Design and Development of HRI-based Intervention for ASD Children using ADDIE Model and ABA: A Preliminary Study

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Abstract

The growing interest in Human-Robot Interaction (HRI) based early intervention therapies for autism spectrum disorder (ASD) children brings about the prospect of adapting this platform as assistive tool during therapy. Though this field has garnered myriad of attention, more research is needed in developing systematic design for human-robot interaction using standardized process models. One of the most well-established systematic process models in developing instructions is the Analysis, Design, Develop, Implement and Evaluate (ADDIE) model. While the ADDIE model was used to design the interaction during the first phase, Applied Behavioral Analysis (ABA) technique, an evidence-based practice for ASD children were also integrated into our modified model. This preliminary study discusses three subjects: 1) guideline in adapting ADDIE model for HRI-based ASD intervention, 2) a preliminary modified ADDIE model for human-robot interaction with ASD children and 3) robot's behavior integrated with ABA technique. Preliminary evaluations on the developed framework were done by a therapist with experience working with ASD children on the severe end of the spectrum.

Keywords

Autism Spectrum Disorder, ASD, Human-robot interaction, HRI, Applied Behavioral Analysis, ABA

1. Introduction

Autism Spectrum Disorder (ASD) is a pervasive neurodevelopmental disorder that is characterized by difficulties with social and communicative skills, restricted interests, repetitive behavior, and sensory issues [1]. Current prevalence data estimated that 16.8 per 1,000 (one in 59) children aged eight years in 2016 has autism. This is approximately 2.5 times higher than the first ADDM Network ASD prevalence estimates of 6.7 (one in 150) from 2000 and 2004 [2]. As there are no known medical cure for ASD, main method for interventions are focused on behavioral modifications such as Applied Behavioral Analysis (ABA)[3], TEACCH Autism Program [4], LEAP [5] and Sensory Integration Therapy [6].

This has also caused for increasing popularity in utilizing technologies, especially robots as assistive tools for educators/therapies during therapy. Although there are various robotic platforms available, studies on ASD children in this domain usually focuses on humanoid robotic research [7] due to their ability to mimic, behave and interact like a human. Educators also assumed that ASD children will be able to generalize skills learned with robots due to their consistent predictability and human-like features [8]. However, as many studies are still focusing on robots' technologies, more research is needed in systematic Human-Robot interaction (HRI) development using process models. This step is important in ensuring HRI-based interventions are accepted as an evidence-based practice (EBP) by the clinical community.

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In instructional design community, the Analysis, Design, Develop, Implement and Evaluate (ADDIE) model is one of the most widely used systematic process model. There are five elements to ADDIE model: analysis, design, develop, implement, and evaluate. This method was chosen as the five elements are ongoing activities that continue throughout the process. The process can be referred to in Figure 1. Clear and effective intervention programs can be designed using this method. Although it is originally developed to be hierarchical, it can also be tailored to be a continuous 'iterative' approach. The first five phases are followed in order, then, once complete, the data obtained can be used as a guideline and researchers may restart from the analysis phase, improving the final product. Considering that HRI-based intervention requires continuous rigorous tests and evaluation, the systematic nature of ADDIE process model can be applied to the HRI-based intervention for future performance improvement.

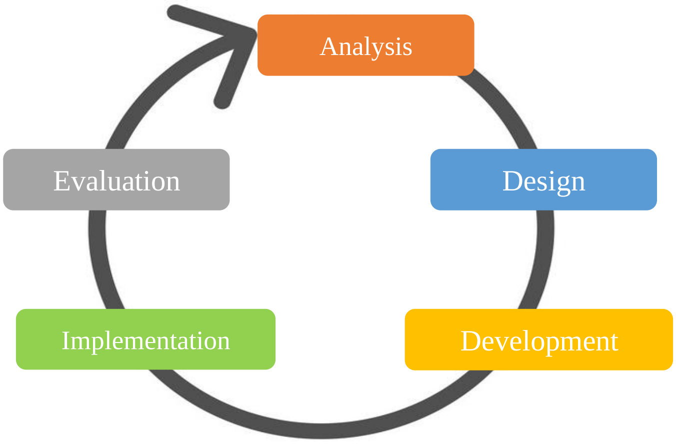


Figure 1. The ADDIE model.

While the ADDIE model was used during development and design of the research, Applied Behavioral Analysis (ABA) technique were used to program robot's behavior. This is to ensure the robot is predictable and consistent, which is important in effective learning for ASD children. ABA is based on operant conditioning where consequences influence behavior. The first step in ABA clinical practice is to perform mental/developmental assessments for ASD children (ASDC) in determining the baseline and appropriate goals for each individual. The step is followed by the development of a clear intervention plan which includes clearly defined procedures for instruction, error correction, prompt levels, reinforcement, and performance data collection. Our project proposes on the development of HRI-based intervention by utilizing the systematic ADDIE model during research development and building framework for robot's behavior using ABA's core technique.

2. Human-Robot Interaction (HRI)

HRI is an interdisciplinary study of interaction dynamics between humans and robots [9]. HRI has been recognized as a new probable approach in the research on autism research. It is the changing relationship between intelligent robots and humans, which are done through social interaction. HRI can be described both by the user's behaviors and by the role of the robots during the therapy session. The goal of HRI for ASDC involves encouraging imitative behaviors, mediating turn-taking, extracting referencing and enhancing joint attention between ASDC and another human.

2.1. Robots for ASD children

As mentioned in many studies, the use of HRI for ASDC is not to replace therapists, but the main aim is to successfully integrate robot into a normal therapy as a mediator between therapist and ASDC [10,11]. Based on previous literatures, various types of robot were used.

The robots are generally used to improve foundational skills such as imitation (I), joint attention (JA), social (S) and other (O) skills. Other skills taught by the robot include reading, comprehension, and literacy skills. Example of robots used in the earlier studies, and the skills targeted can be referred to in Table 1.

Table 1. List of current robots used and the skills targeted.

Robot	JA	S	I	O	Studies
NAO	/	/	/	/	[12–17]
Pleo		/			[18]
Probo	/				[11]
QTRobot	/			/	[19]
Zeno	/		/	/	[20–22]
RoboParrot			/		[23]
TurtleBot				/	[24]
Popchilla		/			[25]
IROMEC				/	[26]

3. The ADDIE Model

ADDIE model is the most common model used in instructional field design. This is due to it being generic enough to create any type of learning experience for many learners. Although this model is usually used by training instructors, we believe the model can be modified according to ASD children's needs. The systematic nature of this model may help facilitate researchers in the HRI and ASD domain to move in the correct direction. The model comprises of five phases as shown in Figure 1. Each phase is critical as the researcher must make crucial decisions after thorough analyzation to deliver an effective training/intervention. Figure 2 defines each phase of the model. The entire intervention can be designed thoroughly by following the guideline. ADDIE model for HRI were referred from [27] and were further improvised to suit our research objectives.

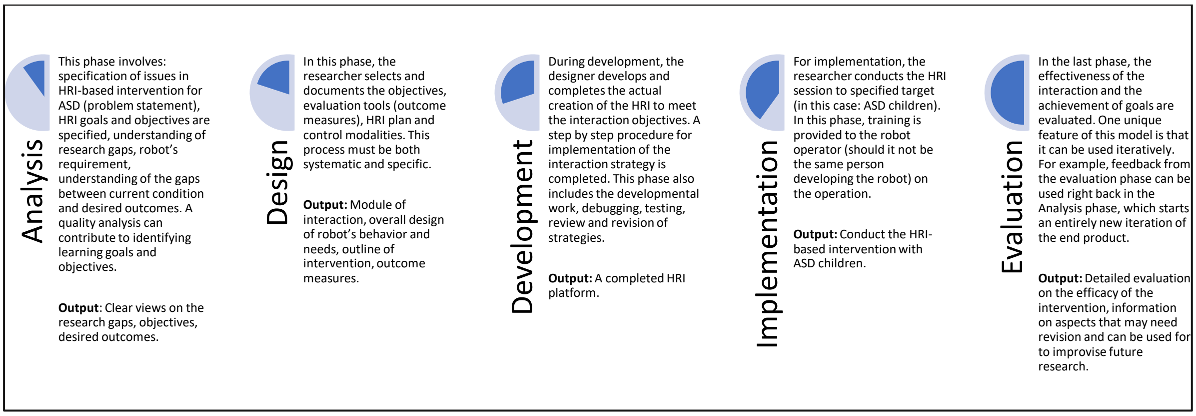


Figure 2. Details for each elements/phase in the ADDIE model.

3.1. Applied Behavioral Analysis (ABA)

ABA is based on operant conditioning where consequences influence behavior. The first step in ABA clinical practice is to perform assessments in determining the appropriate goals for each individual using several tools such as the Verbal Behavior Milestones Assessment and Placement Program [28] and Vineland Adaptive Behavior Scale [29]. Assessment is then followed by the development of a clear intervention plan which includes clearly defined procedures for instruction, error correction, prompt levels, reinforcement, and performance data collection.

3.1.1. Teaching Technique (Discrete Trial Training)

ABA approach uses discrete trial teaching (DTT) to teach skills. Discrete trials or the three-part teaching unit is a special behavioural sequence used to maximize learning. DTT is used to make teaching session clearer, let the child know when he/she is right or wrong, helps teacher maintain consistency and makes assessment of progress simpler [30]. Operant conditioning implies that a behaviour that results in something that is liked (reinforcement) will be repeated [31]. As reinforcer is something that is liked by ASDC, the reinforcers are a critical tool to be embedded in ABA program. The reinforcers are given as consequence whenever the child respond correctly. Figure 3 shows the sequence of DTT and its' component.

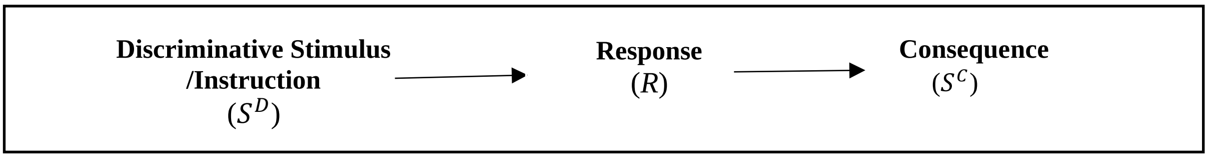


Figure 3. Components of DTT.

3.1.2. Prompting Techniques

As shown in Figure 3, prompting is a means to induce an individual with added stimuli (prompts) to perform a desired behavior. Prompting is provided when an ordinary antecedent is ineffective and is extensively used in behavior shaping and skill acquisition. It provides learners with assistance to increase the probability that the desired behavior will occur. Successful performance of a desired behavior elicits positive reinforcement, therefore reinforcing learning. A prompt is used as a cue to support and encourage a desired behavior that otherwise does not occur.

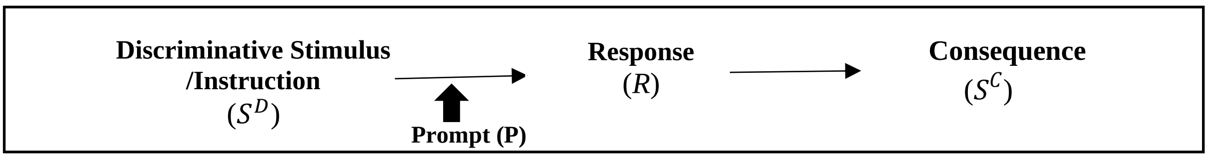


Figure 4. Prompting as part of DTT.

3.1.3. Application of ABA in HRI

Existing literatures were reviewed to identify studies that adapted ABA technique into HRI applications in the past. There are a few techniques that have been frequently used by researchers in the past which are reinforcement (R), prompt levels (PL) and discrete-trial teaching (DTT) technique. Results may be referred to in Table 2.

Table 2. ABA-based HRI studies.

Studies	Robot	R	PL	DTT
[32]	NAO	/		
[33, 34]	NAO	/	/	
[7,33,35]	NAO	/	/	
[36]	PABI	/		
[37]	NAO	/	/	
[38–40]	NAO	/		/
[41, 42]	NAO	/		/
[43]	KASPAR	/	/	
[44]	KASPAR	/		/
[45]	ReRO	/		
[46]	NAO	/	/	/

All studies reviewed applied the reinforcement technique (reward). The reward can be in the form of social praise ("Good job!", "Well done!") or music played by the robot. Prompt levels are also one of the most applied ABA techniques. If the child answered wrongly, the robot will ask the child to try again and prompt will be provided. DTT is a structured teaching technique used to help ASD child learn effectively. However, there are more to DTT than following the special behavioral sequence. An effective DTT must follow the correct technique in terms of differential reinforcement, intonation, and timing. [47] focused more on how to use social stories and visual schedule instead of using those two techniques in a therapy.

4. Preliminary output based on ADDIE model.

4.1. Analysis Phase

In this phase, our focus lies on analyzing and identifying test subjects to determine interaction goals and learning context. More precisely, we assessed the developmental age of the children by using Vineland Adaptive Behavior Scale (VABS-3) to determine suitable module of interaction. Having a clear view on the baseline of each child is important as no ASDC is the same and their chronological age does not necessarily determine their developmental/mental age. Knowing the baseline can guide decision for the next phase and provide realistic approach for the intervention. Therefore, all available information on the ASD children from a center in Malaysia were identified. Three main issues that were analyzed in this phase include:

a) Selection of center

Due to the movement-controlled order (MCO) imposed by Malaysian government during the period of this study, a center for ASD children located near the university were chosen. This issue has limited the sample size of this study.

b) Target age of ASD children

In the center chosen, although all ASD children were diagnosed with ASD, no records on their exact developmental age were available. Therefore, help from the clinical team were obtained to administer VABS-3 to the children. While this center consists of child aged from 4-9 years old, only child with physical age 6-9 were selected as participants. Participants went through VABS-3 assessment and developmental age for all participants were obtained.

c) Selection of robot

Existing literatures were reviewed to obtain the most optimal robot suitable for ASD children. Studies in HRI for ASDC combines both robotic and clinical teams, therefore buying a commercial robot is the better choice to bridge this gap [18]. Besides, parents, clinicians and teachers can easily buy and customize the robot for certain needs due to the availability of the robot in the market. To summarise, commercial robots have more advantages in terms of cost, robustness, and their lower failure rate. During selection phase, recommendations from previous studies were adapted for inclusion criteria. Some commercial robots that have been shortlisted are Bioloid, DARWIN, NAO and QTRobot. However, for this study, Bioloid and Darwin were eliminated due to its small size (39.7cm and 45.5cm respectively). As our target audience are ASDC aged 6-9 years old, robot with a similar size with the child will be used. This is so that the child can see the robot at his or her eye-level. In addition, imitation tasks are intuitively easier for ASDC to follow compared to using robots that are extremely large or small in size [48]. The robot must also be easily integrated into the existing therapy framework and agenda (objectives, setting, timing, etc.). To conclude, the selection criteria for the work are as follows: (a) The robot must be easily programmable by therapists (has block-based coding); (b) Has developer mode for researchers to embed a more complex program using programming languages such as Python/C++/Java; (c) Able to display facial expressions, changes in emotional expression in the robot must be able to be subtly observed. Although both NAO and QTRobot has almost the same features, QTRobot was chosen because of its' ability to subtly show emotional expression. The importance of this aspect is discussed in the next sub-section.

4.2. Design Phase

In this phase, learning objectives were defined and modules of interactions were also constructed. Based on our preliminary VABS-3 assessment, most of the participants were mostly lacking in the social domain. Therefore, learning objectives and modules of interaction were designed to focus on learning emotions as it is an important aspect in building social reciprocity.

Table 3. Modules of interaction developed based on findings from analysis phase.

Modules	Methods	Objectives
Introduction	Robot slowly starts movement according to child's response and one-way communication using voice recognition.	To measure robot's approachability and create a friendly environment for the child during interaction.
Module 1 (Identify emotion)	Robot will perform simple actions and child are expected to imitate.	To assess child's engagement with the robot and child's ability to listen to robot's instruction.
Module 2 (Express emotion)	Robot asks the learner to identify the picture that is the correct match of a sample picture.	
Goodbye	Robot says goodbye and wave its arms. Thanks child and attempts handshake.	To communicate robot's limitation to the child.

4.3. Development Phase

4.3.1. Robotic Platform (QTRobot)

QTRobot is a 58cm tall humanoid robot that is. QTRobot Studio were initially used to program QTRobot's behaviours. QTRobot Studio is a development environment provided by the robot manufacturer, LUX AI. The interface is mainly drag and drop, and allows the programmer to create a sequenced combination of predefined or custom behavior boxes to manipulate the QTRobot's joints or attributes. QTrobot has an expressive social appearance and its screen allows the presentation of animated faces. It has 12 degrees of freedom to present upper-body gestures. Eight degrees of freedom are motor-controlled, two in each shoulder, one in each arm plus pitch and yaw movements of the head. The other four degrees of freedom, one in each wrist and one in each hand, are manually configured.

QTrobot has a RealSense 3D camera mounted on its forehead and is provided with a microphone array. QTrobot is powered with an Intel NUC processor and Ubuntu 16.04 LTS, and provides a native ROS interface to program it in Python or C++ programming languages. QTrobot also provides a visual programming interface for IT non-experts, used in this study, to easily script custom applications and control the robot by an Android application from tablets and smart phones. In the present study, the robot's interactions with the children were pre-scripted and controlled by the experimenter via a tablet. During the development phase, this robot will first be programmed using QTRobot Studio to test for the framework validity. Feedback on the framework validity will be done by a therapist. The equivalent module will then be converted to a Python/C++ equivalent program in ROS environment.

4.3.2. System Architecture

The system architecture may be referred to in Figure 5. A researcher will operate the supervisory controller for procedure control, robot feedback decision and data acquisition.

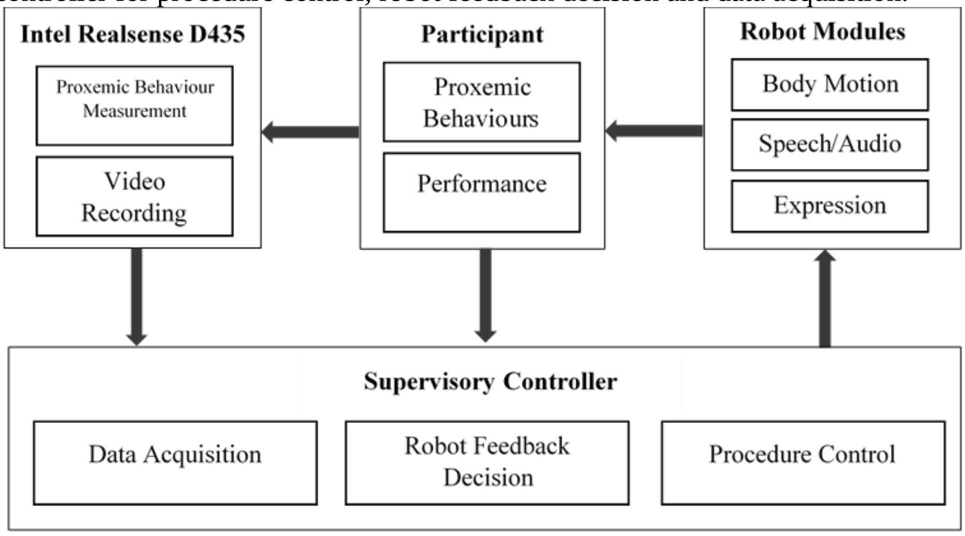
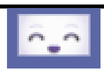


Figure 5. System Architecture.

4.3.3. Robot Teaching Structure

Note that the robot follows the DTT sequence (Sd -> R -> Sc). Prompt level (PL) was programmed to help child feel successful. Reinforcement given in this context is social praise, gesture an expression. The previous three actions have categorized according to prompt levels as differential reinforcement Table 4. ASD child values consistency, the robot was made sure to give consistent feedback to the child based on their response. This aspect was something that the therapist considers important, as this is even difficult to maintain by experienced therapist. Consistency by human therapist may vary according to their level of stress, moods, or environment.

Table 4. Differential reinforcement technique.

Prompt Level	Expression	Gesture	Tone/Praise
No Prompt		Clap Hands up	Enthusiastic. (Exclamation mark used)
First Prompt		Clap	Less enthusiastic response. (no exclamation mark)
Second Prompt		No gesture	Praises are ended with 'try' at the end of sentence to signify this is not the expected behavior.

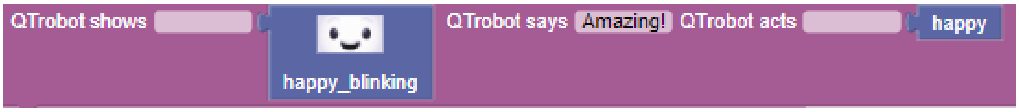


Figure 6. Example of programming block for correct response.

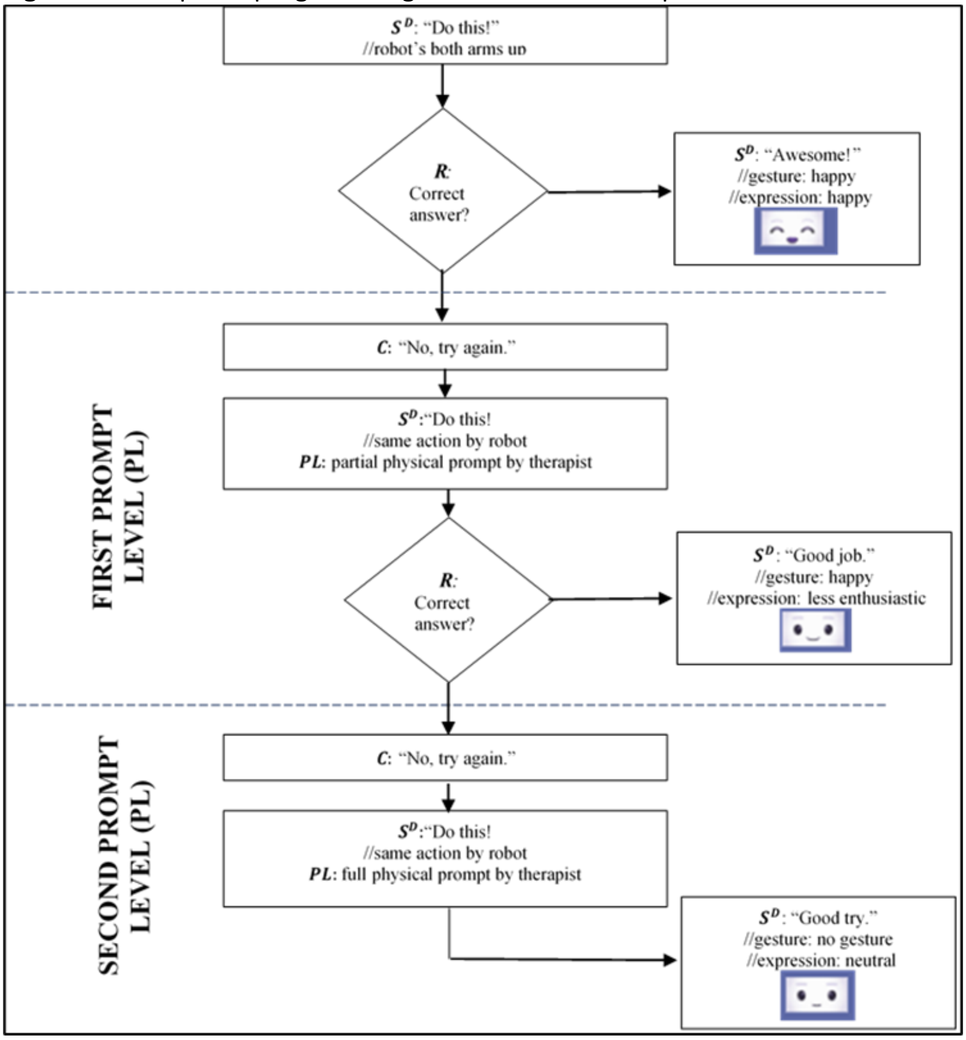


Figure 7. Example flowchart for imitation's interaction module.

Figure 7 summarizes the flow of robot's behavior. Sentence with exclamation mark at the end will be said by the robot with an enthusiastic tone. To summarize, the more PL the child need, the less enthusiastic the robot's response will be. Being consistent in this aspect will help child learn targeted behaviors effectively. Even when the child does not give the correct answer, the robot will help ASD child feel successful by giving prompts.

4.4. Implementation Phase

This phase involves the interaction between robot and ASDC. The experiment will be conducted at the child's center to maintain familiarity and ensure ASDC is comfortable. Researcher will be hidden to minimize the number of unfamiliar people during HRI session. The flow of intervention, preparation and challenges that might emerge during intervention must also be considered.

4.5. Evaluation Phase

The interactions will be recorded via Intel Realsense D435 embedded with the robot. The child's behavior will be analyzed via post session video analysis. In measuring the behavioral engagement, proxemics imaging method is used to measure the distance between the subject and the robot to identify their interest with the robot and levels of engagement throughout intervention. The same method was previously applied by [49] and [50] who also measured the engagement between children with autism and a humanoid robot using distance. Proxemics behavior includes interpersonal distancing, eye gazing, and body gesture that can express the behavior of the person towards the engagement.

5. Conclusion

The present work introduces the design of a HRI platform aimed for ASD children by using ADDIE model and ABA. Our purpose is to support children with ASD and the educators by introducing robots as assistive tool. We would also like to propose for future researchers in this discipline to follow a more standardized model to increase replicability and acceptability by the clinical community with our design.

6. Acknowledgements

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