (2008)	The children prefer to look at dynamic things such as a rotating wheel, hand movements, blinking eyes rather than static objects.
Alcorn et al. (2019)	Educators commented that ASD children is very motivated when interacting with humanoid robots.
Huijnen et al. (2017)	Educators gave feedback that successful robot application would need teacher-planned activities where teacher can easily personalize the robot.

Sidek et al. (2019)	Wizard of Oz-style in controlling robots are more efficient than an automated one as every ASDC is unique. The robot needs to be controlled by the clinician or teacher based on the current behavior of ASDC in specific time.

For inclusion criteria, recommendations from previous research were referred to and adapted. While there are currently many commercial robots available in the market, robots that are close to our inclusion criteria is listed. Robots shortlisted are as followed: Bioloid, NAO, DARWIN and QTRobot (refer to Table 2.4). Bioloid (39.7 cm) and DARWIN (45.5 cm) were eliminated due to their small size. Based on the previous section, most educators recommended a robot that most resemble humans, which are humanoid robots. In addition, Giullian (2010) mentioned that it is intuitively easier for children to imitate objects that are similar in size to them. Table 2.4 summarizes the features of each robot based on their features and attributes. The selection criteria are as follows:

- The robot should be easily programmed by therapists or teachers (includes graphical programming);
- Comes with Software Development Kit (SDK);
- Changes in facial expression should be able to be displayed subtly in order to be easily observed and followed by children.

While both QTRobot and NAO has the same attributes, size and feature, QTRobot was chosen as it is the most cost-efficient with features it comes with and mostly due to its ability to show subtle facial expression with its' LED screen. This ability to subtly display facial expression is a very crucial feature as this is going to be utilized during our differential reinforcement technique. While it is not mobile like NAO, QTRobot's various features suits criteria of the project and has a huge advantage over NAO due to this ability.

Table 2.4 Selection process based on robot’s characteristic

Robot	SDK	Height	Easily Programmable	Interactivity	Facial Expression
Bioloid	Yes	39.7	Yes	Yes	Static
Darwin	Yes	45.5	Yes	Yes	Static, only eye colour can be changed.
NAO	Yes	57.3 cm	Yes	Yes	
QTRobot	Yes	64 cm	Yes	Yes	LCD screen as the robot's face, ability to change facial expression

2.8.1 QTRobot’s features and development

During this phase as well, QTRobot’s features were studied to help plan for future development during the later phase in this study.

2.8.1.1 Robot’s computation and networking

QTRobot operates using two computers: (i) QTRP – a Raspberry Pi based computer used to control the main hardware and; (ii) QTPC – an Intel NUC PC to provide more computational power and accelerate software development cycle. Both computers run on Ubuntu/Debian Linux operating system and leverage for flexible software architecture (refer to Figure 2.7).

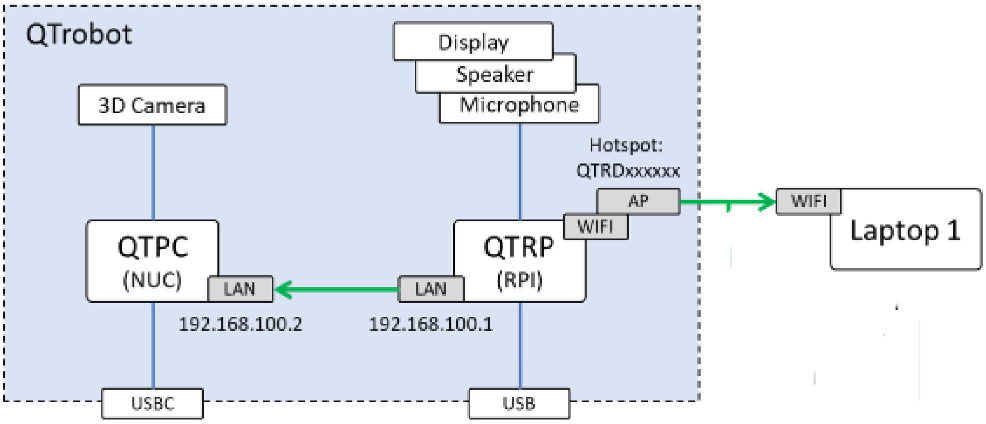

Figure 2.8 QTRobot's network and interfaces

Figure 2.8 shows the network configuration during development and experiment. QTPC can be connected directly to laptop via secure shell (SSH). The SSH is a cryptographic network protocol for operating network services securely over an unsecured network. Its most notable applications are remote login and command-line execution. SSH applications are based on a client–server architecture, connecting an SSH client instance with an SSH server. To SSH to QTPC, laptop is connected QTRobot's Wi-Fi hotspot and the command used can be referred to Figure 2.9.

Figure 2.9 The command used to connect laptop to QTPC's IP address

2.8.1.2 Operating System (OS) and Robot Operating System (ROS)

The current version of QTrobot came with Ubuntu 16. However, in order to use the latest operating system (OS), the laptop used to control QTRobot were installed with latest stable version of Linux. **Ubuntu 20.04 LTS were installed and the** latest stable version of **ROS Noetic** with **Python 3** were also installed as default. The latest is particularly used as offer access to wider list of open-source software and libraries which use Python 3. As for the ROS setup, the roscore runs on QTRP automatically at QTrobot boot time.

2.8.1.3 QTRobot Startup Process

The following diagram depicts the default process of QTrobot's startup. Upon turning on the robot (either by plugin the power line or by pressing the power button), the QTRP will boot and set up the network for Lan, Wi-Fi hotspot and connecting to the home/office router (if set up). Then it runs the ‘roscore’ and launch the QTrobot interfaces such as ‘qt_motor’,’qt_robot_interface’ and etc. When the basic interfaces is up and running, it then turn on QTPC via wake-on-lan (Figure 2.9).

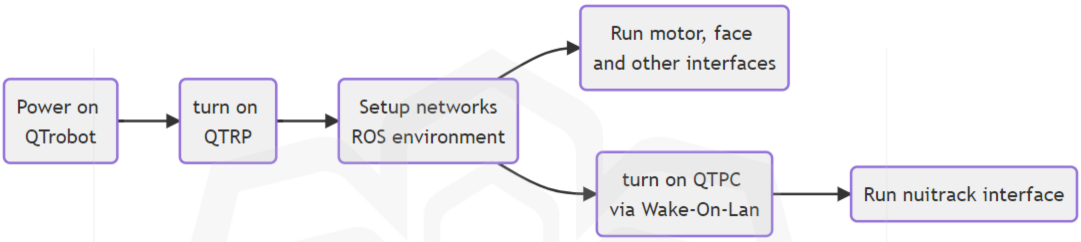

Figure 2.10 QTRobot's startup process

Powering off QTrobot almost follows the reverse procedure of powering on. The QTrobot's power button is connected to Raspberry PI and trigs the power off procedure of QTRP. During the shut down process of QTRP, it also sends power off command to QTPC via SSH so that both computers turn off using a single power button. Below is an overview of the power-off process of QTRobot (refer to Figure 2.8).

2.8.1.4 Microsoft Visual Studio Code

Microsoft Visual Studio Code (VSC) were used to develop and test the codes. Visual Studio Code is a powerful open-source code editor developed by Microsoft. It has built-in debugging support, embedded Git control, syntax highlighting, code completion, integrated terminal, code refactoring, and snippets. As this software is available in the Microsoft apt repository, apt were used to install VSC for Linux. The following extensions were also installed in VSC to build the ROS workspace (Figure 2.11).

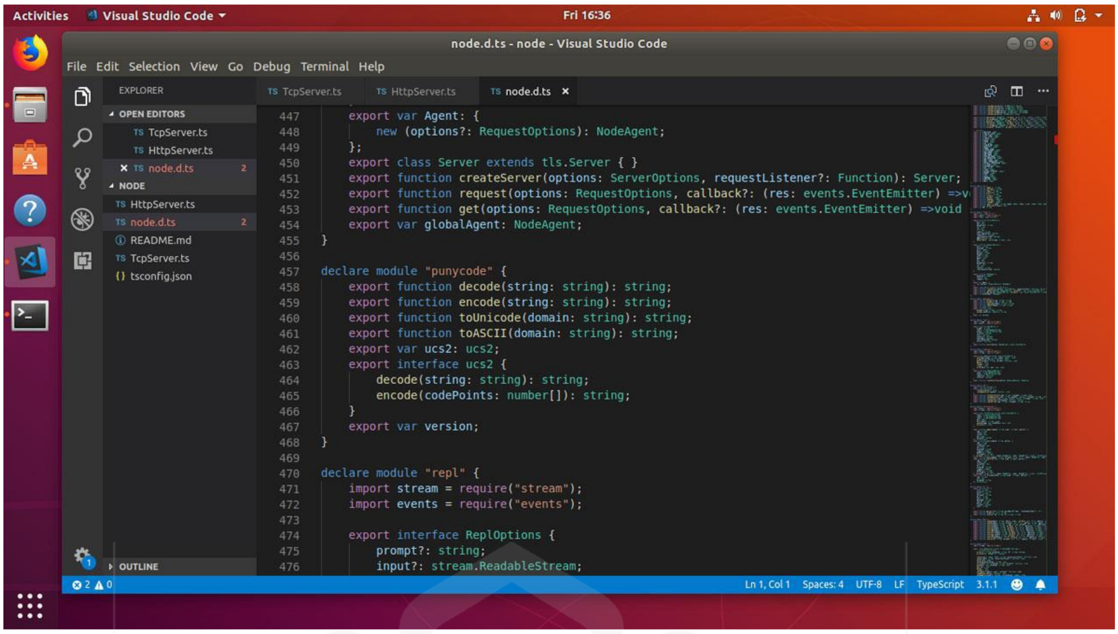

Figure 2.11 VSC were used during the code development process

2.9 SUMMARY

In this chapter, the implementation of conventional therapy for ASDC using robotic platform is explored. Various methods of robot-aided rehabilitation designed to help ASDC improve their skills are discussed. HRI-based studies for ASDC are compared based on the research participant selection, robot used, skills targeted, outcome measures and technologies used. It is concluded that using a humanoid robot are better for use in intervention sessions compared to other types of robots for multiple reasons. Humanoids looks more alike to humans, and this increased educators' confidence for it to be used during therapy. Detailed reviews on association of correct teaching technique and effective learning sessions for ASD children were also highlighted. It Is important to apply evidence-based conventional practices with the robotic platform to ensure that HRI-based studies may be accepted as EBP by the clinical community in the future.

With insights gained from the literature review, a HRI framework were developed based on ABA technique. This ABA technique follows a rigid structure that is consistent and predictable for ASDC. This enables it to be converted to Finite State Machine consisting of multiple states and state transitions that can be easily understood and followed by researchers from the technical side. This FSM 'template' were programmed using Python3 in Linux-environment and has the potential to help future researchers reduce the time taken to develop another HRI from scratch as this template can be immediately used or iterated easily.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter describes the research methodology of this dissertation. The methods section is reported according to guideline provided by (Ghasemi et al., 2019). In brief, it is comprised of framework development, data collection process and validation process. In developing a research that is sustainable and for ease in future iterations, a model called the ADDIE model were adapted from the instructional design community. The platform were implemented in a controlled environment with clinically validated subjects. The success rate of the platform was then validated by two sets of structured questionnaires and quantitative measurements on child's engagement with robot.

3.1.1 The ADDIE Model

The Analysis, Design, Develop, Implement and Evaluate (ADDIE) model is a systematic process model and is one of the most widely used by the instructional design community. The ADDIE model consists of five elements: analysis process, design, development, implementation, and evaluation. This method was chosen as the five elements ensure that continuous improvements and iteration can be made as those five elements are activities that will be ongoing and continue throughout the process. This process can be seen in Figure 3.1. This method also allows for clear and effective intervention programs to be designed. The first five phases can be followed in their respective order, then, the data collected can be utilized as a guide once complete and future researchers may restart or replicate research from the analysis phase, improving the final outcome. As any HRI-based session needs continuous rigorous tests and evaluation after development, ADDIE's systematic nature of process model ensure for an easily improved future performance.

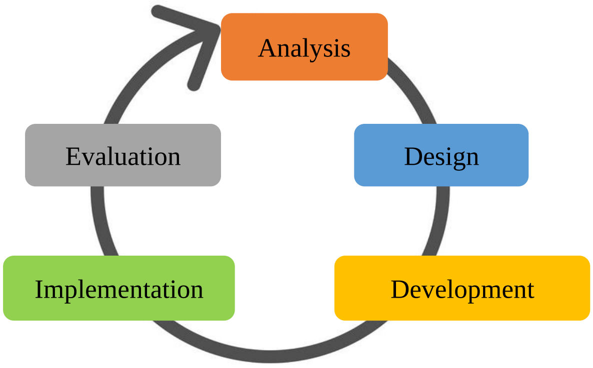

Figure 3.1 The ADDIE Model

Robot's behavior were programmed using the Applied Behavioral Analysis (ABA) technique while the ADDIE model was used in the development stage and design process of the study. This is important in order to ensure that the robot remains predictable and consistent, an important aspect in ensuring effective learning for ASD children. ABA is a technique in which it is believed that consequences can influence future behavior. Firstly, mental/developmental assessments must be conducted for ASD children (ASDC) in order to determine their respective baseline in which appropriate goals with clear plans can be designed for each individual. This is then followed by the design of a clear intervention session that includes clearly designed steps and procedures for instruction, prompt levels design, error correction, rewards, and performance data acquisition. The development of this HRI-based session utilizes the systematic ADDIE model during development stage and framework for robot's behavior were built using ABA's core principle.

3.2 FRAMEWORK DEVELOPMENT

The framework development consists of analysis on suitable modules, subjects, robotic platform and evaluation method. As previously stated, the ADDIE model were used. Suitable modules of interaction to be embedded in the robotic platform were analysed. Figure 3.2 shows steps followed for development. The process for each steps are discussed further in depth in the following sub-sections.

Figure 3.2 Summary of each phase of framework development

3.2.1 Analysis

The purpose of the Analysis Phase is to determine, formulate and formalize the system's requirements. This is accomplished by establishing what the system is to do, according to the expectations and requirements of the system's end users (ASD subjects). Important components of the research are as follows: scope of the research and system, target participants, key technical requirements, tools for each stage of development, learning modules and robot's states/response were analyzed. The main purpose is to combine all the pieces together and form a conceptual model that ties previously said components, along with their attributes, relationships, together with the system constraints This is to enable the system to be designed and developed with respect to scope and requirements. The output is a conceptual model that were carried over to the next phases (design and development). Figure 3.3 shows the conceptual model.

During the analysis phase, the most important aspect of this research, the subjects' initial demographics were determined. Criteria for the ASD children who may participate in this research are listed as follows: a) The children are diagnosed with autism spectrum disorder (ASD); b) The children are in the age group of 4-9 years old; c) The children cannot have hearing and vision deficit; d) The children can understand and follow simple English instructions. After subjects has been selected, Vineland Adaptive Behavior Scale (VABS-3) were administered to each subject.

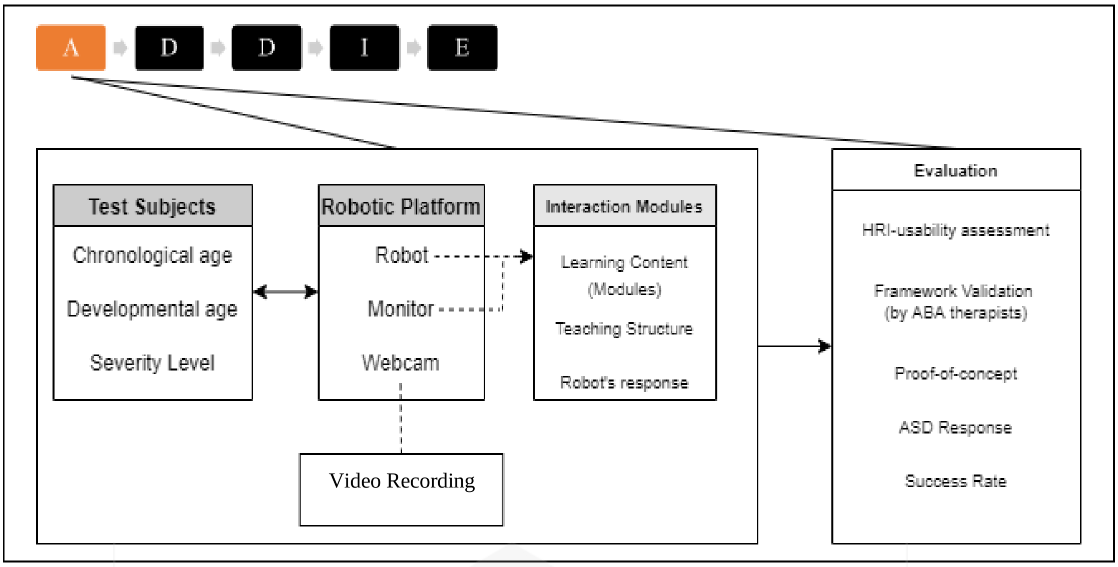

Figure 3.3 Summary of output and conceptual model from the Analysis phase

During this process, each subject's parents/guardian were contacted and an interview were done. Each interview took 50-60 minutes to complete. In the interview, a practitioner qualified to conduct VABS-3 thoroughly identified the child's ability and learning difficulties and scores for each domain were obtained. The main domains measured are: Communication, Daily Living Skills, Socialization, Motor Skills, and Maladaptive Behavior (refer to Table 3.1 for complete domain). Before the experimental stage, each subject went the scores for each subject and each domain were obtained. As there are multiple domains that ASD children may need intervention with, this research focuses only on improving social skills of the ASD children.

Table 3.1 Domains and subdomains measured by VABS-3

Domains	Subdomains
Communication	Receptive, Expressive, Written
Daily Living Skills	Personal, Domestic, Community
Socialization	Interpersonal, Play, Coping Skills
Motor Skills	Fine Motor, Gross Motor
Maladaptive Behavior	Internalizing, Externalizing, Critical Items

3.2.2 The Design Phase

In this phase, objectives of learning were designed and interaction modules were developed. Based on the VABS-3 scores, most of participants recruited were mostly weak in the social domain. This is why learning objectives and interaction modules in this research will focus more on social skills development.

3.2.2.1 Modules Design

As the basic foundation of social skills is recognizing emotion of others, learning objectives and modules of interaction (refer to Table 3.2) were designed to focus on learning emotions as it is an important aspect in socialization. Therapist's feedback on suitable early intervention modules were gained. It was also noted that instruction to the child must be short and concise to reduce confusion. Robot's capabilities were explained to the therapists and the following modules were recommended:

Table 3.2 Interaction module developed from analysis phase

Module(s)	Method(s)	Objective(s)
Introduction Module	Robot starts movement slowly following the child's response. This is a one-way communication.	To help create comfortable environment for the child to warm up for the initial interaction. This helps researcher to predict child's current mood and social ability, and comfortability with a new object or stranger.
Module II	Robot performs simple gestures and child are	To measure child's attention and engagement with the

(Identifying emotion)	expected to be able to follow and imitate.	robot and child's ability to listen to robot's instruction. Skills targeted – social / emotional identification and expression skill.
Module III (Expressing emotion)	Robot instructs the child to express emotion.	
Goodbye Module	Robot waves arms and says goodbye. Attempts handshake and thanks child.	To communicate robot's limitation to the child. Skills targeted: social skills.

As previously stated in Chapter 2, the robot follows a rigid teaching structure (by following ABA technique) to give predictability and consistency to the ASDC. The complete robot's behavior is shown in the next sub-section.

<u>*3.2.2.1.1 Teaching Structure*</u>

Therapists were interviewed to gain more insight on effective learning structure. Possible implementation of therapist's technique during conventional therapy is followed as closely as possible. All the modules were recommended to not take more than 5 minutes as ASD children are well-known for their short attention span. Important techniques possible to be adapted by the robot is as follows:

(a) Discrete Trial Technique (DTT)

ASDC can learn more effectively when there is consistency. Hence, making DTT an important technique of ABA. As explained in Chapter 2, DTT consists of three components, which is instruction, response and consequences. However, correct implementation of the techniques is crucial. Instead of just following the behavioral sequence, using DTT with the correct technique can help for effective learning. The correct technique in application of DTT can be referred to in Table 3.3.

Table 3.3 Early intervention techniques

Technique	Guidelines
Reinforcement	The reinforcement should immediately be delivered following the desired behaviour, even a slight delay could allow another behaviour to occur. To avoid from reinforcing negative behaviours, reinforcers should be delivered immediately following the correct response.
Differential reinforcement	Change degree of reinforcement according to level of accomplishment. This is called differential reinforcement because it varies with circumstances. The reason for this is that you want the child to respond to the first request.
Tone	The tone must be consistent with the message. Make sure that reinforcement sound positive and enthusiastic. When saying "no" or "try again" in the context of a lesson, tone should be neutral.
Consistency	Be consistent in what is being praised.
Label	Be specific about what is being reinforced and label it. It not only lets the child know why he is being praised, but it will help him to learn receptive labels of items or actions.
Time Delay	The time frame from instruction to child and providing prompt to help child perform intended behavior. Give child 4-5 seconds to answer correctly by themselves before giving prompts.

(b) Prompting Technique

Proper technique in applying prompts were gained from the therapists. Prompt is any assistance provided to teach target behaviour/response. It can help child learn easier and teaches target behaviour without confusion. Prompts should occur within 4-5 seconds of instruction. Every program must end with child feeling successful.

(c) Reinforcement at the end of each trial.

Rewards in terms of social praises or videos loved by the ASD children is important to keep the child motivated to learn. However, rewards must also be differentiated (refer to Table 3.4) according the child's response so that the child may learn that performing the expected behavior will provide them with a more rewarding reinforcement (differential reinforcement).

Table 3.4 Differential reward technique

Prompt Level (PL)	**Expression**	**Gesture**	**Tone/Praise**	**Video Reward**
PL0		Clap Hands up	Enthusiastic. (Exclamation mark used)	20 seconds
PL1		Clap	Less enthusiastic response. (no exclamation mark)	15 seconds
PL2		No gesture	Praises are ended with 'try' at the end of sentence to signify this is not the expected behavior.	10 seconds

3.2.2.2 System and sub-system design

The complete architecture of the system is presented in Figure 3.4. The robot is controlled using the WoZ technique. For procedure control, robot feedback decision and data acquisition, an operator/researcher will manage the supervisory controller. The technique was proved as being universal and efficient. For implementing the robot modules in this work, the Finite Automaton (FA) approach were used during the integration of all three components of interaction modules: (a)learning content (developed with ABA therapist); (b)rigid teaching structures; (c)robot's response/behavior. The main advantage of applying FA lies in its universality and efficiency in system prototyping. For this research, while the ABA technique is developed by a clinical psychologist, Dr. Ivar Lovaas, the finite structure of some ABA technique made it possible to be adapted with the Automata theory, an element from the theory of computation (TOC).

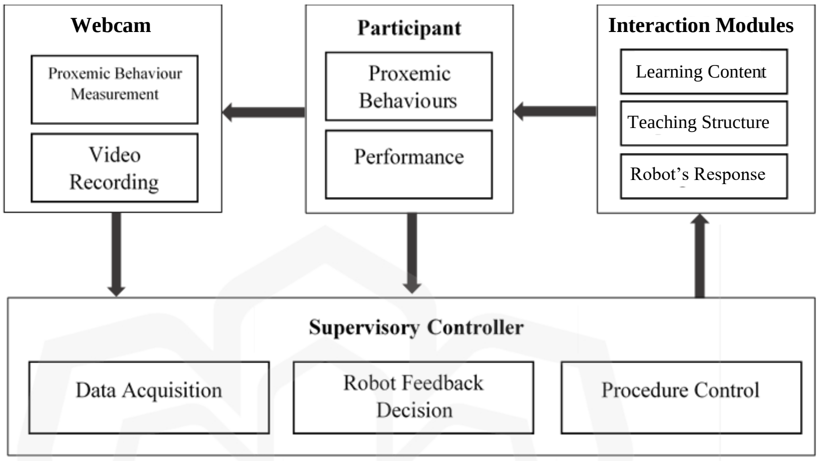

Figure 3.4 System and sub-system of the robotic platform

3.2.2.3 Robot's behavior based on FA design

Robot behavior modeling is a common task in robot software development. After the content of the module has been finalized, robot's behavior based on FA were designed. FA is a mathematical model of a system with discrete inputs, outputs, states and set of transitions from state to state that occurs on input symbols from alphabet. They are used in many domains, enabling both hardware and software applications. Generally, an FA describing robot's behavior can be defined as a 5-tuples (Eq. 1). where *Q* is a finite set of robot's possible behaviors (states), Σ is an alphabet which names the robot's superseding response, δ are transitions from one defined state to another, *qo* is the starting state (initial state) and *F* is a set of final states (accepting state). A probabilistic rt1CA (probabilistic real-time one-counter automaton – rtP1CA) is a 5-tupleP= (Q, Σ, δ, q1, Qa), where Q denotes the set of internal states, Σ is the input alphabet, not containing the end-marker symbols ¢and $, q1∈Qis the initial state, Qa⊆Qis the set of accept states, and δ is known as the transition function. We define ˜Σ=Σ∪ {¢,$}.

$$M = (Q, \sum, \delta, q_0, F) \qquad (1)$$

The flow of robot's behavior for each module is based on the use of state machines describing several robot tasks and actions. Considering that the flow must rigidly follow the ABA teaching structure requires careful design of states and state transitions. The prerequisite to the robot's behavior that complies to ABA structure and learning content, all possible states and transitions must be identified in advance, explicitly described and sufficiently structured. Different modules and tasks are described in a uniform way. Transitions among actions are modelled. Interesting idea is that the finite state automaton has both states and sub-states so it can be seen like two-levels finite automata arranged hierarchically. Each state consists of another finite automaton inside.

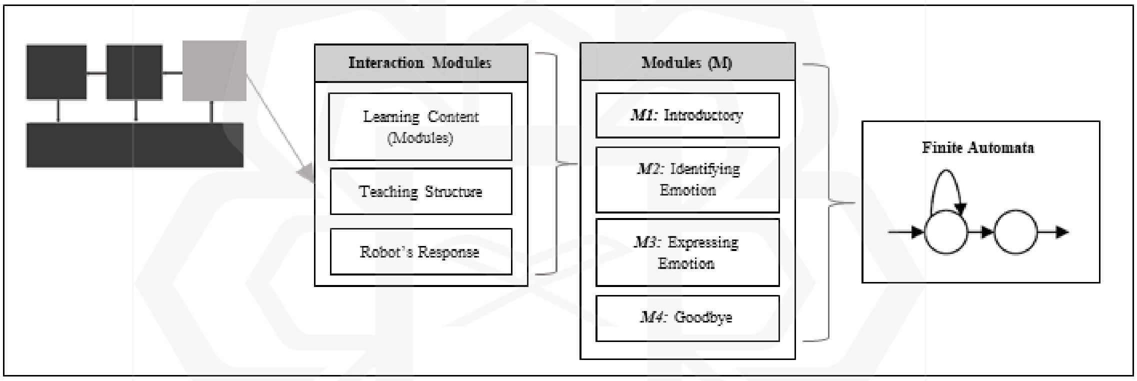

Figure 3.5 Modules developed during analysis phase converted to finite state machine (FSM)

The robotic platform in the study follows the DTT technique (Sd -> R -> Sc). This level of prompt (PL) was used to assist child and feel successful in completing the tasks. Reward given in this research is in the form of social praise, expression and gesture. As ASD children values consistency and predictability, the robot was programmed to give consistent feedback/response to the child based on their respective behavior. This is an aspect considered to be important by many therapists as this is an aspect difficult to be maintained even by an experienced therapist. The consistency by human therapist will differ according to their environment, moods or even level of stress.

3.2.2.3.1 FSM for Module 1

Module 1 were developed to gauge child's interest and comfortability with the robot. This module is crucial as it is important to ensure that the child is comfortable learning with the robot. Many things in life flow better when there is a connection and rapport between people involved, especially so with ASDC. The first connection makes a world of difference in ensuring effective learning. If the robot moves unnecessarily when ASDC is having a tantrum or meltdown, the child will have negative association with robot that may affect future learning.

This is another important ABA technique, called the OWL (observe, wait, listen) technique used during the therapy, where the therapist will first observe, wait and listen before responding. The robot will initially be static and show no expression. If the child is comfortable with the robot (no tantrums, meltdowns or unexpected behaviors), then only the robot will proceed to the next state (S2: showing expression and gestures). If the child is still comfortable with the robot, then only the robot will move to the next state (refer to Table 3.6). This module is crucial in helping child build rapport with ASDC before learning.

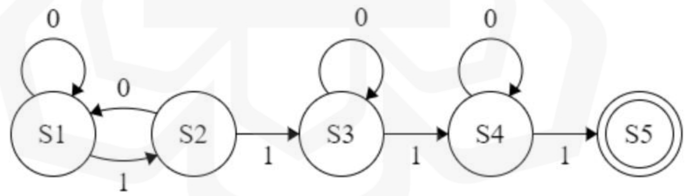

Figure 3.6 FSM for Module 1

In Figure 3.6, the bubbles represent the states, and the arrows represent state transitions. The arrow labels indicate the input value corresponding to the transition. The input is divided into two binary [0,1] where '0' represents that the child performed undesirable behavior or no response, so the robot will remain at its' current state or move to the previous state while '1' indicates that the child respond correctly and the robot will move to the next transition.

The robot's behavior for each states can be referred to in Table 3.5. For example, based on Figure 3.6, the module starts with S1 where the robot will be completely static and only show emotions (columns in which any controls or monitor were used are noted with 'x'). If the child shows desirable response, researcher will input '1' to the terminal and the robot will move state transition S2 where the robot will start showing emotions and making gestures. If the child shows undesirable response, the robot will maintain at state transition S1 where the robot remains static until child shows desirable or until the researcher/therapist decides to pull out the subject from experiment.

Table 3.5 Details for each state and transitions

States	Robot's Behavior				
	Emotion	**Gesture**	**Voice**	**Monitor**	**Notes**
S1	x				Robot will be completely static (no movements).
S2	x	x			Robot will start showing emotions and making gestures.
S3	x	x	x		Robot will introduce itself, show emotion, expression,
S4	x	x	x	x	Robot will give predictability to child by stating next activity, give expectations and give the child reward(video) to help child make positive association with the robot.

3.2.2.3.2 FSM for Module 2 and 3

Modules 2 and 3 are learning modules in which the ASDC will learn skills, and in this context, the skills learned are identifying and expressing emotions. Integrating crucial ABA technique (discrete trial technique, prompt levels, differential reinforcement) into FSM has enabled the same flow of FSM to be used for both modules and sub-modules.

This has also enabled the robot to be more predictable and consistent, something that is really valued by the ASDC.

In this module, by referring to Figure 3.7, the states are divided into two sections, simple introduction on what the child is going to learn to give child predictability (left), and conditional behaviors, in which the robot is going to transition to the next behavior dependent on the child's behavior (1 signifies if child displays expected behavior, and 0 if the child does not display expected behavior).

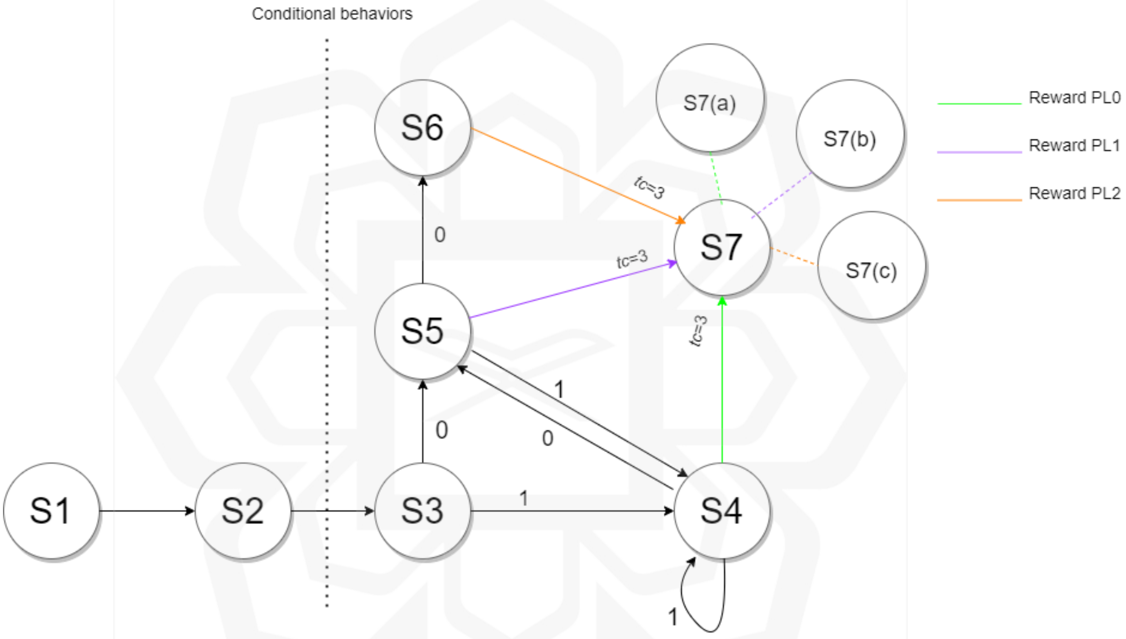

Figure 3.7 FSM for Module 2 and 3

Table 3.6 Robot's behavior for Module 2 and 3

States	Robot's Behavior				
	Emotion	**Gesture**	**Voice**	**Monitor**	**Notes**
S1	x	x	x	x	Robot to communicate to ASDC on the modules to be learned to give predictability to the child.
S2					
S3	x	x	x		Robot start asking questions
S4	x	x	x	x	PL0
S5	x	x	x	x	PL1
S6	x	x	x	x	PL2
S7	x	x	x	x	Reward

3.2.2.3.3 FSM for Module 4

This is another important module that must be done with the ASDC before stopping therapy session. In this module, the robot will say goodbye to the child, and tell the child that it is going to recharge its' battery. This is to communicate to the child that the robot is not human, and has limitations. As suggested by (Alcorn et al., 2019a), educators has doubts and worries that the child might connect too much with the robot, hence, it is important to communicate the robot's limitations. In contrast with the introductory module, the robot will decrease its' level of engagement gradually, so as to communicate with the ASDC that they will now part ways. ASDC does not deal well with changes or have things they are fond of suddenly taken away, therefore it is important to communicate and give predictability to the ASDC before ending session.

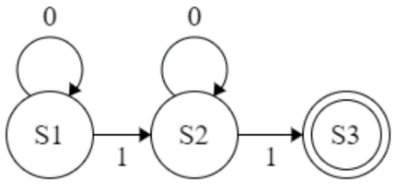

Figure 3.8 FSM for Module 4

Table 3.7 Robot's behavior for module 4

States	Robot's Behavior				
	Emotion	**Gesture**	**Voice**	**Monitor**	**Notes**
S1	x	x	x	x	Robot to reward child for learning.
S2	x	x	x		Robot to say goodbye to child, and communicate that it will need its' battery recharged.
S3					Robot will turn off its' display and show no gestures.

3.2.3 Development

3.2.3.1 Robotic Platform – QTRobot

The robotic platform used in our experiment is QTRobot (A P Costa et al., 2018) that is 58cm tall. It is a humanoid robot that looks like a toy. In the various studies that have used it, this robot was perceived by the participants as a smart, non-threatening educational tool with whom children and the elderly can positively interact. The robot has 25 degrees of freedom, which allows it to perform a variety of movements. QTRobot has been used as therapeutic and educational aides and it is widely used in SAR, particularly in acceptance studies.

To program the QTRobot’s behaviours during the early phase, in order to test the applicability and suitability of modules created in Section 3.2.2, *QTRobot IDE.* This development environment were provided by LUX AI, the robot’s own manufacturer. The interface utilizes graphical programming, using drag and drop functions, allowing programmers to easily create or follow their own modules to easily manipulate the robot’s joints or other attributes, such as its voice or LED colours. After the modules has been embedded to the robot, tested and approved by the therapist, the modules were then converted to an equivalent Python program. The Python-equivalent program were written using Microsoft Visual Studio in Ubuntu environment.

3.2.3.2 Logitech Webcam C170

Logitech C170 webcam model as shown in Figure 3.9, were used to develop the computer vision system for proxemics behavior measurement.

Figure 3.9 Webcam used to record the experimental session

3.2.4 Implementation

Implementation is the third step in the ADDIE Model. To study whether certain modules are of interest to specific groups of ASD children, diagnostic assessments (VABS-3) wee used to differentiate among the children.

3.2.4.1 Description of the subjects (Participants)

The methods section is reported according to guideline provided by (Ghasemi et al., 2019). The subjects for the analysis consisted of 20 (75% male) ASD children, with chronological age of 4-9 years old. Subjects wee recruited from IDEAS Autism Centre. The inclusion criteria for the ASD group were as follows: (1) an ASD diagnosis confirmed by a local clinical psychologist, (2) able to sit properly during learning, and (3) can understand simple instructions in English. Details of the participant are provided in Table 3.8. The VABS-3 were assessed through survey interviews with child's guardians via Google Meet orand phone call. Approval for the implementation of the study was granted by IIUM's Research Ethics Committee (IREC).

Table 3.8 Average characteristics of the twenty ASD children included in analysis

Measure	**Number of subjects**	**Mean (SD)**	**Range**
Age (months)	20	84 (19.073)	48-108
Sex			
Male	15	-	-
Female	5	-	-
Diagnosis	All participants are diagnosed with ASD by certified psychiatrist.		
VABS-3			
Adaptive Behavior Composite	20	60.73 (11.36)	39-77
Communication Domain	20	49.80 (20.95)	20-79
Developmental Score	20	61.13 (13.07)	36-81

3.2.4.2 Experimental Setup

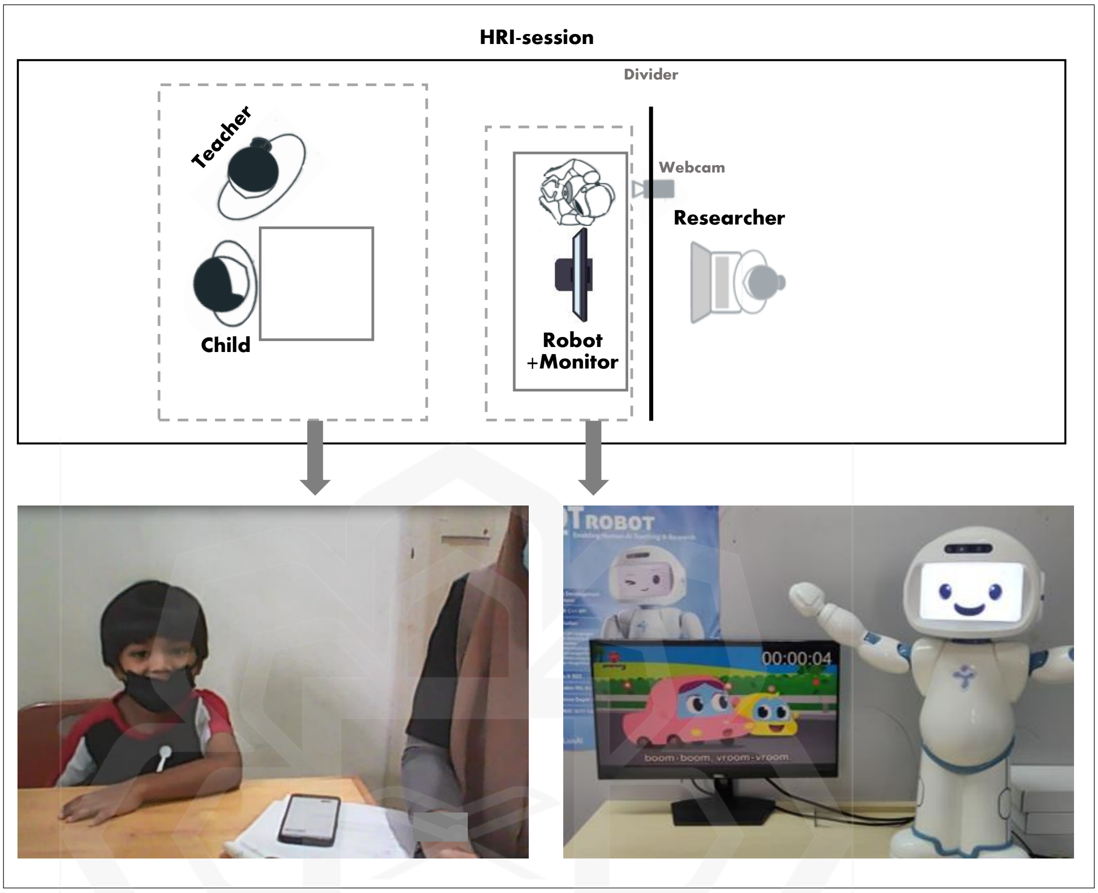

Figure 3.10 Experimental setup at IDEAS

The study were conducted at the child's rehabilitation center to reduce the effect of being in an unfamiliar place. The setup was separated into two areas: the experimental area and the operational area. All distracting and unnecessary stimuli that can affect child's attention were removed as per therapist's suggestion. The experimental area was used to conduct the task. The setup during robotic intervention is illustrated by Figure 3.10. The child sits in front of the robot placed on a small table. The height of the table is adjusted so that the robot's face can be on eye-level as the child. This setup was made to match the conventional ABA therapy setup where child needs to be on an eye-level with the interaction partner.

3.2.5 Evaluation

The interactions will be recorded using a video camera as reference. Evaluation on the efficiency of this framework will be evaluated by recording the subject's ability to complete modules and their engagement towards robot.

3.2.5.1 Completion task for all modules.

This part involves adapting partial data-taking techniques from ABA. Data were collected on the participants' performance with the robot for learning modules (matching and imitation). Plus (+) will be recorded for a correct response without a prompt, a 'p' for a correct response after a prompt (second and third level) and a minus (−) for an incorrect response without a prompt (first level only). Note that data-taking technique during ABA in human condition are much more complex than this. However, to adapt to the robot's capability, the level of complexity was reduced. The rate of completion of the modules will be compared to the child's social and communication domain score from VABS-3 to observe for correlation.

3.2.5.2 Engagement

Child's engagement during studies can be measured by using set of questionnaires (Salvatore Maria Anzalone et al., 2014; Hamzah et al., 2014; Srinivasan et al., 2016). This questionnaire is filled by the therapist on-site for each module Engagement of the child is an emotional behavioral measurement consisting of interest, affect and eye contact observation of the children towards the robot. The engagement score will be compared to the child's social and communication domain score from VABS-3 to observe for correlation. The Likert Scale and description for each score can be referred to in Table 3.9. Questions are adapted from (Ishak, Yusof, Ramlee, et al., 2019b). The questions are as follows:

1. Are the subjects happy throughout the interaction?
2. Did the child makes eye contact with the robot?

Table 3.9 Likert Scale description for the questionnaire

Score	1	2	3	4	5
Description	Poor	Fair	Average	Good	Excellent
Occurrence Frequency	Rarely occurs	Sometimes	Often occurs	Usually occurs	Always occuurs

3.3 SUMMARY

This chapter presents the process flow during framework development which includes problem analysis, interaction modules and robot design, development process, planning for implementation and framework evaluation. Four interaction modules related to teaching emotions were developed and were embedded to a commercial robot called QTRobot. The modules were first embedded to QTRobot using a drag-and-drop program before being converted to a python equivalent program in Ubuntu. The modules were designed following ABA technique and Finite State Machine theory were integrated into the technique. The robotic platform were then tested with 20 subjects from IDEA, an autistic centre in Rawang. The framework's efficiency on ASD children were evaluated from subject's ability to complete modules and their engagement towards robot throughout the session. Overview of the FSM development process can be referred to in Figure 3.11.

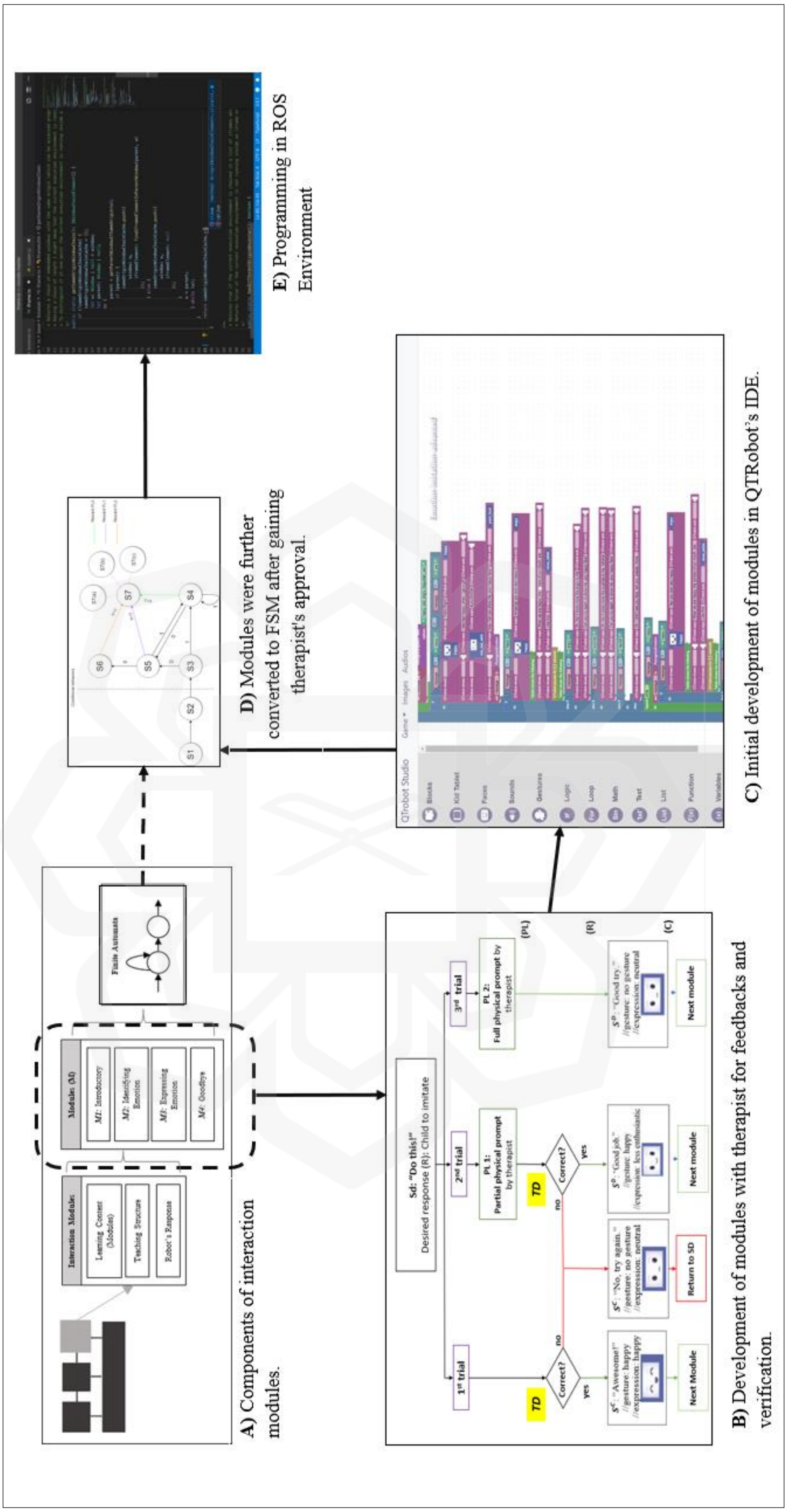

Figure 3.11 Overview of the tools used to get the final product (FSM template)

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

This chapter presents the validation and efficiency of the developed HRI platform for ASD children. To validate the developed framework, an ABA therapist were referred to. Improvements were made until final validation and tested on 20 ASD children. The experiment were conducted at the child's respective centres to avoid the ASD children having to be in an unfamiliar environment which can cause for anxiety and lead to tantrums. Task-oriented experiments, in the form of modules to be completed are carried out. Modules involve identifying and expressing emotions. Video rewards (cartoons) are reinforced frequently between each modules and trials to help the child stay motivated. Refer to Figure 4.1 for a summary of the framework developed.

Prior to the implementation of the framework on ASD children, the framework were first evaluated on typically developing adult. In two pilot studies, the module were first tested to check for the time taken to finish the module for best case and worst case scenarios. Therapists then evaluated the time taken and had advised for the modules to be shortened considering the short attention span of ASD children in which taking too long would induce tantrum from the children. In another pilot test, the framework were then evaluated based on the accuracy of the system in adapting ABA technique to the robotic framework, multiple changes in terms of the robot's behavior, tone and suitability of stimuli were done until approval from therapist is obtained. Overview of the framework may be referred to in Figure 4.1.

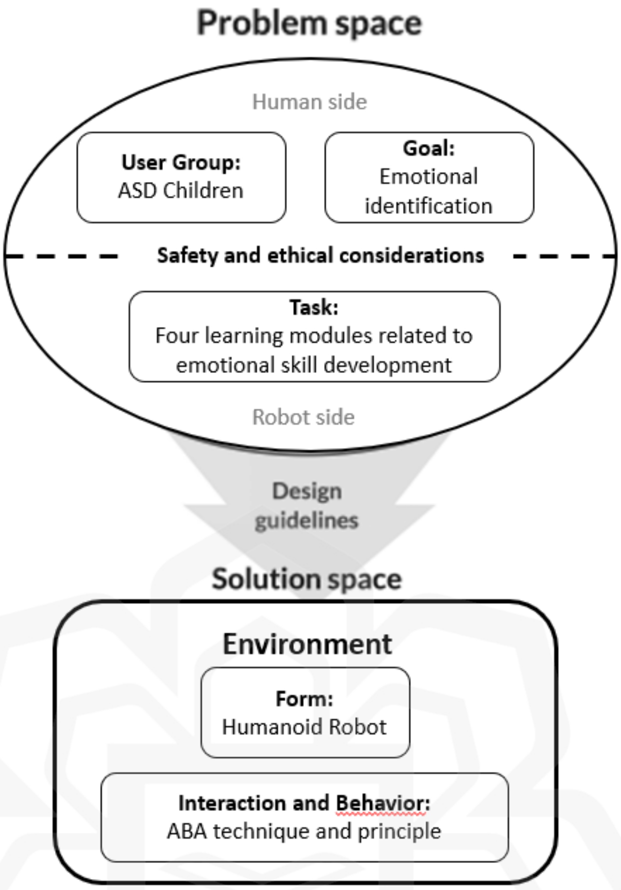

Figure 4.1 Framework design for the robotic platform, with the three phases of the design process: (1) problem statement components, (2) framework design based on ethical guidelines and consideration, and (3) integration of all components in the solution space

4.2 ANALYSIS OF RESULTS

To recap, the main objectives for all the modules is to help subjects learn about emotions which is the initial step to building social skills. The module first started with helping child learn identifying emotions and then express emotions.

4.2.1 Ethical Considerations

During the design phase of this research, ethical guidelines were also taken into consideration. Potential ethical problems and their respective solutions from both the users' perspectives and robots' end were taken into consideration (refer Figure 4.2).

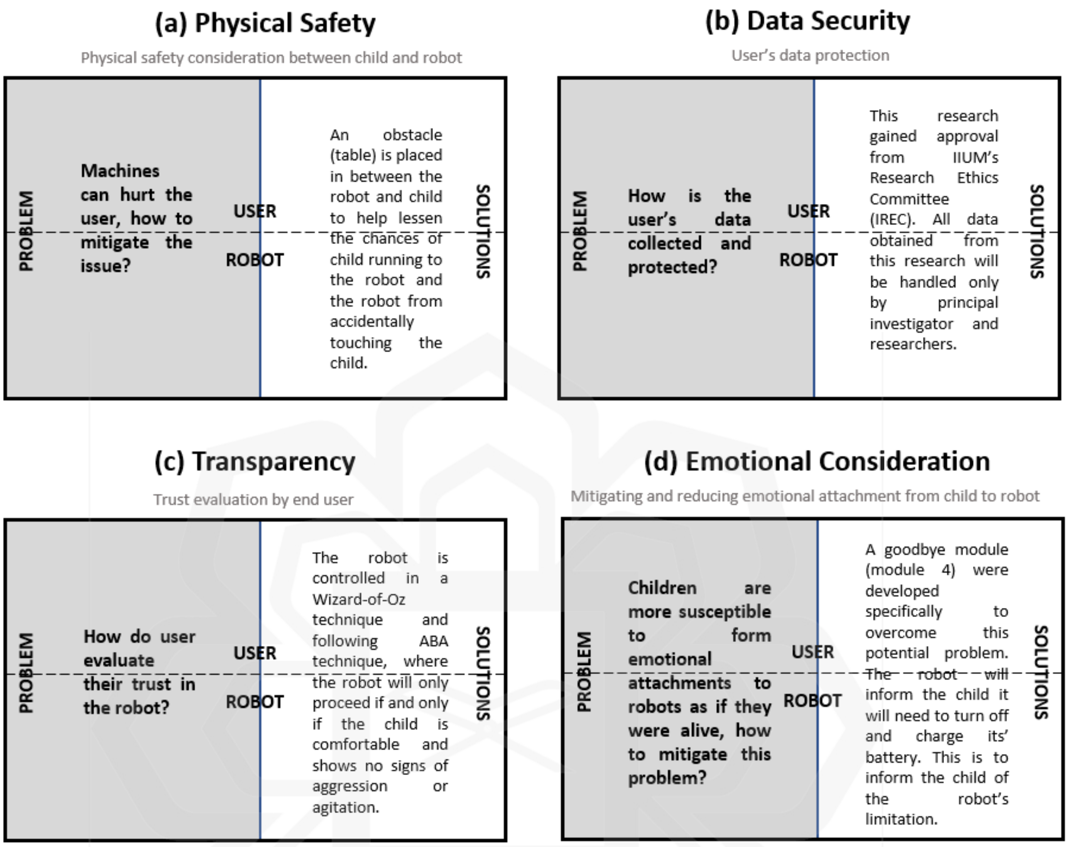

Figure 4.2 Ethical consideration design for the robotic platform involving guidelines from the perspective of: (a) Physical Safety, (b) Data Security, (c) Transparency, and (d) Emotional Consideration

By referring to Figure 4.2, four potential problems were considered. Firstly, the physical safety of the child were investigated. One potential problem that might arise is the robot accidentally touching or hitting the child during the course of the module. To help mitigate this issue, a table were placed in between the child and the robot, the child were also made sure to be more than 6 feet away from the robot at all times. By the end of the module, if the child attempts handshake or any type of touch with the robot, it is only with the therapist's permission and strict monitoring.

Data security and privacy of the child were also taken into consideration, an agreement were signed with the parents where it was agreed that data will only be handled by the principal investigator and the researchers, in any instance that video recording or photo must be used during conferences or presentations, the child's face will be censored. Users will also be able to evaluate trust to robot, however, as most the ASD children are yet capable to make informed decision on an object's trustworthiness, researchers used facial expression to gauge and control the robot's next behavior. Should the child show any signs of aggression or discomfort, the robot will not progress to the next step. A child that showed extreme discomfort to the robot were taken out of the experiment in order to not cause any physical or emotional discomfort to the child.

Lastly, emotional consideration on the attachment by the child to the robot were also considered. A goodbye module, subtly showing the robot's limitations and were developed in order to inform the child that the robot is not a human.

4.2.2 Cycle Time

The HRI-session were recorded and referred to in order to observe for interaction types initiated by the subjects. Robot cycle time is the time taken for a robot to complete one complete cycle of its programmed task. It includes both the value-added time — when the robot is moving or performing the operation — and any non-value-added wait time. However, for this research, cycle time is the time taken for each child to finish each module with the robot. Time taken to finish the module were recorded to evaluate their cycle time.

Each session lasted from 6 min 54 s to 10 min 10 s. On average, the sessions from Module 1 to Module 4 lasted 8 min 30 s (SD = 1 min 56 s). For Module 1, most subjects were likely to finish the module in less than 2 minutes as they were seen to show attention and are likely to listen to the robot's instruction.

While Module 1 were done in less than 2 minutes, Module 2 and 3 took the most time as the subjects started showing signs of discomfort during these two modules, in which for each of the module, the subjects will take an average of 3-4 minutes to finish. This is also due to some subjects starting to stand up from the chair causing for therapists to take time to instruct subjects to remain seated. Lastly, Module 4 were able to be finished in less than one minute due to subjects showing eagerness to finish the session and touch the robot.

4.2.3 Success Rate

Data were collected based on the subjects' response during learning modules (identifying and expressing emotions). Subject's response were also recorded during the introductory (Module 1) and goodbye (Module 4) modules to observe for their reaction from start to the end of session.

Plus (+) were used when subjects performed the correct response without using prompt (PL0), a 'p' is recorded when subject displays the intended response after a prompt (first and second level) and a minus (−) for an incorrect response after being prompted. Success rate is defined as the successful trials percentage (trials that helps subject perform desired response at any of the three prompt levels) out of the total trials available.

Table 4.1 Summary of modules

Modules	Target	Methods
Module 1	Introductory module	Introduction to robot.
Module 2	Identifying emotion	Robot expresses emotion and child to identify.
Module 3	Expressing emotion	Robot asks learner to express emotion learned in previous module.
Module 4	Goodbye	Robot says goodbye and wave its arms.

The experiment was participated by 20 subjects. From the 20 subjects, one subject were excluded due to from learning modules due to discomfort with robot. The subject came in the experiment room calmly but started becoming scared when sat against the robot. She managed to sit down prior to experiment albeit being restless, but started hugging the researcher and wanted to get out of the room once the robot started doing gestures. The data is recorded, and the subject scored (-) for all modules and sub-modules. Success rate were identified according to the prompt level that the subjects needed in order provide the correct response.

4.2.4 Prompt Level

To recap, prompt levels are used whenever the subjects are not able to follow robot's instructions. The prompts are divided into three levels, PL0 (no prompts), PL1 (partial prompt) and PL2 (full prompt). Based on Figure 4.3, it can be seen that most subjects are able to go through the introductory module with the robot successfully without any prompt.

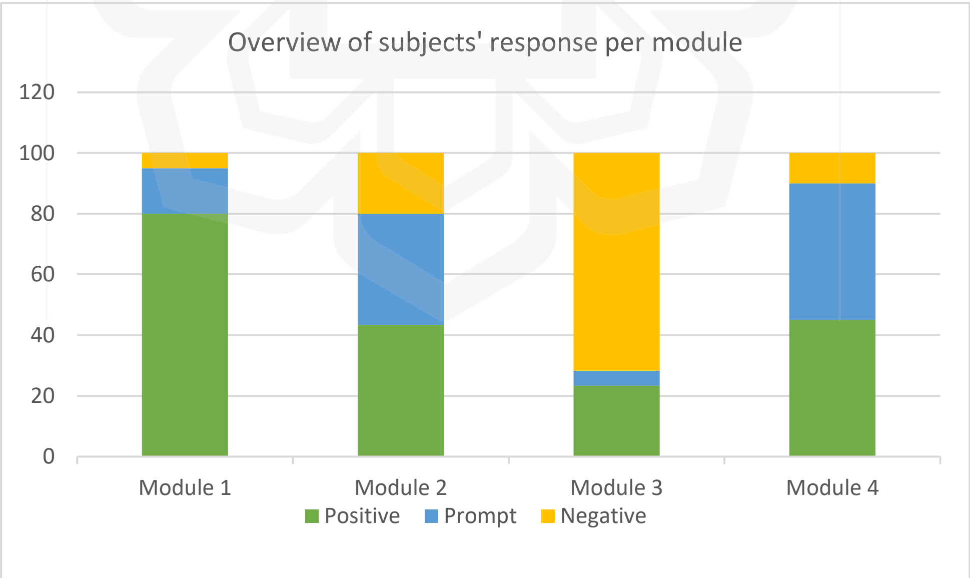

Figure 4.3 Overview of subject's response for each module throughout the session

As per stated before, one subject were pulled out of the session as he was visibly scared of the robot and another three subjects needed prompt from the teacher to continue with the session. The three said subjects were initially observed to be unable to sit still once meeting the robot. The behaviors are as recorded in the following: (1) tried to shake hands with robot; (2) leaned over the table to touch robot; (3) not focusing on the robot and tried to play with teacher.

While all the children were familiarized with the robot before starting the session, it was a limitation of this study that the children were not exposed individually with the robot but by groups. The negative response and prompts during the very first module might be able to be eliminated with longer familiarization session with the robot, and the familiarization must be done individually through a 1:1 session with the robot instead of a grouped session.

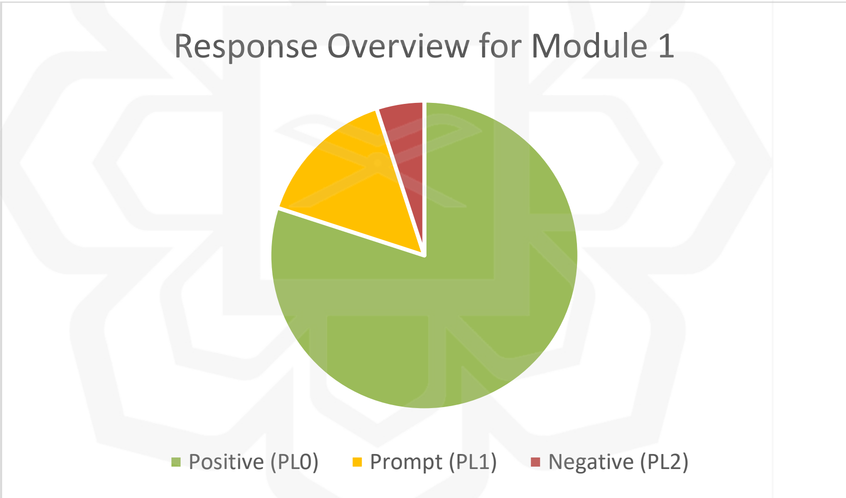

Figure 4.4 Overview of subject's response for Module 1 based on prompt level

Based on Figure 4.4, it can be seen that most of the subjects are able to follow the robot's instructions without any prompt (PL0). 80% of the subjects showed interest to the robot at first and was able to finish the introductory module while another 15% needed prompt from the therapist. One subject showed negative response toward the robot in which the child needed a full prompt from the therapist in order to proceed.

For Module 2, 43% subjects managed to finish the module consisting of 9 trials successfully without any prompts while another 36.7% needed prompts. Of the 36.7%, 4 subjects needed full prompt (PL2) to be able to respond correctly while another 2 subjects only needed partial prompt (PL1). Subjects that provided negative response even after full prompt were excluded from the next module. This is another ABA technique, where the child can only move to the next step if they are able to fully understand the foundation. In this case, identifying emotion is the foundation skill before being able to express emotion correctly. Figure 4.5 shows an overview of the response per prompt level. Module 3 was then tested on 14 subjects.

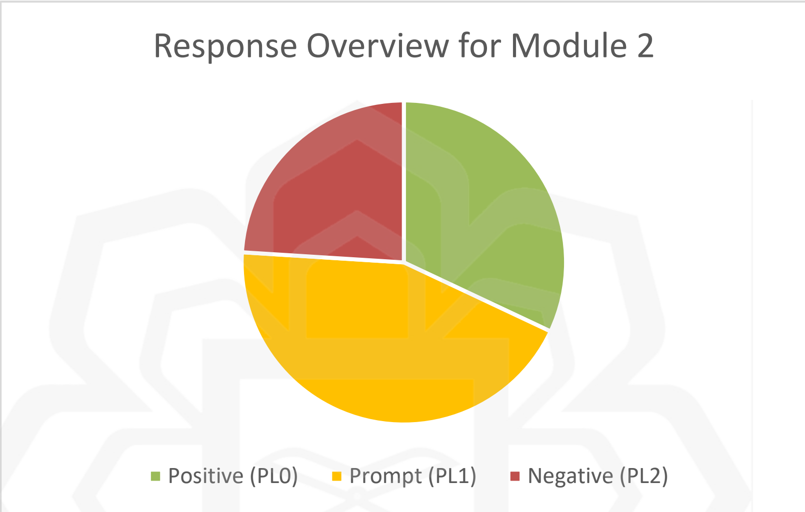

Figure 4.5 Overview of subject's response for Module 2

Based on Figure 4.3, it can be seen that the number of subjects being able to provide the correct response decreased exponentially during Module 3 and there were various observations that we can see from the subjects during this module. While some subjects are observed to be unable to follow therapists after getting full prompt due to genuinely being confused of our expected response, some subjects were simply not following the robot/therapist as they were observed to be getting restless and fidgeting throughout.

Refer to Figure 4.6 for a complete overview of the response per prompt level. Based on the figure, it can be seen that less than a quarter of the subjects were able to finish the module without prompt. The red bar in the pie chart indicates subjects who were not able to finish the module without full prompt. Suggestions and comments from therapists were sought to discuss the potential cause of this outcome.

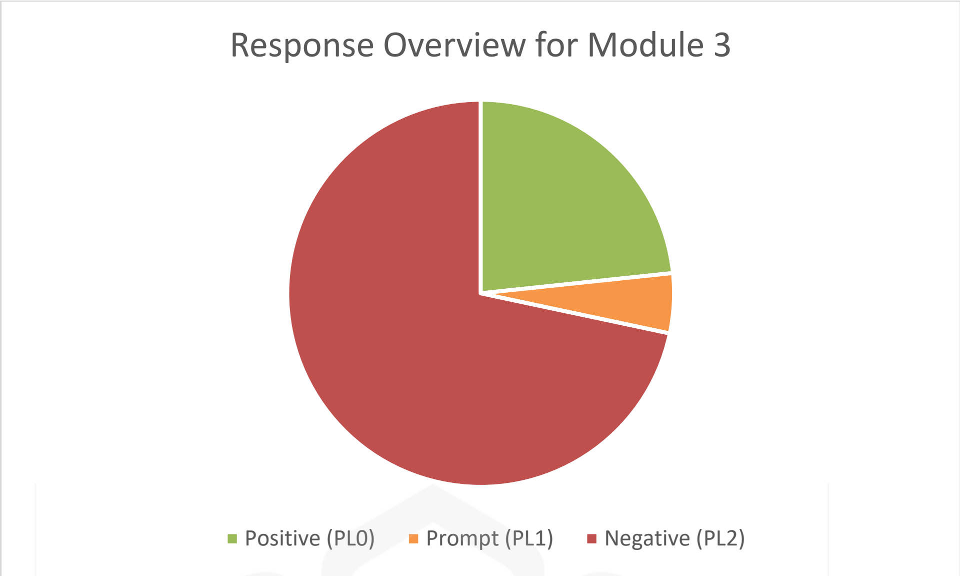

Figure 4.6 Overview of subject's response for Module 3 based on prompt level

The therapist commented that this could be due to the child getting bored of the session (Module 3 started at an average of 5.3 minutes mark after Module 1), and possibly due to the robot's movement that could be quite slow. Only 4 subjects were able to complete Module 3 without prompts, 5% needed prompts while the other 46.7% were not able to complete the module.

To recap, even subjects that were not able to finish Module 2 still went through Module 4 (saying goodbye to robot). Module 3 were skipped and the robot will go straight to Module 4. Module 4 took place at an average 7 minutes mark of the session and mixed reactions were observed from the subjects. 45% of the subjects managed to say goodbye properly to the robot and attempted handshake with the robot. They remained enticed and attentive towards the robot throughout the session. Another 45% needed prompt to stay through Module 4. Of these 45%, some were no longer listening to robot's instruction and we needed help from the therapist to replace robot in giving instructions, some were noticeably restless. Another 10% gave negative response even after being prompted by robot and teacher (attempted to escape/not sitting properly). Refer to Figure 4.7 for complete overview on response based on prompt level.

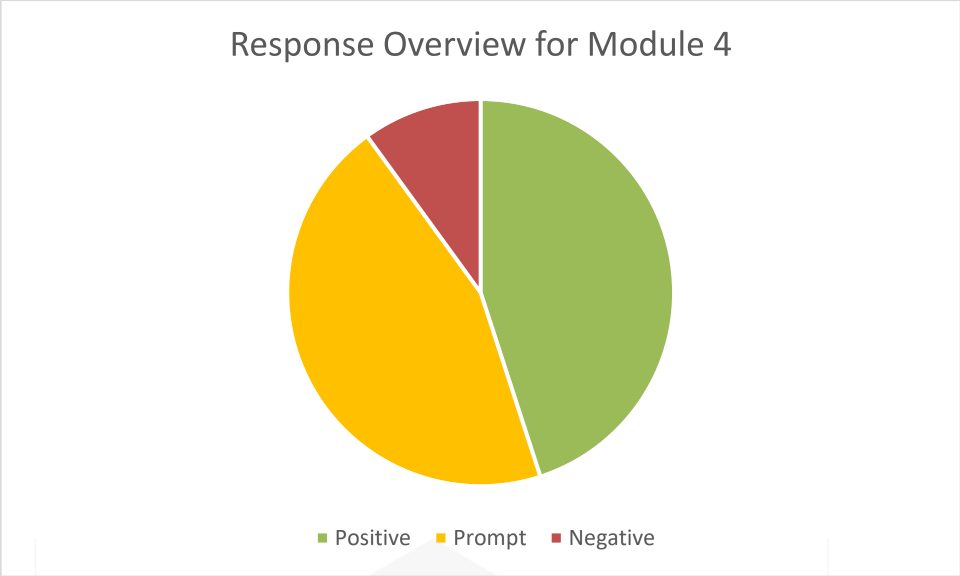

Figure 4.7 Overview of subject's response for Module 4 based on prompt level

Figure 4.3 had showed that the subjects showed more negative response (not able to answer correctly) towards Module 3, this could be due to the module's increase in difficulty, as it requires subjects to express emotions. ASDC are also well known for their short attention span and difficulty maintaining focus, the total time taken to finish all the modules could also lead to this. This observation was expected before the research was done, which was why rewards were given frequently after each trial. However, it was found that this does contribute to increase in subject's focus.

Subjects were found to only be motivated during the video reward and immediately loses their motivation and focus after the video reward ended. As the average time taken for subjects to finish the session is 8 min 30 sec and it was observed that subjects started getting restless by the third module, future research should consider reducing the cycle time by half.

4.2.5 Engagement

Scores obtained are represented using boxplots to see their spread for each module. Child's engagement during studies can be measured by using set of questionnaires (Salvatore Maria Anzalone et al., 2014; Hamzah et al., 2014; Srinivasan et al., 2016).

This questionnaire is filled by the therapist on-site for each module. Engagement of the child is an emotional behavioral measurement consisting of interest, affect and eye contact observation of the children towards the robot. To recap, the Likert Scale and description for each score can be referred to in Table 4.2. Questions are adapted from (Ishak, Yusof, Ramlee, et al., 2019b). The questions are as follows:

1. Are the subjects happy throughout the interaction?
2. Did the child makes eye contact with the robot?

Table 4.2 Likert Scale description for the questionnaire

Score	1	2	3	4	5
Description	Poor	Fair	Average	Good	Excellent
Occurrence Frequency	Rarely occurs	Sometimes	Often occurs	Usually occurs	Always occuurs

Figure 4.8 shows a boxplot of subject's engagement with robot throughout the session. Based on the boxplot (SD= 0.9987-0.997), we can see that most subjects started out being really engaged with the robot, and the frequency of eye contact with robot is good. However, as the module progresses, and as per stated in the previous section, the engagement and frequency of eye contact started decreased gradually from Module 1 to Module 4. The outliers in Module 1 (represented as asterisk) were the score given to the subject who were visibly scared of the robot. During Module 3 and Module 4, the outliers represented subjects who remained engaged with the robot.

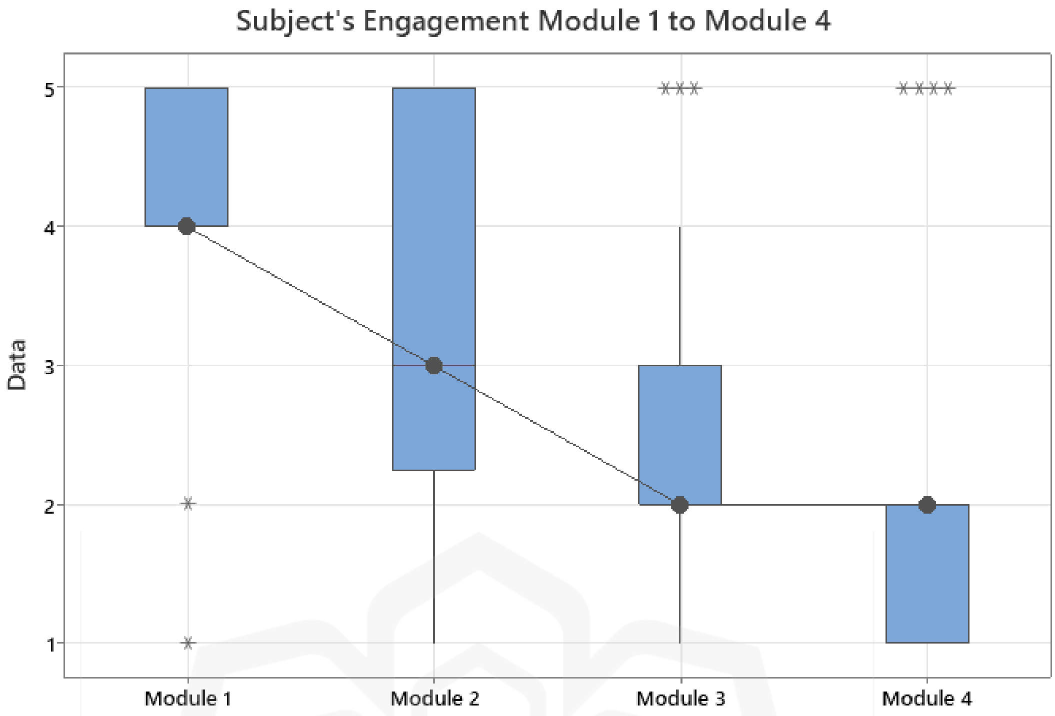

Figure 4.8 Subject's engagement with robot throughout the session

This significant reduce in engagement by the end of the session, can be due to the session's long cycle time for each module, the robot's cycle time and content of module/reinforcement. As per discussed in the previous paragraph, subjects were observed to show a significant reduce in engagement and were not able to display desired behavior in Module 3. Therapist mentioned that a possible contribution to this is due to the robot's slow movement and the long cycle time to finish session (Average: 7 min 20s).

The robot's cycle time is the time taken for a robot to complete the task that it has been programmed with. In this research, this includes three component: (1) the user-added time where the robot waits for child to perform task, (2) the value-added time — when the robot is moving its' body to run the programmed module, and (3) any non-value-added wait time where child starts to lose focus and time were consumed when therapists has to instruct subjects to return to their seat and finish the module.

Research has shown that lower cycle times with ASD children can result in a more effective learning session as their attention span is very limited. The longer the cycle time, the more the subject loses focus causing for an ineffective session. It was found that subjects started to become restless during the value-added time, when the robot is moving its' body. It is advised for future researchers to use a robot that are able to move its' motors in an increased speed as QTRobot's slow motor movement were found to increase waiting time for the subjects. It is recommended for future research to lessen the experiment time as ASD children has short attention span.

In order to ensure the module to be interactive, the robot should also have a clear recorded audio. The intonation of the audio also needs to be suitable for each type of conversation to attract the attention of the children. The pitch of the recorded sound cannot be too high or low because most of ASD children have a sensitive hearing condition. This may lead them to cover their ears and do not cooperate well with the robots.

The significant reduce in engagement during Module 3 could be due to the differences in the developmental age in the subjects who participated. The subjects included in this study, while they are of similar physical age, the developmental age between the participants was found to have a huge gap between each other. It is recommended for future studies to recruit subjects and design the modules according to their developmental scores, so that the data and correlation made can be more valid. The relationship, or effects of huge gap in physical and developmental age can be referred to in Figure 4.9.

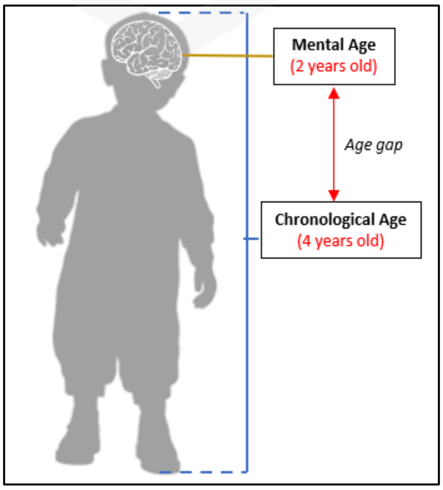

Figure 4.9 Relationship between developmental and physical age

The age gap between the developmental and physical age can cause developmental delay (Mhatre V. Ho, Ji-Ann Lee, 2012). The larger the age gap between developmental and physical age, the more severe symptoms of autism present in ASD child. To recap, one main goal of therapy is to reduce this age gap. Demographic of the subjects can be referred to in Table 4.3.

Table 4.3 Average characteristics of subjects (ASD children)

Measure	**Number of subjects**	**Mean (SD)**	**Range**
Age (months)	20	84 (19.073)	48-108
Sex			
Male	15	-	-
Female	5	-	-
Diagnosis	All participants are diagnosed with ASD by certified psychiatrist.		
VABS-3			
Adaptive Behavior Composite	20	60.73 (11.36)	39-77
Communication Domain	20	49.80 (20.95)	20-79
Developmental Score	20	61.13 (13.07)	36-81

4.3 SUMMARY

The first module showed that most subjects are able to go through the introductory module with the robot successfully without any prompt. 43% subjects managed to finish the second module consisting of 9 trials successfully without any prompts while another 36.7% needed prompts. There was a significant difference in response during module 3, where only 4 subjects were able to complete Module 3 without prompts, 5% needed prompts while the other 46.7% were not able to complete the module. All subjects participated in Module 4, 45% of the subjects managed to say goodbye properly to the robot and attempted handshake with the robot. They remained enticed and attentive towards the robot throughout the session. Another 45% needed prompt to stay through Module 4.

The difference in engagements and attention by subjects from Module 1 to Module 4 were due to the module's cycle time. Although mixed results were obtained on the efficiency of the system, we believe that the basis of this research, the FSM template developed can be used by future researchers to improve the FSM we used using efficiency testing from this study. FSM will enable works in this field to be easier to iterate and replicate technically and reduce the time taken to research ASD from the clinical side. Overview of the complete framework design can be referred to in Figure 4.10.

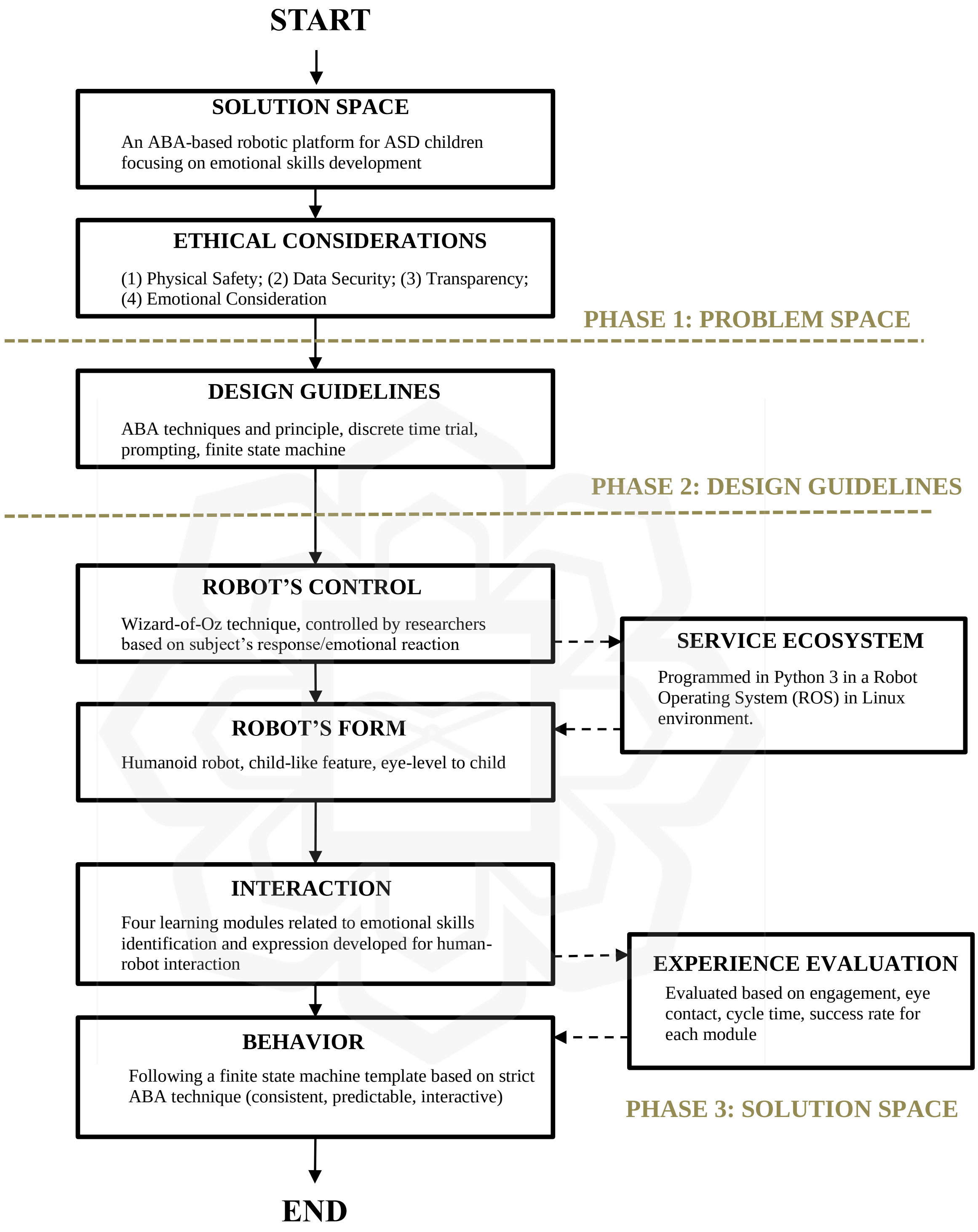

Figure 4.10 Overview of framework developed and evaluation method

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The main aim of this research is to facilitate ASD children in improving their social skills using robot as a medium of interaction. develop a framework of Human-Robot Interaction (HRI) based on Applied Behavioral Analysis (ABA) technique for ASD children. Details on the research objectives' completion are described as follows.

The first objective of this research is to investigate the characteristics of robots effective for human-robot interaction (HRI) session in ASD children (RO1). Based on literature survey done, best characteristics for robots include - mobile, humanoid form, child-sized, interactive, easily programmed, robust and attractive. Robots must be able effectively engage with the children. QTRobot were chosen as it complies to features needed while also being cheaper than its' competitor, NAO.

Next, second objective is to develop and integrate framework for HRI session based on ABA technique into Finite State Machine (FSM) method for robot's control. (RO2). Framework includes - interaction modules, test subjects, robotic platform and evaluation methods. Modules tested are 1) introductory, 2) identifying emotions, 3) expressing emotions and 4) goodbye module. The subjects include are between 4-9 years old. The modules were first embedded into QTRobot by using a drag-and-drop program and were only converted to a Python-equivalent program after the flow of modules were validated and improved by the therapists. This objective is successfully achieved as a verified ABA module that can be used as a template for future researchers were developed and converted into FSM. FSM will enable works in this field to be easier to iterate and replicate technically and reduce the time taken to research ASD from the clinical side.

Finally, the third and last objective of this research is to **e**valuate efficiency of the HRI framework on ASD children by verifying and validating the developed framework from ABA therapists and ASDC's engagement to robot (RO3). Framework developed were designed alongside an ABA therapist. Multiple improvements in terms of total cycle time, robot's speech, dialogue, reinforcement and setup were made before the approved modules were tested with ASD children. For first module, it can be seen that most subjects are able to go through the introductory module with the robot successfully without any prompt. For module 2, 43% subjects managed to finish the module consisting of 9 trials successfully without any prompts while another 36.7% needed prompts. The third module showed a significant difference in response, where Only 4 subjects were able to complete Module 3 without prompts, 5% needed prompts while the other 46.7% were not able to complete the module. All subjects went though Module 4, 45% of the subjects managed to say goodbye properly to the robot and attempted handshake with the robot. They remained enticed and attentive towards the robot throughout the session. Another 45% needed prompt to stay through Module 4. The final objective were successfully achieved as the HRI platform were tested on 20 ASDC. Although mixed results were obtained on the efficiency of the system, we believe that the basis of this research, the FSM template developed can be used by future researchers to improve the FSM we used using efficiency testing from this study.

5.2 LIMITATION

There are a few limitations of this research that can be improved and used as a reference for future researchers to not repeat the same mistake. The limitations are described in this section. Firstly, the research utilized a webcam that is placed on top of the robot. The recording of the video was important as a reference for therapist and the researcher to analyse the efficiency of the research. However, the webcam's low resolution has sometimes made it difficult for the researcher and the therapist to gauge correctly the subjects' comfortability, eye gaze and reaction to the robot as the video/image captured is blurry.

Next, as the study is quantitative, an adequate sample size is very important to ensure the validity of the study. However, major difficulties were faced during data acquisition. The first challenge was obtaining mandatory consent from the guardians of subjects during Movement Controlled Order (MCO). Some parents were reluctant to give consent and communications difficulty has caused for some delays in the project completion. Second challenge was getting cooperation from the ASD children, some were visibly afraid of the robot. Thirdly, limited time for data collection had caused for the researcher to be unable to do improvements and retest.

Finally, ASD Children are famous for their inability to maintain focus for long, while some of them are visibly engaged with the robot to the end of experiment, some also lost focus in the middle of the experiment, possibly due to the length of time it took to finish all the modules.

5.3 RECOMMENDATION AND FUTURE WORK

Based on this research and its' limitations, some recommendations can be made for future projects. Firstly, it is recommended to have an earlier introductory session between the robot and the children. This is a very important aspect in dealing with ASD children, ASD children are very sensitive with unfamiliar people. Thus, having the subjects feel comfortable during the experiment can help researchers obtain a more accurate result. Before experiment, it is recommended to create a rapport with the subjects, both with researchers and the robot. Researchers are advised to spend some time with the subject, and to make sure it does not appear to be a learning session, but rather a play-time session with the robot so that the child can create positive association with the robot.

As per discussed in Chapter 4, it was observed that most subjects failed to show a positive response in Module 3. It was hypothesized that this is due to the robot's slow movement and the long cycle time to finish session (Average: 7 min 20s). It is recommended for future research to lessen the experiment time as ASD children has short attention span.

In order to ensure the module to be interactive, the robot should have a clear recorded audio. The intonation of the audio also needs to be suitable for each type of conversation to attract the attention of the children. The pitch of the recorded sound cannot be too high or low because most of ASD children have a sensitive hearing condition. This may lead them to cover their ears and do not cooperate well with the robots.

Due to limitation of time to do testing and screening of developmental age, it was also a limitation of this study that subjects tested vary in their developmental age. It is recommended for future studies to recruit subjects and design the modules according to their developmental scores, so that the data and correlation made can be more valid.

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