# ASHESI UNIVERSITY

**DESIGNING AUGMENTATIVE AND ALTERNATIVE COMMUNICATION SYSTEMS THAT FOCUS ON REAL-WORLD CONTEXTS AS WELL AS THE MOTOR, COGNITIVE AND LINGUISTIC PROCESSING OF AUTISTIC CHILDREN**

**UNDERGRADUATE THESIS**

B.Sc. Management Information System

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**ASHESI UNIVERSITY**

# Designing Augmentative and Alternative Communication Systems that focus on real-world contexts as well as the motor, cognitive, and linguistic processing of autistic children

**UNDERGRADUATE THESIS**

Thesis submitted to the Department of Computer Science
Ashesi University College in n partial fulfillment of Science degree in Computer Science

**Rahmat Ajike Raji**

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# DECLARATION

I hereby declare that this Undergraduate Thesis is the result of my own original work and that no part of it has been represented for another degree in this university or elsewhere.

Candidate’s Signature:

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Candidate’s  Name:

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Date:

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I hereby declare that the preparation and presentation of this Undergraduate Thesis were supervised in accordance with the guidelines on supervisors of Undergraduate Thesis laid down by Ashesi University

Supervisor’s Signature:

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Supervisor’s  Name:

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Date:

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# Abstract

Children with autism spectrum disorder (ASD) require Augmentative and Alternative Communication (AAC) Systems to be able to communicate their feelings, thoughts, and expressions. However, AAC systems are not being developed to focus on the complex communication needs of individuals such as the motor, cognitive , sensory needs of the users of the system. Without a focus on the complex and varying competencies of the users of the system, the technology does not perform its intended role of enhancing communication but rather places a cognitive load on the users. In this project, guidelines, and recommendations for developing a tablet-based AAC application that satisfies the complex needs of autistic children with a different ASD diagnosis would be provided. The study analyzed the user interface of Eline Speaks, a tablet-based AAC system and identified the limitations, accessibility and usability issues of the system. Recommendations on developing an accessible AAC system was derived from testing a high-fidelity prototype in comparison to that of Eline Speaks, an already existing system.



**Keywords:**

*Augmentative and Alternative Communication (AAC); Autism Spectrum Disorder (ASD)*

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# Chapter 1: Introduction and Background

## 1.1 Introduction

Communication is an integral part of an individual's day to day functioning. It enables us to interact with others in society by understanding people's expressions, emotions, wants and needs. The ability to communicate is developed right from infancy to adulthood. However, when this development is impaired, it affects various aspects of an individual's development such as social and interpersonal skills. Individuals with communication disorders face difficulties with communication. Communication disorders range from inability to follow instructions, produce sounds and understand spoken language. The failure or struggle in communicating is one of the primary indicators when autism spectrum disorder is diagnosed [11].

Recent studies done by the Autism Society report that 1 in 45 children are born with an autism spectrum disorder. Autism or Autism Spectrum Disorder (ASD) is a neuro-developmental disorder that encapsulates a wide range of conditions which are characterized by a series of impairments. Children born with autism face challenges such as difficulties in social interaction, communication using verbal and non-verbal languages and patterns of restricted behaviors during adaptation to a new environment [8]. The level of communication impairment varies amongst individuals with the diagnosis. Impairment in communication for individuals who have ASD can take the form of severe language delay and limited language production. Wodka, Mathy, and Kalb through their research found that data from the Simon Simplex Collection demonstrated that 40% of children at the age of 8 (n=1456) had no phrase speech or onset of phrase speech after age 4 [10]. Behavior modifications such as speech training and antipsychotic drugs were primarily used as a form of treatment. However, these treatments offered limited capabilities and improvements for children with ASD.

Technology has become a more prevalent form of treatment for ASD. Technology has led to the emergence of assistive technology, which is any form of technology aimed at improving the functional capabilities of individuals with disabilities. Advances in assistive technology have adopted interactive environments within computers, virtual environments, devices and games to enhance the quality of life and communication skills for those with autism. Assistive technology has improved the organizational and critical thinking skills that permit children with ASD to sustain pace within their environments. For those with autism, Augmentative and Alternative Communication (AAC) systems are assistive tools that aid in communication. AAC systems have traditionally been adopted to enhance communication for individuals with ASD. AAC systems range from speech generating devices, picture exchange systems, communication boards, and others.

However, there is still a gap that exists with AAC systems. Augmentative and Alternative Communication Systems do not take the needs of different ASD impairments into consideration. Janice argues that AAC systems are not intended to incorporate the different needs of users such as motor and sensory capabilities [3]. With this dilemma, the technology used by the patient does not adequately cater to their complex needs ,which leads to inefficiency on the part of the system and a decrease in the communication capabilities for the user.

The paper highlights user interface design elements necessary for developing a tablet-based Augmentative and Alternative communication system which caters to the needs of autistic individuals with different competencies. From carrying out a usability study, the paper aims at providing guidelines for designing AAC systems that match the motor, sensory, linguistic and cognitive needs of non- verbal autistic children with complex communication needs.

### 1.2 Background

Augmentative and Alternative Communication (AAC) systems are assistive devices that are used to supplement or replace speech and therefore improve communication skills. AAC devices are adopted by individuals who have difficulties with non-verbal communication, as the system provides an avenue for speech enhancement [8]. Autistic children show limited expressive language output [11]. Hence, these patients use these systems to improve their communicative functions. AAC systems include sign languages, video and audio material, low tech picture cards where the user selects on an image to communicate. In addition, AAC devices include speech synthesis capabilities and large vocabularies to accommodate different linguistic competencies of the users [8].

The earliest approach to communication interference for autistic children was through behavior modification, which are techniques used to increase speech by using positive reinforcement which involved pairing a positive stimulus to a behavior. However, this approach only yielded improvements for children with some degree of speech. Due to the flawed outcome of behavior modification, autistic children were introduced to sign language. This intervention showed more promising results than speech training interventions. However, children with ASD lack excellent motor control skills, hence the sign language intervention was difficult for them to grasp. Sign language was also only valid when the instructors or communication partner also understood sign language [1]. In Bonvillian's research, he observed that the majority of the participants, which were non-verbal autistic children were able to produce only five or more signs

[2]. Therefore, Augmentative and Alternative Communication systems prove to be predominant of treatment as it has demonstrated positive outcomes for autistic children. Augmentative and Alternative Communication systems have significantly improved the communication capabilities of children with developmental disorders such as ASD. The advent of AAC has offered new and enriching opportunities to access an improved quality of life. Thus, they provide a significant array of communication, social, behavioral possibilities that were not achievable before [3]. With AAC, individuals are now able to overcome communication and interaction barriers by enhancing their communication competence.

### 1.3 Problem Statement

AAC technologies are developed without due consideration of the complex needs and skills of autistic children. The technologies seldom focus on other factors such as the linguistic, cognitive and sensory capabilities of the children with complex communication needs. The significance of the problem is that with the improper design of AAC technologies, the technology imposes significant processing and language demands on the patients which negatively affect their communication performance. An increase in the learning and processing demands in some cases results in a withdrawal from the system. Also, a gap that exists is that AAC development tests and interventions are not conducted in the individual's natural environment nor with their natural communication partners; instead, interventions are carried out in controlled environments [8].

### 1.4 Motivation

Communication is an integral part of a human being's day to day functioning. Children born with autism face numerous difficulties in performing everyday activities, one of that includes communication. Autistic children will experience severe mental health difficulties which will negatively affect their development and quality of their lives as well as their parents, peers, and caregivers [3]. Having autism presents challenges to participation in the home, school, work, and community environments. To illustrate the difficulties faced by autistic children, up to 90% of students with complex communication needs proceed into adulthood without acquiring functional literacy skills which affect their employment opportunities, educational qualifications and social interaction [3].

AAC systems are designed to make communication and life easier for autistic children as it offers an alternative medium for interaction. However, once these systems are improperly developed, they fail to contribute positively to the communication needs of these individuals and negatively impacts their quality of life. When technology is poorly fit to an individual with complex communication needs, it will pose a burden as they will undergo cognitive overload. In such a case, AAC systems do not aid communication or improve the standard of living but rather hinder the ability to converse and interact.

### 1.5 Research Questions

- How to design Augmentative and Alternative Communication Systems that focus on real-world contexts as well as the motor, cognitive, and linguistic processing of autistic children?

### 1.6 Objectives

The objectives of this paper are to:

- Carry out usability tests and evaluate an existing AAC app and identify the adaptability issues for autistic children.
- Identify user interface design techniques and elements for building AAC systems that match the varying needs of the users.
- Design a functional tablet based AAC app adaptable by autistic children with varying competencies

# Chapter 2: Review of Literature

## 2.1 Introduction

To obtain a deeper understanding of the context of this research paper, related work on autism spectrum disorder, interface design, and augmentative and alternative communication systems were reviewed. The literature review covers areas such as the characteristics of individuals with the autism spectrum disorder, interface design, ensuring appropriate technology to person fit and attaining communicative competencies. This literature review was approached from an exploratory point of view, allowing for the development of themes and reoccurring areas of research.

In the area of interaction design and user interface design, the analysis of literature focused on horizontal layout, vertical layout, visual symbols, grid display, and visual screen display. Attaining communicative competence was examined from the perspective of focusing on the integration of skills, participation in real-world scenarios and focusing on the full breadth of communication goals. Lastly, in the area of autism spectrum disorder, studies on communication impairment, motor, linguistic and cognitive deficits of autistic children were examined.

## 2.2 Autism Spectrum Disorder

Autistic spectrum disorder identifies a range of disorders that encompasses difficulties with communication, social interaction, motor deficits, sensory impairments, linguistic competencies. [11]. Individuals with ASD experience different patterns of behavior; hence it affects the presentation of the disorder.

### 2.2.1 Communication Impairments

Communication impairments in individuals with ASD can range from the inability to develop any speech to failure in using speech and language. According to the American Psychiatric Association, approximately 50% of individuals with autism spectrum disorder are unable to develop speech adequate enough to meet their everyday communication needs [11]. Children with ASD experience difficulties in understanding language and non-verbal expression during communicative scenarios. Due to the inability to communicate, children with autism spectrum disorder tend to develop unconventional means of communication. This often translates to aggressive behavior and outbursts which negatively impact the child's ability to function in society [12]. According to Venter, the presence of fluent speech before a child turns 5 was a good indicator of high IQ scores, improved social interaction, academic excellence, and adaptive skills in adolescence [13].

### 2.2.2 Motor Deficits

Researchers have identified the variations of motor skills in children with autism. A study conducted by Green assessed the motor skills of children aged 6-11 with a diagnosis of autism spectrum disorder by adopting the Movement Assessment Battery for children. The aim of the assessment was to evaluate the child's motor skills which included balance, ball skills, object control, grips, and manual dexterity. The results of the evaluation showed that children with ASD scored below the $15^{th}$ percentile which indicated their motor deficits. In addition, research has shown that children with autism experience delays in their overall motor development as well as disorders in locomotor and graphomotor skills. Studies carried out by Zittel found that roughly 50-70% diagnosed with ASD had motor deficits. [14][15]. Motor deficits impact communication; hence they should be taken into consideration when designing AAC systems.

### 2.3 Attaining Communicative Competence

Communication competency refers to the awareness of standards communication patterns and the ability to implement this knowledge in communication. It encapsulates an individual's understanding of linguistic syntaxes and patterns. Light and McNaughton identify that although the focus on the acquisition of specific skills is crucial in building new skills, it is not enough [4]. The problem at hand is that AAC devices are developed with the aim of creating what is technologically possible, rather than focusing on the needs of individuals with communication needs. Light and McNaughton provide a historical illustration of this issue by analyzing the history of AAC design over the years. One of the earliest AAC interventions for nonverbal individuals was the nonelectronic communication boards. In the article, the design model behind the communication board has been replicated throughout time, thus implying that designs from the 1980s/1990s are still reflected on 21$^{st}$-century hardware such as the iPad and other mobile technologies [3]. Light and McNaughton encourage that researchers rethink the design of AAC technologies to cater to the learning demands and functional status of individuals, rather than adopt conventional standards of design. With the rise of AAC technology, it is crucial that extensive research should be carried out on the communicational competencies of autistic patients [3]. It is necessary to understand the cognitive, linguistic and motor profiles of people with autism to identify their communication needs. Light proposes the following measures to attain communicative competence:

### 2.3.1 Focus on the Integration of Skills

Light and McNaughton argue that communicative competence is an integration of linguistic, operational, motor and cognitive skills in response to the communicative requirements within real-world interactions with communication partners and within a natural environment [4]. According to Light, few studies have been done that consider individuals integration in response to the communicative demands from the individual's natural environment. Hence, this paper will contribute to the research of autistic children within their natural environment and with natural communication partners.

### 2.3.2 Focus on Participation in Real-world scenarios

Communicative competence for individuals who require AAC is achieved when individuals cultivate the skills necessary to meet the communicative demands within their natural environment. Individuals should be able to respond to the functional requirements of their communication partners in real-world contexts. The integration and social interaction between individuals with complex communication needs with others are essential in ensuring that they participate effectively in society and achieve their goals. However, AAC interventions for children rarely take into consideration the real-world environments with families [7]. Therefore, in an attempt to fill this gap, this research would be conducted in the natural environments of the participants.

Individuals who require AAC are within several environments such as hospitals, rehabilitation centers, clinics, etc. which differ from their natural habitats. AAC models should not be developed on the assumption that the skills generated in these controlled environments would apply to real-world contexts. Intervention studies reveal that AAC intervention is administered in decontextualized situations and natural communication partners are replaced by strange partners such as clinicians or researchers.

### 2.3.3 Focus on the Full Breadth of Communication Goals

AAC intervention must focus on the full breadth of communication goals to achieve educational, vocational and social goals of individuals with complex communication needs. Individuals with complex communication needs need to have linguistic competence. They should be able to develop substantial knowledge and competencies in the linguistic code of written and non-verbal languages. Individuals must also be abreast with the language code of AAC systems which include elements such as the semantics and AAC symbols.

## 2.4 User Interface Design/ Human-Computer Interaction

The interaction between an individual with complex communication needs and the AAC system is the backbone of the systems design process. Human-Computer Interaction (HCI) is fundamental in designing assistive technologies, as it analyzes the user interaction and experience that users of the system have with the technology. Usability and HCI are aimed at enhancing the technologies functionalities and therefore satisfying the needs of individuals. By understanding how individuals would interact with a system, AAC designers can incorporate this knowledge in designing practical technologies. A well-designed AAC technology would positively impact communication [6]. Furthermore, AAC systems should focus on the interaction design and elements that ensure that positive interactions take place [5]. Usability is essential in guaranteeing that the patient can operate the system and communicate effectively. Therefore, this research would focus on developing user interfaces that are accessible and ensure easy navigation.

Light states that the lack of understanding of human factors in technology design can establish barriers and hinder operational effectiveness as well as effective communication [3]. In designing the interface for AAC technology, Light and McNaughton argue that AAC design should be driven by the needs and behavior of the individuals.

Design principles for developing AAC systems include:

### 2.4.1 Horizontal and Vertical Layouts

Research carried out by Janice Light illustrates that horizontal and vertical layouts create another potential mismatch between standard AAC technology designs and the needs and skills of end users [3]. A study carried out, tasked students with the responsibility of using a mouse to access computer technology. The results of the survey revealed that younger children improved their performance when their access was dependent on vertical selection. The vertical layout reduced the demands as the children were not required to deviate from the layout; instead, they focused on the selection process.

From these results, Light and McNaughton suggest that new individuals using AAC technology should be introduced to vertical displays rather than using horizontal or grid displays [3]. This design technique would aim at improving selection accuracy for those with complex communication needs.

### 2.4.2 Visual Symbols

The assertion made by Sampath states that visual symbols such as photographs and graphic images are critical elements in developing visual schedules for children with autism [8]. The most common picture-based communication intervention technology is Picture-based communication system. With this system, the child communicates by selecting an image of the desired item. According to Sampath, with this system, the minimal cognitive load is placed on the child, no additional skills are required, and imitation skills are not necessary [8].

### 2.4.3 Grid Display and Visual Screen Displays

Light questions if individuals with complex communication skills can learn to use the traditional grid displays that fit their cognitive, language and sensory skills. Visual Scene Displays(VSD), have served as an alternative to the typical grid approach. VSD's are images of memorable experiences that incorporate language concepts embedded within the scene [7].

Research has demonstrated that individuals with complex communication needs benefit from access to VSD. The results show that children attend first to VSD's when compared to grid displays of symbols. Also, children are selecting vocabulary more accurately with VSD than with grid displays [9]. With VSD's children can participate in social interactions and improve their language.

## 2.5 Ensuring Appropriate Technology Fit

With the increased emergence of AAC systems, parents, teachers, and caregivers of individuals with autism spectrum disorder adopt these technologies without due consultation from speech and language pathologists. Gosnell identified the need of using a clinical approach to adopting AAC systems [16]. Light and McNaughton argue that instead of an individual to adapt to the demands of AAC technology, the technology should adapt to the demands the person [3]. However, in practice, AAC systems are administered based on popularity rather than needs and skills. When AAC technologies are selected based on reputation, the chosen technology may not optimize the expected results.

In the development of an AAC system, designers are required to evaluate the skills and linguistic, social, motor and cognitive competency of the individual with complex communication needs. In addition, the designers should take into consideration other factors such as the individual's environment and communication partners. Gosnell proposed a model based on the feature matching process [16]. The model evaluates the individual's competencies and needs in the AAC assessment. The model indicates the criteria of systems to identify when matching AAC technology to individuals. These criteria are the purpose of use, output, speech settings, representation, display, feedback features, rate enhancement, access, motor competency, support, and customization.

The functional features of the AAC system should be identified and reviewed to determine the potential of the AAC technology in aiding communication for the individuals. After all internal factors and external factors are evaluated, designers would be able to identify the best-suited person-technology fit.

# Chapter 3: Methodology

## 3.1 Introduction

The methodology commonly used in AAC research is the adoption of a case study design aimed at collecting quantitative data which highlights the improvement or reduction in communication attempts [17]. The goal of the study is exploratory; hence proper measures were adopted to ensure that data collection was taken and observations recorded.

An existing tablet based AAC technology; Eline Speaks, tested on autistic children. Usability tests conducted on the system identified the adaptability of the technology to the varying motor, sensory, linguistic and cognitive capabilities of children with ASD. Monitoring the interaction process allowed the researcher to derive the limitations of the system. Identifying the constraints of the system in satisfying the complex communication needs of the users, highlighted the inefficiencies of the technology as well as constructed guidelines for building an adaptable system. The accessibility issues of the tablet-based systems and the feedback obtained contributed to the development of a high-level prototyped tablet-based AAC system.

## 3.2 Research Design

The design research for this study included a case study design. This design was adopted to execute an in-depth observation of the research participants while examining the usability of the system. The case study design  also used to identify the impact of the independent variable on one more dependent variables. The independent variable was the Prototyped system, or Eline speaks interface. The dependent variables were the time taken to communicate, the level of intervention required by the users to communicate and the number of right and wrong attempts made when communicating. The case study tracked and monitored the subject's responses to derive conclusions on the competencies and capabilities of each participant. The case study design is commonly adopted with individuals with autism due to the variation in motor, linguistic and behavioral characteristics [18].

The following steps were taken during the research design process. The task-centered design process was adopted by the researcher to define the techniques taken to derive the limitations of Eline Speaks and develop the prototyped system. The task-centered design illustrates the specific tasks that the participants executed when communicating with the AAC system. The sequence of the research process is as follows:

**a)User Analysis**

The participants in the study were identified. Background knowledge regarding the competency and ability of the child were also collected during the teacher interview.

**b)Usability Tests**

During each session, usability tests were carried out on the system, Eline Speaks. The system served as a reference used to generate guidelines for designing an adaptable and inclusive AAC system. The number of right and wrong attempts, the form of intervention and time taken to complete the task were the metrics recorded during the tests.

**c)Analyze User Interaction**

The user interaction was analyzed to identify the limitations of the system. Also, accessibility issues and poor user interface design were recorded.

**d)Create a Prototype**

A prototyped tablet-based system was then created. The prototype was built based on the findings sourced during the usability tests and analysis of user interaction. The mock-up was developed with Indigo Studio; a user interface tool kit.

**e)Test Prototype**

The prototype was then tested with the subjects to identify the validity of the guidelines suggested by the researcher. The aim of testing the prototype was to determine if the prototyped solution improved the communication rate for children when compared to communication rate obtained with Eline Speaks.

**f)Iterate**

After every session, the layout and design of the prototype interface were iterated. Constant iteration allowed the researcher to develop a system that could satisfy the functional needs of the users. The iteration process provided critical insights into the usability of the system.

## 3.3 Research Methods

### 3.3.1 Empirical Study

The observational method was conducted to study the participants and their behaviors in their natural environments. In addition, the observational study was undertaken to gain perspective of the linguistic, motor and cognitive capabilities of the participants. The research was done in the subject's natural environment (the autistic center) and with their natural communication partners to deduce an uncontrolled response to the study.

### 3.3.2 Interviews

The interviews conducted were only applicable to the children's natural communication partner such as the teacher or the caretaker. The interview was conducted to gain a detailed understanding of the competencies and behavioral patterns of the children with complex communication needs. The interview allowed the teachers to rate the participants motor skills, cognitive, linguistic, receptive and expressive language skills. Also, open-ended questions were asked to gain insight into the child's familiarity with technology, past experiences with AAC systems and their impacts on the child's communication competencies.

Teachers were asked questions such as "Does your child respond to his/her name spoken?". With each question asked, the teachers/caregivers were required to rate their answer by indicating either often, sometimes or never. Teachers were asked about various communication domains such as listening and understanding, motor skills and linguistic skills. 'Often' ratings received 5 points, while 'Sometimes' received a score of 3 points and 'Never' received 1 point. The total score for each child was then calculated per domain. The interview questions can be found in Appendix A.

### 3.3.3 Usability Tests

Usability tests carried out on Eline Speaks and the prototyped solution that was developed throughout the study. The test conducted observed the interactions the children had with the AAC system. The usability test offered insights on the user interface design flaws and strengths, the participant's expression, behaviors, and reaction to the AAC system. The usability tests identified if the AAC system was developed using a user-centered approach. The heuristics that were examined included the time taken by the subject to communicate, the task motivation, interventions from teachers, motor effort, cognitive effort, and linguistic effort. Stauffer conducted related work on AAC usability on the User Interface Adaptability within an Augmentative Communication App for Children with Autism Spectrum Disorder. Stauffer held a case study design with 3 participants. The study was conducted to analyze the accuracy of using the device across varying user interface settings [20].

### 3.4 Research Participants

Twenty autistic children were selected and recruited from Reyo Paddock Special School; an autistic center in Madina, Ghana that provides therapy and assistance for children with autism. The chosen participants had a diagnosis of autism spectrum disorder, were aged between 4- 18 years and used a limited number of words to communicate frequently. Secondary participants included the teachers who were the natural communicators of the children. The teachers supported the subjects as they used the systems. Therefore they were part of the research. Teachers were required to take part in an extensive interview session. They were asked to sign the consent form to ensure that participation carried out was voluntary. The primary research participants were grouped into three user groups namely: participants with motor deficits, participants with linguistic deficits and participants with moderate capabilities.

#### 3.4.1 Sampling Method

The sampling method adopted was convenience sampling. Convenience sampling is a non-probability sampling technique. The participants were selected based on their availability. All the autistic children at the center took part in the study.

### 3.5 Data Collection

#### 3.5.1 Data Gathering Tools

The research instruments adopted for the study included structured and unstructured interview questions. The usability study was executed with an iPad equipped with the app, Eline Speaks. Data gathered during the observational study were documented in notes. The interview questions and the observational study were centered around the research question. The data gathering tools aided in obtaining relevant data. The data was used to analyze the adaptability of the system to the varying competencies of the autistic participants.

#### 3.5.2 Data Collection Procedure

The data gathered for the study was obtained through a series of trials. Each session lasted for about a maximum of 1 hour, and the study was conducted over four weeks. The participants were informed about the research, and their consent was derived through the consent form.

#### 3.5.3 Data Analysis

The video recordings took during the sessions were to be run using Noldus Observer XT. Observer XT was to be used for the collection, coding, analysis of observational data obtained from the sessions. The software quantitatively presents the observational data by synchronizing eye tracking, emotions, behavior, and physiology. The FaceReader software was to be used for the recognition and analysis of facial expressions of the participants while participants were undergoing the usability study. Videos were to be analyzed with Noldus Observer XT and FaceReader software. However, the recording of videos was prohibited by the autistic center; hence Noldus Observer XT and FaceReader software were not used during the research.

**Chi-Square**: The chi-squared analysis was conducted to identify if there was a significant difference between the expected frequency, which was communication rate when the participants used Eline Speaks and observed frequency which was the communication rate when participants used the prototyped system to communicate. It was used to assess if there was any correlation between the two variables.

**T-test:** The t-test was conducted to determine the statistical difference between the rate of communication of the participants when they used Eline Speaks and the prototyped solution.

### 3.6 Technology and Softwares Implemented

Indigo Design system in conjunction with Sketch UI kits was utilized to develop the UI design and components of the prototyped system. The system allowed for the addition of interactions and transitions on the prototypes. The prototype was programmed using Angular HTML (Hypertext Markup Language), CSS ( Cascading Style Sheet)  and JavaScript. Usability tests were conducted using Thunkable, a cross-platform app builder. The code for the final prototyped solution can be sourced from the git hub repository below:

https://github.com/RahmatRaji/AAC-Application

# Chapter 4 : Experiment and Results

## 4.1 Introduction

. This chapter focuses on the procedures that were followed in conducting the experiment. The experiment section of the paper discusses the outcome of the sessions held, the findings observed during the usability studies and design process executed for the development of the prototyped system . The result section analyzes the data that was gathered during the experiment. The results were analyzed using tables and statistical tools.

## 4.2 Experiment

The research was conducted in sessions. Each session involved observational research and usability tests. The sessions were supervised by the teachers, who served as a natural communication partner. The study was conducted in a classroom setting, which was a natural setting for the participants.The following are sessions conducted during the experiment:

### 4.2.1 Session 1

The autistic center that was chosen for the research study was Reyo Paddock Special School located in Medina, Accra. The center housed 23 students from the ages of 4- 22. However, one of the students had a diagnosis of cerebral palsy, and two others were above the age of 20. Hence, they were excluded from the study. Therefore, the sample size for the research was 20. The session comprised of debriefing the coordinator and the speech therapist at the institution on the intended research.

An observational study was also conducted to get a better understanding of the daily activities of the children at the center. The students at the center used PECS (Picture Exchange Communication System) which is a type of augmentative and alternative communication system to communicate with their teachers and instructors. The children at the center used the PECS system to request for items when performing three significant activities which are eating, outdoor activities and indoor activities.

**Table 1: Commonly requested items**

| **Eating** | **Indoor Activities/ Toys** | **Outdoor Activities** |
|---|---|---|
| Drinks | Spikey ball | Wash hands |
| Fruits | LEGO blocks | Toilet |
| Biscuits | Colouring Books | Drink (Water) |
| | Story Books | Games |
| | Sand play | Water Play |

Hence, the AAC application, Eline Speaks was modified was to mimic the PECS system. Within each category (Snacks, Outdoor Activities, Toys) located on the index page, items frequently requested by the participants were displayed.

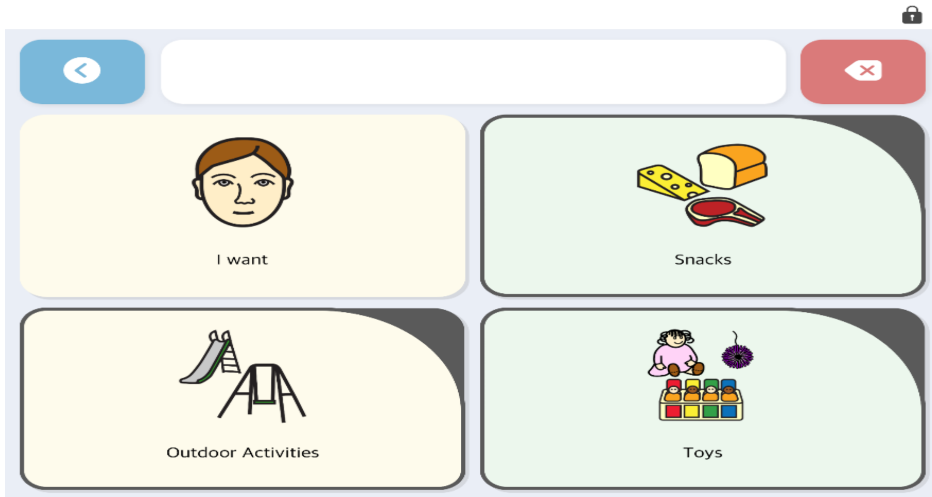



**Figure 1: Index Interface**

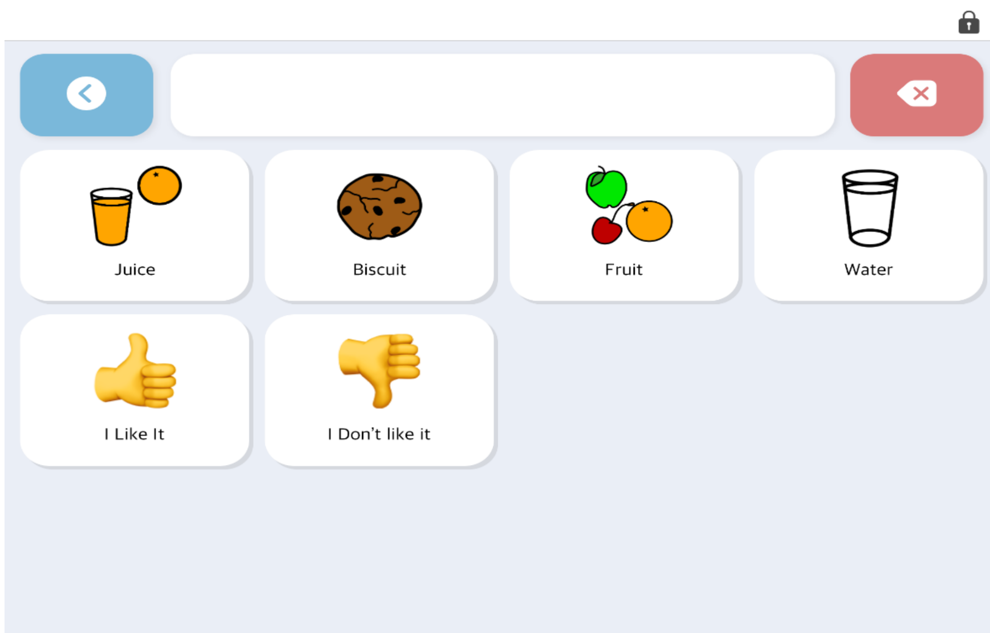



**Figure 2: Items to be selected in the snack category**

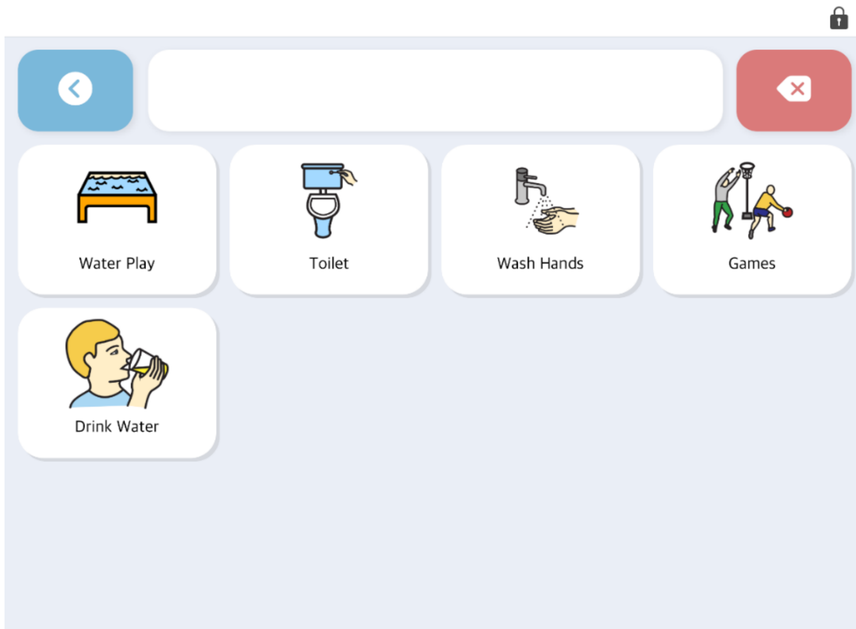



**Figure 3: Items to be selected in the outdoor activity category**

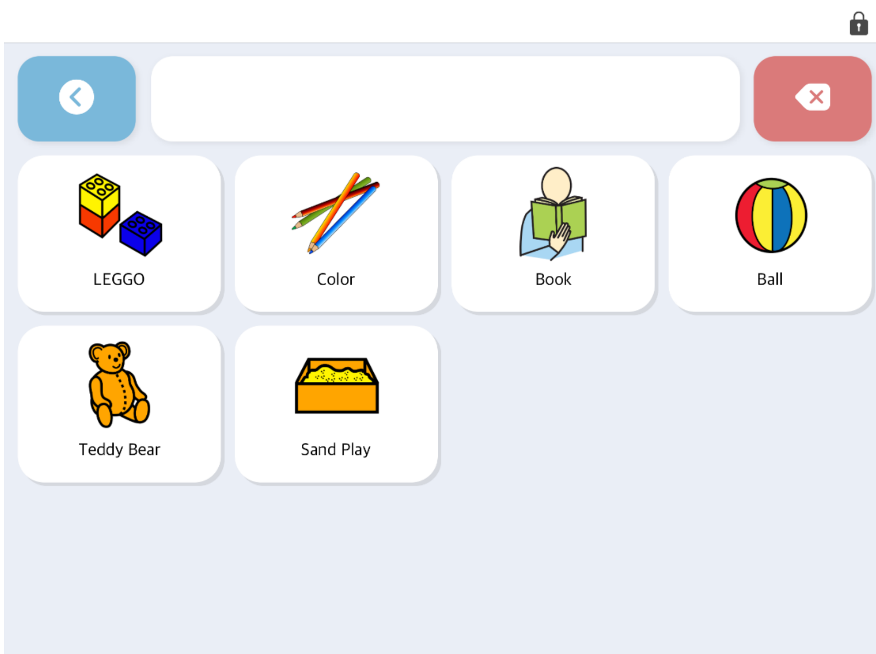



**Figure 4: Items to be chosen in the Toy Category**

### 4.2.2 Session 2

The session comprised of an interview and usability tests on Eline Speaks. The interview conducted covered information on the motor skills, expressive and receptive language skills and literacy skills of the participants. In addition, open-ended questions about each child's past experiences with tablet-based technology were collected to provide detailed information on the child's capabilities. Data from the interview was recorded through notes taken by the researcher.

The participants were then grouped according to their capabilities. The groups consisted of participants with motor deficits, expressive language deficits (non-verbal) and moderate competencies. After the participants were grouped according to their capabilities, the teachers were trained and debriefed about the application. The children were introduced to the application by their teachers. The following were the steps taken during the session:

1. The teachers gave commands, such as "Show me a drink" to the participants. The children were then required to select the item using the PECS system. The item selected, the number or frequency of right and wrong attempts, the level of intervention and the time taken were recorded.

2. After the child responded to the prompt and provided the appropriate PECS card, the iPad was placed in front of the child with the Eline Speaks interface displayed.

3. A *"trial"* begins when the child is given the same command but is asked to select the requested item on the tablet. The prompts used by the teacher was done either by physically guiding the participant to choose the item, gesturing the participant to select the item or by using repetitive commands such as positive reinforcements. For some trials conducted there was no intervention or prompt used. Data recorded during the tests included the item selected, the frequency of right and wrong attempts, the level of intervention and the time taken to select the item.

4. After the participant has selected the item, the researcher continued the next trial.

#### 4.2.2.1 Data Collection

From the trials conducted, the following results were obtained:

**1. Participant with motor deficit**

**Table 2: Using Eline Speaks (Tablet AAC System)**

| Trial | Right attempts | Wrong attempts | Intervention | Time (seconds) |
|---|---|---|---|---|
| 1 | None | 5 | Physical intervention and gesture prompts | 120 s |
| 2 | 1 | None | Physical intervention | 4s |
| 3 | 1 | 4 | Physical intervention | 22s |

During the trials, it was observed that the participant with motor deficits lacked fine motor movements needed to activate the touch screen tablet and create a device reaction. The participant required physical interventions for all the trials conducted with the system. The subject diverged from the tests multiple times; hence it resulted in physical intervention.

**2. Participants with limited expressive language (non- verbal)**

The participants with limited expressive language included those who were completely unable to verbally respond to instructions as well as those who had limited expressive language.

**Table 3: Eline Speaks (AAC System)**

| **Participant** | **Trial** | **Right attempts** | **Wrong attempts** | **Intervention** | **Time (seconds)** |
|---|---|---|---|---|---|
| **Participant 1** | 1 | 1 | None | None | 3s |
| | 2 | 1 | None | None | 2s |
| | 3 | 1 | 4 | Physical intervention | 27s |
| | 4 | 1 | None | None | 1s |
| **Participant** | 1 | 1 | 1 | Gesture Prompts | 15s |
| | 2 | 1 | None | Physical Prompts | 6s |
| | 3 | None | None | Physical promts, Gesture prompts, Positive reinforcements | 29s |
| | 4 | 1 | None | None | 3s |
| **Participant 3** | 1 | 1 | None | None | 12s |
| | 2 | 1 | 5 | Physical prompts | 81s |
| | 3 | 1 | 6 | Physical prompts | 76s |
| **Participant 4** | 1 | None | 1 | Gesture prompts | 36s |
| | 2 | 1 | 5 | None | 11s |
| | 3 | 1 | None | None | 3s |

| | | | | | |
|---|---|---|---|---|---|
| | 4 | 1 | None | None | 3s |

After the second trial, it was observed that the fourth participant was focused on the researcher and not the system; possibly due to unfamiliarity. This led to the removal of the researcher from the classroom. After 2 minutes, the researcher came back to the classroom and the trials resumed after which the participant responded accordingly.

**3. Participants with moderate verbal competencies**

Subjects with moderate verbal competencies had good expressive languages and could also read, understand commands as well as match text to images. The participants did not use the PECS system.

**Table 4: Eline Speaks (AAC System)**

| Participant | Trial | Right attempts | Wrong attempts | Intervention | Time (seconds) |
|---|---|---|---|---|---|
| **Participant 1** | 1 | 1 | None | None | 6s |
| | 2 | 1 | None | None | 17s |
| | 3 | 1 | None | None | 7.8s |
| | 4 | 1 | None | None | 1s |
| **Participant 2** | 1 | 1 | None | None | 2.5s |
| | 2 | 1 | None | None | 1.6s |
| | 3 | 1 | None | None | 1.4s |

| | | | | | |
|---|---|---|---|---|---|
| | 4 | 1 | None | None | 1.6s |
| **Participant 3** | 1 | 1 | None | None | 2.5s |
| | 2 | 1 | None | None | 1.9s |
| | 3 | 1 | None | None | 1.5s |

#### 4.2.2.2 Accessibility and Usability Issues with Eline Speaks

The following were the usability issues encountered by the participants during the study:

**1. Use of categories**

Deducing from the session, the researcher observed that the participants were having difficulties using the interface due to the presence of categories. Categories in this instance had items that could only be displayed when the user clicked on the category . For example, to select the item juice, the user has to click on the category *"snack"* to be able to find juice. This placed a cognitive load on the users as the controls were not visible for the users to access. This resulted in the inefficiency of the system as it made it hard for the participants to navigate the system.

**2. Font Size**

The researcher observed that some of the participants could not match the image to the text due to the font size. The font size was small; therefore participants with visual impairments suffered major difficulties in communicating. Hence, the children solely relied on the image to respond to the commands of their teacher.

### 3. Spacing

For participants with motor deficits, selecting the requested image proved to be difficult, as the spacing between each element in the interface was small. Due to their lack of motor control, the participants made wrong selections. The researcher observed that the participants had a higher level of frustration as they made selections. Most of the time, the element that was wrongly selected by the participant was the closest item to the intended item of selection. Hence, for these participants, they had a higher rate of wrong attempts.

### 4. Complex Texts

Participants who had limited literary capabilities such as the inability to identify a maximum of 8 letters had problems identifying complex texts. Components titled “Water Play” or “I like it” , were not understood by most of the participants. According to Pavlov, in designing user interfaces for children with autism, sentences should be as short as possible due to their cognitive and literary capabilities [21]. In light of this knowledge, complex texts should be avoided in developing AAC systems.

### 5. Buttons without text

The presence of buttons without text such as the *delete* button distracted the participants when communicating. Participants randomly clicked the back button in order to derive a device response.

### 4.2.3 Session 3

The Eline Speaks interface was modified after the feedback on usability issues was generated in the second session. The use of categories was eliminated in the interface. All the components were presented in the index interface. The interface was then modified to a 4x3 array. However, the system did not have any feature that allowed for an increase in the font size. Hence the font size remained the same. In addition, the space between each element on the system could not be increased. Hence the spacing between the components did not change.

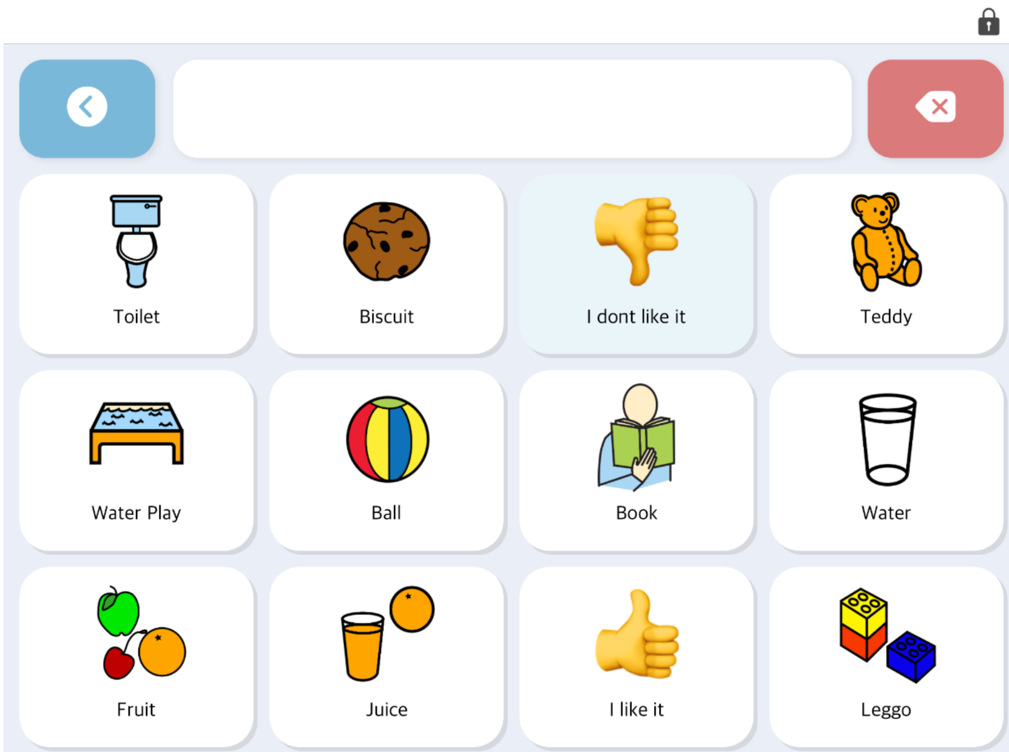



**Figure 5: Modified Interface**

#### 4.2.3.1 Prototyped Solution

A mock-up prototype was developed using Indigo Studio. As previously stated, the prototype was developed from the limitations of the system obtained during the usability study conducted on Eline Speaks. Hence the following were the features of the prototyped system:

**1. 2x 2 Array Size**

In order to reduce the cognitive load on the participants, the use of categories was eliminated from the interface. In addition, the interface was developed using a 2 x 2 array. The principle that was adopted was the 'clustering principle'. This principle states that the interface should be organized to separate blocks of similar control [22].

**2. Increased font-size**

To satisfy participants with visual impairments, the font-size for the text was set to 60px. This was done to increase the accessibility of the elements in the interface.

**3. Widened Spacing**

To satisfy the needs of participants with motor deficits, adequate spacing was given between each element. The aim of increasing the spacing was done to reduce selection errors caused by the close proximity of elements in the interface.

**4. Buttons with Text**

Since buttons with only icons, such as the delete button distracted participants, they were eliminated from the prototyped interface. Since the delete button was eliminated, when the user clicked an element, the previous title of the item in the text box was erased and replaced with the title of the item currently clicked. This eradicated the need for a back button.

**5. Background Color**

Since ASD children have heightened senses, they have a higher sensitivity to color. Hence, the prototype's background color was set to blue. Blue as a choice of color was selected due to its soothing and calming nature; hence it was ideal for autistic children [25].

The operational prototype was iterated several times based on feedback generated through the usability study. Teachers' comments and feedback on Eline Speaks contributed to the development of the prototype. The teachers' provided design assistance and recommendations. The teachers also served as proxy users as they identified the competencies and abilities of all the participants in the study.

In designing the prototype, the researcher first created paper prototypes:

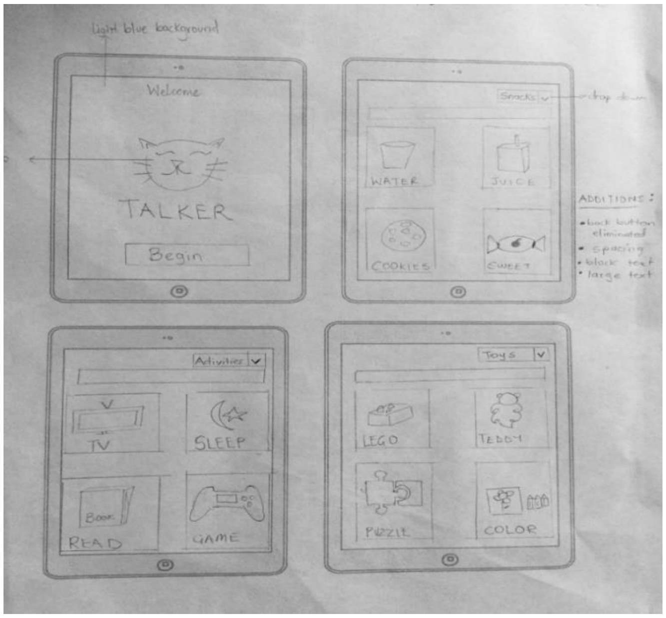
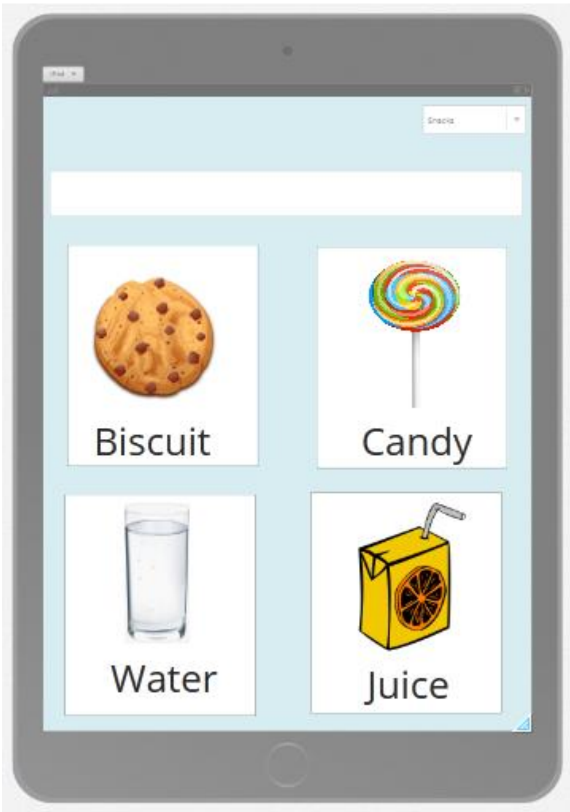
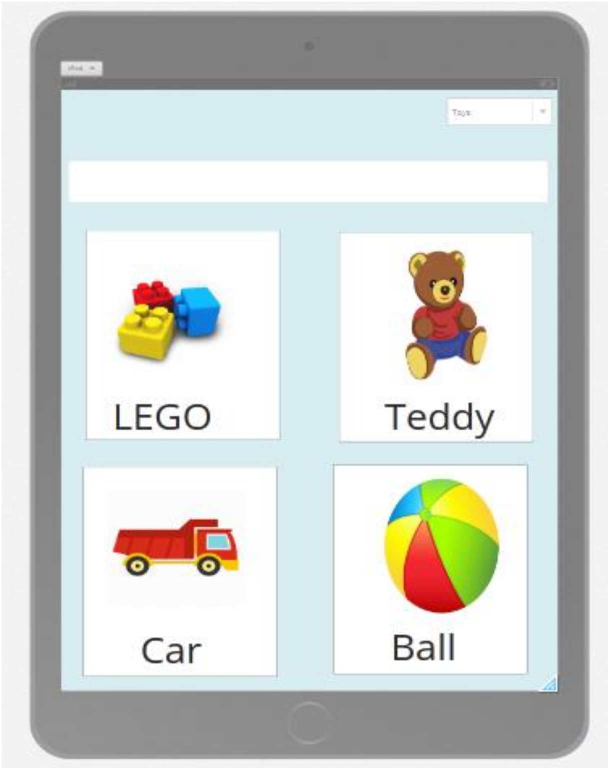



**Figure 6: Paper Prototype**

After the paper prototypes were designed, a high-fidelity prototype was then developed.

Below are the snapshots of the prototyped developed:




The link to view the interface of the prototype is below:

https://indigodesigned.com/share/knbjpnwya6r0

#### 4.2.3.2 Data Collection

The trials conducted during the sessions involved usability tests on Eline Speaks and the prototyped solution. The observational findings and data derived during this session are documented below:

**1. Participants with motor deficit**

**Table 5: Comparison between Eline Speaks and Prototyped Solution**

| Participant | Trial | Right attempts | | Wrong attempts | | Time (seconds) | |
|---|---|---|---|---|---|---|---|
| | | Eline Speaks | Prototyped Solution | Eline Speaks | Prototyped Solution | Eline Speaks | Prototyped Solution |
| **Participant 1** | 1 | 0* | 1 | 4 | 0 | 27.3s | 3.4s |
| | 2 | 1* | 1 | 3 | 0 | 16.5s | 4s |
| | 3 | 1* | 1 | 5 | 0 | 30s | 5.8s |
| | 4 | 1* | 1 | 0 | 0 | 3.8s | 3.5s |
| | 5 | 1 | 1 | 0 | 0 | 3.6s | 3.6s |
| | 6 | 1* | 1 | 0 | 0 | 4.0s | 4.0s |
| **Participant 2** | 1 | 1* | 1 | 6 | 4 | 48s | 20.2s |
| | 2 | 0** | 0 | 7 | 7 | 65.3s | 22.4s |
| | 3 | 0** | 0 | 0 | 1 | 67.3s | 21.5s |
| | 4 | 1** | 1 | 0 | 0 | 59.9s | 13.2s |
| | 5 | 0** | 0 | 0 | 2 | 59.3s | 20.3s |
| | 6 | 1** | 1 | 0 | 2 | 61.2s | 25.2s |

*Physical Intervention

** Physical Prompts

***Gestural Prompts

**2. Participants with limited expressive language (non- verbal)**

**Table 6: Comparison between Eline Speaks and Prototyped Solution**

| Participant | Trial | Right attempts | | Wrong attempts | | Time (seconds) | |
|---|---|---|---|---|---|---|---|
| | | Eline Speaks | Prototyped Solution | Eline Speaks | Prototyped Solution | Eline Speaks | Prototyped Solution |
| Participant 1 | 1 | 1* | 1* | 2 | 1 | 10.5s | 4.7s |
| | 2 | 1* | 1* | 4 | 0 | 9.9s | 3.8s |
| | 3 | 1* | 1* | 4 | 0 | 1.4s | 2.3s |
| | 4 | 1* | 1* | 2 | 1 | 6.6s | 3.2s |
| | 5 | 0* | 1* | 2 | 1 | 12s | 3.1s |
| | 6 | 0* | 1* | 6 | 0 | 67s | 4.1s |
| Participant 2 | 1 | 1*** | 1 | 1 | 0 | 10.6s | 0.9s |
| | 2 | 0** | 1 | 4 | 0 | 60.9s | 1.2s |
| | 3 | 1* | 1 | 4 | 0 | 2.3s | 1.8s |
| | 4 | 1 | 1 | 3 | 0 | 6s | 0.9s |
| | 5 | 1* | 1 | 2 | 0 | 54s | 1.6s |
| | 6 | 1 | 1 | 1 | 0 | 2.3s | 1.4s |
| Participant 3 | 1 | 0* | 0* | 1 | 1 | 36s | 20.4s |
| | 2 | 0* | 0* | 5 | 5 | 50.8s | 38.8s |
| | 3 | 0* | 0* | Off task | 8 | 80.3ss | 60.3s |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 4 | 0* | 0* | Off task | 4 | 58.2s | 55.8s |
| | 5 | 0* | 0* | 10 | 5 | 40.7s | 70.7s |
| | 6 | 0* | 0* | 7 | 7 | 40.2s | 60.4s |

“Off-task” indicated that the participant deviated from the activities.

**3. Participants with moderate verbal competencies**

**Table 7: Comparison between Eline Speaks and Prototyped Solution**

| **Participant** | **Trial** | **Right attempts** | | **Wrong attempts** | | **Time (seconds)** | |
|---|---|---|---|---|---|---|---|
| | | **Eline Speaks** | **Prototyped Solution** | **Eline Speaks** | **Prototyped Solution** | **Eline Speaks** | **Prototyped Solution** |
| **Participant 1** | 1 | 1 | 1 | 0 | 0 | 3.2s | 2.2s |
| | 2 | 1 | 1 | 0 | 0 | 3.6s | 1.8s |
| | 3 | 1 | 1 | 0 | 0 | 5.2s | 1.4s |
| | 4 | 1 | 1 | 0 | 0 | 4.8s | 2.9s |
| | 5 | 1 | 1 | 0 | 0 | 10.2 | 3s |
| | 6 | 1 | 1 | 3 | 0 | 36s | 2.4s |
| **Participant 2** | 1 | 1 | 1 | 0 | 0 | 3.2s | 2.1s |
| | 2 | 1 | 1 | 0 | 0 | 6.4s | 1.8s |
| | 3 | 1 | 1 | 0 | 0 | 8s | 1.2s |
| | 4 | 1 | 1 | 0 | 0 | 7.1s | 2.2s |
| | 5 | 1 | 1 | 0 | 0 | 3.2s | 2.1s |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 6 | 1 | 1 | 0 | 0 | 3.8s | 1.6s |
| **Participant 3** | 1 | 1 | 1 | 0 | 0 | 4s | 3.2s |
| | 2 | 1 | 1 | 0 | 0 | 4.3s | 3s |
| | 3 | 1 | 1 | 0 | 0 | 5.6s | 2.9s |
| | 4 | 1 | 1 | 0 | 0 | 2.4s | 2.6s |
| | 5 | 1 | 1 | 1 | 1 | 8.1s | 3s |
| | 6 | 1 | 1 | 0 | 0 | 4.0s | 2.8s |
| **Participant 4** | 1 | 1 | 1 | 0 | 0 | 2.5s | 2.5s |
| | 2 | 1 | 1 | 0 | 0 | 1.9s | 1.9s |
| | 3 | 1 | 1 | 0 | 0 | 1.5s | 1.5s |
| | 4 | 1 | 1 | 0 | 0 | 2.2s | 2s |
| | 5 | 1 | 1 | 0 | 0 | 2.1s | 1.4s |
| | 6 | 1 | 1 | 0 | 0 | 2.4s | 2.2s |
| **Participant 5** | 1 | 1 | 1 | 0 | 0 | 3s | 0.9s |
| | 2 | 1 | 1 | 0 | 0 | 3.9s | 1.2s |
| | 3 | 1 | 1 | 0 | 0 | 2.2s | 1.8s |
| | 4 | 1 | 1 | 0 | 0 | 2.8s | 1.6s |
| | 5 | 1 | 1 | 0 | 0 | 2.3s | 0.9s |
| | 6 | 1 | 1 | 0 | 0 | 2.1s | 1.4s |
| **Participant 6** | 1 | 1 | 1 | 0 | 0 | 3.9s | 2.1s |
| | 2 | 1 | 1 | 0 | 0 | 1.8s | 2.8s |
| | 3 | 1 | 1 | 2 | 0 | 13.2s | 0.9s |
| | 4 | 1 | 1 | 0 | 0 | 2.6s | 1.6s |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 5 | 1 | 1 | 0 | 0 | 3.3s | 1.3s |
| | 6 | 1 | 1 | 4 | 0 | 13.9s | 0.9s |

There was no form of intervention for these participants during this session.

## 4. 3 Quantitative Results

For the quantitative data analysis , the t-test and the chi-squared tests were the statistical tools used to analyze the data.

### 4.3.1 T-test

The t-test was conducted to determine if there was any statistical difference between the communication results of the participants when they used Eline Speaks and the prototyped solution. The t-test was used to analyze the right and wrong attempts made by the participants when communicating.

The hypothesis being tested was:

*Using the prototyped system increases the participant's right attempts made when communicating and reduces their wrong attempts*

**$H_0$**= There is no difference between the number of right attempts/ wrong attempts made using Eline Speaks or the prototyped solution

**$H_1$**= There is a difference between the number of right attempts/ wrong attempts made using Eline Speaks or the prototyped solution

The level of significance was 0.05.

From using the t-test, the null hypothesis indicated that there was no difference between the number of right attempts or wrong attempts when the participant used both systems. The p-value indicates if there is any statistical difference between the two data sets. This provided insight into whether there was an improvement in communication when the participant used the prototyped solution.

**Participants with motor deficits**

When participant 1 used the prototyped solution to communicate, the number of right responses made increased by 20% , while wrong responses decreased by 100%. In addition, the total time taken to communicate decreased by 60.9 seconds. Hence, the prototyped system increased the communication rate for participant 1 when compared to the communication rate of Eline Speaks. In order to communicate using Eline Speaks, the participant required physical intervention from their teachers to be able to select the needed item; however, with the prototype, there was no form of intervention. The participant was able to navigate the system without any aid.

From the t-test carried out on the number of right attempts, the p-value generated was 0.34 ($p=0.34$). Hence, since the p-value is greater than the level of significance which is 0.05, we fail to reject the null hypothesis which states that there is no difference between the number of right attempts made by participant 1 when using Eline Speaks and when using the prototyped solution. For the wrong attempts, the p-value was 0.051 ($p=0.0051$), since it is $\leq 0.05$, we reject the null hypothesis. Hence ,there is a statistical difference between the wrong attempts made using Eline Speaks and the prototyped solution. When the participant used the prototyped system, the number of wrong attempts decreased significantly.

For participant 2, the number of right attempts when using Eline Speaks and the prototyped solution remained the same. However, the number of wrong attempts decreased by 48.3%. The total response time taken by participant decreased by 238.3 seconds. This indicated that the prototyped system aided in successful communication as less time was taken by the participant to relay their thoughts, in addition, the participant was able to select the desired object successfully when compared to using Eline Speaks.

The p-value for the number of correct attempts for participant 2 was 1 ($p=1$). The p-value indicated that there was no difference between the number of right attempts made when the participant used both systems.

**Non-verbal Participants**

Participant 1's right responses when using the prototyped system increased by 50%. The wrong attempts reduced by 85% when using the prototyped system. Furthermore, the total time taken to communicate when using the prototyped system was 80% shorter than when the participant used Eline Speaks.

From conducting the t-test, the p-value for the number of right attempts was 0.144 ($p=0.144$). Hence, since the p-value was greater than 0.05, it meant that the null hypothesis could not be rejected. Hence, there was no difference between the number of right attempts made when participant 1 used Eline Speaks or the prototypes system. For the wrong attempts, the p-value was 0.002 ($p=0.002$),which was less 0.05. This indicated that there was a statistical difference between participant 1 wrong attempts when using Eline Speaks and the wrong attempts when using the prototyped system. This is a clear indicator that the prototyped solution was more effective as it reduced the error rate as well as time taken to communicate.

On the other hand, participant 2's right responses increased by 20% when using the prototype. The wrong responses decreased by 100% which indicated that communication was a total success when using the researcher's prototyped solution. The success rate reflected the 94.2% reduction in total communication time when the participant used the prototype. For the second participant, there was no intervention compared to Eline Speaks, where physical intervention was used in all trials.

The result of conducting the t-test on the right attempts made by participant 2 when using both systems produced a p-value of 0.34 ($p=0.34$). The p-value which is higher than 0.05, indicated that there is no statistical difference between the number of right attempts achieved when using both systems. For the wrong attempts, the p-value was 0.001, ($p=0.001$). This implied that there was a statistical difference between the number of incorrect attempts made by participant 2 when using the two systems. The prototyped solution resulted in a sharp decline in the number of incorrect attempts. This illustrated that the prototyped interface was accessible and easy to navigate.

For participant 3, the number of right responses remained the same when the participant used Eline Speaks and the prototyped system. The number of wrong responses increased by 30% as well as total communication time which increased by 0.2s. During the session, participant 3 went off task five times. During the off-task periods, the participant deviated from the tasks assigned and lost attention and focus. Based on the interview conducted with the teachers, participant 3 was said to have cognitive issues; hence the participant was significantly impaired during the session. The cognitive impairment reflected in participants 3's behavior and results.

Since the number of right attempts made by participant 3, did not change when using either of the systems, the statistical difference on the number of right attempts could not be determined.

For the wrong attempts, the p-value was 0.5, (p=0.5). Hence there is no statistical difference between the wrong attempts made by participant 3 when using the two systems. This is evident, as participant 3, deviated from the task multiple times and appeared unmotivated to continue using either of the applications.

**Participants with moderate competencies**

It is to note that the participants with moderate competencies, are fairly verbal and have stable motor capabilities. They were not dependent on PECS to communicate unlike the rest of the participants involved in the study.

The number of right attempts for participant 1 remained the same while using the AAC app and the prototyped solution. However, there was a 100% decrease in the number of incorrect attempts when participant 1 communicated using the prototyped solution. This highlighted that the prototyped solution was more accessible for the participant to navigate and hence easier for the participant to select the desired item.

When conducting the t-test, the p-value for the number of wrong attempts was 0.54, (p=0.54). Hence, there was no statistical difference between the number of wrong attempts made by participant 1 when using either of the systems. Since the number of right attempts was the same for participant 1 when using both systems, there was also no statistical difference.

For participant 2, 3, 4 and 5, the number of right and wrong attempts made in communicating when using Eline Speaks and the prototyped system remained the same; hence there was no increase or decrease in the communication rate. The p-values could not be determined.

For participant 6, the number of right attempts when using both systems remained the same. When participant 6 communicated using the prototyped system, there was a 100% decrease in the number of wrong attempts. When conducting the t-test, the p-value for the number of incorrect attempts between the two systems was 0.17 ($p=0.17$). Hence, we accepted the null hypothesis which states that there is no statistical difference between the number of wrong attempts made by participant 6 when using the two systems.

### 4.3.2 Chi-squared test

The chi-squared test was conducted to identify if there was a significant difference between the expected frequency, which is the time taken to communicate when using Eline Speaks and observed frequency which is the time taken to communicate when using the prototyped Solution. The participants with moderate capabilities were not included in this test ,because the results of the observational study indicated that there was no communication difference when the participants used both systems.

**Table 8: Average time taken by participants to complete the tasks using Eline Speaks (Observed)**

| | **Motor deficit** | | **Non-Verbal** | | |
|---|---|---|---|---|---|
| Trial | Participant 1 | Participant 2 | Participant 3 | Participant 4 | Participant 5 |
| 1 | 27.3 | 48 | 10.5 | 10.6 | 36 |
| 2 | 16.5 | 65.3 | 9.9 | 60.9 | 50.8 |
| 3 | 30 | 67.3 | 1.4 | 2.3 | 80.3 |
| 4 | 3.8 | 59.9 | 6.6 | 6 | 58.2 |
| 5 | 3.6 | 59.3 | 12 | 54 | 40.7 |

| | | | | | |
|---|---|---|---|---|---|
| 6 | 4 | 61.2 | 67 | 2.3 | 40.2 |
| Average | 14.2 | 48 | 17.9 | 22.68333333 | 51.03 |

**Table 9: Average time taken by participants to complete the tasks using Prototyped Solution (Expected)**

| | Motor deficit | | Non- Verbal | | |
|---|---|---|---|---|---|
| Trial | Participant 1 | Participant 2 | Participant 3 | Participant 4 | Participant 5 |
| 1 | 3.4 | 20.2 | 4.7 | 0.9 | 20.4 |
| 2 | 4 | 22.4 | 3.8 | 1.2 | 38.8 |
| 3 | 5.800E+00 | 21.5 | 2.3 | 1.8 | 60.3 |
| 4 | 3.50 | 13.2 | 3.2 | 0.9 | 55.8 |
| 5 | 3.6 | 20.3 | 3.1 | 1.6 | 70.7 |
| 6 | 4 | 25.2 | 4.1 | 1.4 | 60.4 |
| Average | 4.05 | 20.47 | 3.53 | 1.3 | 51.07 |

**Table 10: Mean and standard deviation(Std)**

| | |
|---|---|
| **Mean** | -14.68 |
| **Std** | 10.57407338 |

The p-value calculated was 0.036069198, and the level of significance is 0.05.

The hypothesis being tested was:

*There is a difference in the average time it takes a participant to communicate when using Eline Speaks and the prototypes system*

**$H_0$**= There is no difference in the average time it takes a participant to communicate when using Eline Speaks and the prototypes system

**$H_1$**= There is a difference in the average time it takes a participant to communicate when using Eline Speaks and the prototypes system

Since the p-value is less than the level of significance which is 0.05, we reject the null hypothesis which states that there is no difference between the mean times and concludes that a significant difference does exist. Therefore, this indicated that there was a statistical difference between the time it took for participants to communicate with Eline Speaks and the prototyped system. The prototyped system reduced the time it took for participants to communicate, therefore indicating that the prototyped system reduced errors and hence allowed the users to communicate more effectively and efficiently.

### 4.4 Qualitative Findings

The findings were derived from conducting the usability tests as well as the observational study. They are:

1. Participants that were between the ages of 13-19 had a higher success rate compared to the rest of the participants. These participants were those with moderate verbal, cognitive and literary competencies; hence there was no significant difference between the number of right attempts made when using Eline Speaks and the prototyped solution. This indicated that AAC systems when used by children between the ages of 13-19, does not significantly increase the user's

communication abilities. At that age range, the participants had already undergone speech therapy and the required education. Hence they were able to read, understand commands, match text to images and speak to some degree. This is not to say that the AAC system did not aid in communication, but the rate of improvement in communication was not significant for older participants.

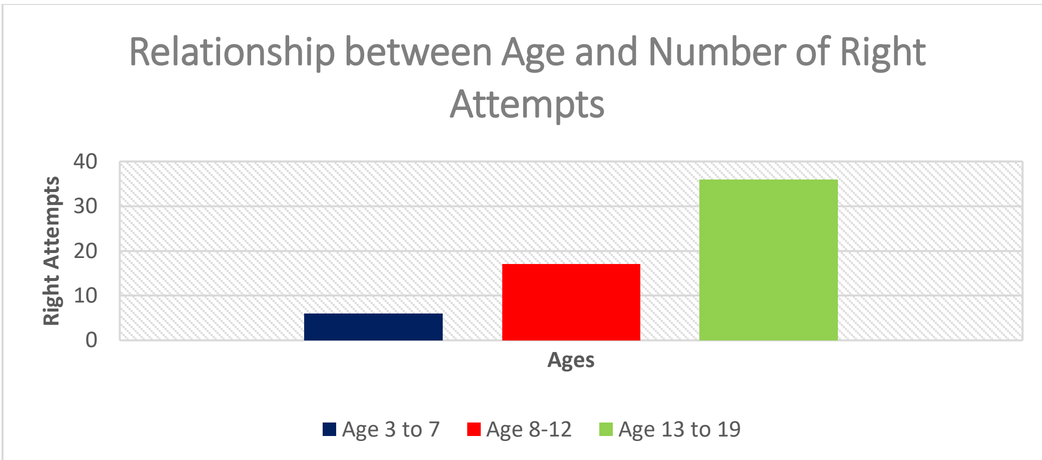



**Figure 7: Relationship between the age and frequency of right attempts made by the participants**

2. Intervention from their teachers during the sessions, helped the participants to communicate better. In sessions where the participant had difficulty selecting the desired object, the teacher either prompted the participant or gestured to the item. After the intervention, the participant's number of right attempts began to increase. Hence, it was deduced that intervention from natural communication partners plays a crucial role in an autistic child's adaptation to AAC systems.

3. The natural setting and interaction with a natural communication partner impacted the participant's ability to communicate. The naturalistic observation did not include altering the environment or controlling the environment to trigger the participants to obtain desired results. The researcher carried out a test whereby , the researcher rather than the teacher tried to prompt the participants to select the item on the AAC system. However, the participants were non-

cooperative when dealing with the researcher unlike when the students interacted with their natural communication partner. By conducting the study in a natural environment, it is guaranteed that the outputs or results are real and not calculated. The reactions are also genuine. Hence research done on autism and AAC intervention should be carried out in natural settings and with a natural communication partner. These studies should not be conducted under controlled environments.

4. Participants with previous experiences with AAC systems demonstrated higher performances than other participants. The Picture and Exchange Communication System (PECS) was adopted in the center; hence for some participants, their level of adaptation to the tablet-based system was not much. Hence, prior experience with AAC systems aided most participants to navigate the tablet-based system easily.

5. Over time, the time taken for the participant to select an item reduced as they began to adapt and become familiar with the system. The familiarity in the use of the system allowed the participants to navigate the application easily.

# Chapter 5 : Conclusion and Recommendation

This chapter discusses the results obtained from the research. The paper provides recommendations to AAC designers on the proper user interface guidelines and elements for developing tablet-based AAC systems. Analysis done in this paper provides insights on how inclusive and adaptable AAC technologies should be developed to factor in the varying and complex competencies of its users.

## 5.1 Conclusion

From the analysis conducted in the paper, it can be deduced that the prototyped solution improved the user's communication rate. The insights from the study indicated that the spacing, font-text, layout/ grid and images on AAC apps should be taken into proper consideration when developing assistive technology for autistic children due to their varying abilities. Feedback from the usability test showed that larger texts, allowed the participants to see the text clearly and match the text to an image, allowing them to select their desired object. Ample spacing between elements was a useful guideline, as it reduced the possibility of errors for participants with poor motor skills and allowed the participants to communicate effectively. The reduction of clutter/ elements on the screen, allowed participants to identify each element on the interface quickly. Participants had a higher rate of success when the items on display were reduced compared to when there were multiple items. The results showed that hierarchies within the system created cognitive pressure for most of the participants; hence the prototyped system eliminated this feature in order to reduce the cognitive load on the participants. Colors also played an essential role in the calming the participants during the study.

From the analysis done in the paper, it can be identified that there is a correlation between the increase in communication while the participants adopted the prototyped system. The prototyped solution was developed from carrying out usability tests ,interviews and observational studies on autistic children with varying competencies. This indicated that the guidelines developed by the researcher do satisfy the varying complex needs of autistic children.

## 5.2 Recommendations

The research conducted highlights the significance of developing AAC technologies that functionally satisfy the varying competencies of its users. AAC developers when designing AAC systems should conduct extensive research with participants of varying motor, cognitive and linguistic competencies. This would provide researchers with insights on how to make the system usable for individuals within the autism spectrum. Researchers should also focus on the user experience that users would have on the system rather than focus on the aesthetic of the system. By focusing on functionality and the processes of interaction, researchers will be to identify elements of the system that users will find it difficult to understand or navigate and in turn improve the users experience using the system.

In addition, it would be recommended that research of this nature by conducted in natural environments and with natural communication partners, as the lack of natural experiments is a gap that exists in autistic research.

## 5.3 Experiment Limitation

There were several limitations that were encountered during the research study. The first limitation was the academic nature of the autistic center. Students were not required to attend classes every day. Due to the student's behavioral patterns , students were permitted to miss classes. Hence, it was difficult to track the progress of some participants since their availability was not constant.

Secondly, the Observer XT software and the FaceReader software could not be utilized to code the behavior of the participants. The autistic center prohibited videos from being taken. In addition, the nature of the videos taken made it difficult to access the media.

Thirdly, the sample size for the study was small. The autistic center had a few students in attendance; hence the sample size for the study was not significant. This affected the statistical results obtained when conducting the t-test and the chi-squared test. In addition, the participants were not diverse in terms of gender. There were only two females that participated in the study; hence statistical data in relation to the sex of the participant could not be calculated.

Lastly, the participants within the study shared similar characteristics and behavioral patterns hence, it was difficult to obtain diverse user groups from the sample population.

### 5.4 Future Research

Research on developing assistive technology for autistic children is extensive due to the wide spectrum of autism. There still exist numerous opportunities that can be explored. In the future, more participants will be involved in the study in order to produce proper statistical data. In addition, multiple existing systems would also be tested in order to identify numerous comprehensive limitations of already existing AAC systems. Lastly, the prototyped solution will undergo numerous iterations based on the feedback generated during usability testing in order to develop a fully functional system.

Future research would also involve conducting usability tests on multiple existing AAC technologies in order to obtain more data on the limitations of AAC systems. In addition, more diverse user groups would be researched upon , in order to generate inclusive guidelines on building accessible AAC technology.

## References

[1] Mirenda Pat. 2013. Toward functional augmentative and alternative communication for students with autism: Manual signs, graphic symbols, and voice output communication aids. *Language, speech, and hearing services in schools*. ( July 2003), 203-216.

[2] John D. Bonvillian, Keith E. Nelson and Jane M. Rhyme. Sign language and autism. *Journal of Autism and Developmental Disorders* 11, 1 (March 1981), 125–137.

[3] Janice Light and David McNaughton. Putting People First: Re-Thinking the Role of Technology in Augmentative and Alternative Communication Intervention. *Augmentative and Alternative Communication*, 29:4, 299-309. DOI: https://doi.org/10.3109/07434618.2013.848935

[4] Janice Light and David McNaughton. 2015. Designing AAC Research and Intervention to Improve Outcomes for Individuals with Complex Communication Needs. *Augmentative and Alternative Communication* 31, 2 (2015), 85-96. DOI: https://doi.org/10.3109/07434618.2015.1036458

[5] Susan Baxter , Pam Enderby, Philippa Evans and Simon Judge. Barriers and facilitators to the use of high-technology augmentative and alternative communication devices: a systematic review and qualitative synthesis . *International Journal of Language &Communication Disorders* , *47* , 2 (March-April 2012) ,115 – 129 .

[6] Krista M. Wilkinson , Janice Light. And Kathryn Drager . 2012.Considerations for the composition of visual scene displays: Potential contributions of information from visual and cognitive sciences , *Augmentative and Alternative Communication* , *28* , (2012), 137 – 147 . DOI: https://doi.org/10.3109/07434618.2012.704522

[7] Susan Fager, David R. Beukelman, Melanie Fried- Oken, Tom Jakobs PE, and John Baker . 2012. Access Interface Strategies. *Assistive Technology: The Official Journal of RESNA* 24, 1(25-33). DOI: http://dx.doi.org/10.1080/10400435.2011.648712

[8] Harini Sampath, Ravi Agarwal, and Bipin Indurkhya. (2013). Assistive technology for children with autism – lessons for interaction design. *Proceedings of the 11th Asia Pacific Conference on Computer Human Interaction*.325-333. DOI: https://doi.org/ 10.1145/2525194.2525300

[9] Drager Kathryn, Janice C. Light, JoHannah C. Speltz, and Lauren Z. Jeffries. (2003) The performance of typically developing 2 ½ -year-olds on dynamic display AAC technologies with different system layouts and language organizations . *Journal of Speech, Language and Hearing Research , 46* , (April 2003), 298 – 312 . DOI: https://doi.org/10.1044/1092-4388

[10] E. L. Wodka, P. Mathy, and L. Kalb. 2013. Predictors of Phrase and Fluent Speech in Children With Autism and Severe Language Delay. *PEDIATRICS* 131, 4 (April 2013), e1128–e1134. DOI:https://doi.org/10.1542/peds.2012-2221

[11] American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Washington, DC: Author.

[12] Lord, C. & Paul, R. (1997). Language and communication in autism. In D. Cohen & F. Volkmar (Eds.), *Handbook of Autism and Pervasive Developmental Disorders* (195-225). New York: John Wiley and Sons.

[13] Venter, Catherine Lord, and Eric Schopler. 1992. A Follow-Up Study of High-Functioning Autistic Children. *Journal of Child Psychology and Psychiatry* 33, 3 (March 1992), 489–597. DOI:https://doi.org/10.1111/j.1469-7610.1992.tb00887.x

[14] Berkley, S.L., Zittel, L.L., Pitney, L.V., & Nichols, S.E. (2001). Locomotor and object control skills of children diagnosed with autism. *Adapted Physical Activity Quarterly, 18*, 405-416.

[15] Janine Manjiviona and Margot Prior. 1995. Comparison of Asperger syndrome and high-functioning autistic children on a Test of Motor Impairment. *Journal of Autism and Developmental Disorders* 25, 1 (February 1995), 23–39. DOI:https://doi.org/10.1007/BF02178165

[16] Jessica Gosnell, John Costello, and Howard Shane. 2011. Using a Clinical Approach To Answer "What Communication Apps Should We Use?" *Perspectives on Augmentative and Alternative Communication* 20, 3 (September 2011), 87. DOI:https://doi.org/10.1044/aac20.3.87

[17] Debora M. Kagohara, Larah van der Meer, Donna Achmadi, Vanessa A. Green, Mark F. O'Reilly, Austin Mulloy, Giulio E. Lancioni, Russell Lang, and Jeff Sigafoos. 2010. Behavioral Intervention Promotes Successful Use of an iPod-Based Communication Device by an Adolescent With Autism. *Clinical Case Studies* 9, 5 (October 2010), 328–338. DOI:https://doi.org/10.1177/1534650110379633

[18] Sajay Arthanat, Christine Curtin, and David Knotak. 2013. Comparative Observations of Learning Engagement by Students With Developmental Disabilities Using an iPad and Computer: A Pilot Study. *Assistive Technology* 25, 4 (October 2013), 204–213. DOI:https://doi.org/10.1080/10400435.2012.761293

[19] Katherine Deibel. 2013. A convenient heuristic model for understanding assistive technology adoption. In *Proceedings of the 15th International ACM SIGACCESS*

*Conference on Computers and Accessibility - ASSETS '13*, 1–2. DOI:https://doi.org/10.1145/2513383.2513427

[20] April Stauffer. 2015. User Interface Adaptability within an Augmentative Communication App for Children with Autism Spectrum Disorder. (2015), 130.

[21] Nikolay Pavlov. 2014. User Interface for People with Autism Spectrum Disorders. *Journal of Software Engineering and Applications* 07, 02 (2014), 128-134.DOI:https://doi.org/10.4236/jsea.2014.72014

[22] Lewis, C., & Rieman, J. (1993). Task-centered user interface design. *A Practical Introduction*.

[23] Sparrow, S.S., Cicchetti, D.V. & Balla, D.A. 2005. Vineland-II: Vineland Adaptive Behaviour Scales, Second Edition. Pearson PsychCorp

[24] Turner Denise. 2017. Color and Autism. (April 2017). Retrieved April 21,2019 from enduratex.blogspot.com/2017/04/color-and-autism.html

# Appendix

**Teacher Interview Questions**

| | |
|---|---|
| Child Pseudonym: | |
| Age: | |
| Sex: | |

**Introduction**

The following questions will cover areas of the child's motor skills, preferences, linguistic, language skills, familiarity with technology, experience using AAC systems. The following statements would be rated using the following: never, often, sometimes.

**Listening and Understanding**

| | Often | Sometimes | Never |
|---|---|---|---|
| Responds to his/her name spoken | | | |
| Responds to yes or no instructions | | | |
| Can listen for more than 5 minutes | | | |
| Responds to instructions | | | |

| | | | |
|---|---|---|---|
| Can point to items when needed | | | |
| Understand commands | | | |

**Motor Skills**

| | Often | Sometimes | Never |
|---|---|---|---|
| Can pick up small items | | | |
| Moves objects from one hand to another | | | |
| Grasps a ball | | | |
| Hold items for more than 5 minutes | | | |
| Put items into and out of a container | | | |
| Fidgets when handling objects | | | |
| Can manipulate objects using hands and fingers | | | |

**Literacy/ Linguistic Skills**

| | Often | Sometimes | Never |
|---|---|---|---|
| Identifies at least 8 letters | | | |
| Uses receptive language | | | |
| Can read or understand short words | | | |
| Can match words to the respective image | | | |

<u>OPEN-ENDED QUESTIONS</u>

**Experience with Augmentative and Alternative Communication(AAC)**

| | Response |
|---|---|
| Has your child ever adopted an AAC system? | |
| If yes, state the name of the system | |
| What criteria was used to adopt the system? | |

| | |
|---|---|
| What level of training was required? | |
| Did you notice an improvement in communication? If yes, elaborate | |
| If not, elaborate | |
| Does your child currently use the system? | |
| Do they require prompting to use the system? | |
| Was the system clinically recommended? | |

**Familiarity with Technology**

| | Response |
|---|---|
| What type of technology is your child familiar with? | |
| Do they have experience with tablet systems? | |
| What activities do they perform on the tablet? | |

| | |
|---|---|
| Do they require assistance to use the tablet? | |
| Do they use the tablets routinely? | |

**RATING SCALE**

| Rating | |
|---|---|
| Often | Can perform the tasks without any assistance.<br>Does not require reminders to perform the behaviors. |
| Sometimes or Often | Can sometimes perform the task without any reminders.<br>Can perform the task partially without any assistance. |
| Never | Cannot perform a task without any help or assistance. |