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# Technological Evolvement in AAC Modalities to Foster Communications of Verbally Challenged ASD Children: A Systematic Review

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**ABSTRACT** Augmentative and Alternative Communication (AAC) emerged as a combination of methods or strategies that constitute any device, such as Speech Generating Device (SGD), Program (mobile applications), Procedure (PECS, Picture Exchange Communication System), which enhances individual's communication ability. Autism Spectrum Disorder (ASD) is a spectrum of comprehensive neurodevelopment disorder that leads to speech impairments, repetitive behavior, and social communication difficulties; therefore, it is imperative to underscore that at the core of all impediments are communication impairment. This article represents a systematic review of research initiatives that investigate multi-modal AAC strategies and functionality, features of mobile applications to reinforce communication and communal skills in verbally challenged ASD children because other researches are focused only on low or high-tech AAC or interventions to provide insights on ASD children respond to a particular approach. Following the PRISMA method, a total of 60 (January 2015 to October 2020) research articles were reviewed, indexed by Springer, Science Direct, Scopus, ACM, IEEE databases, and published in the AAC journal. The selected research articles are categorized into different themes where most of them focused on interactive mobile applications to improve emotional, social, learning, and overall communication skills in verbally challenged ASD children. This systematic review provides an outline of the paradigm shift in AAC modalities from PECS to Artificial Intelligence (AI), Machine Learning (ML), and Augmented Reality (AR) based applications. It opens up underline future opportunities to integrate intelligent analytics features in mobile applications to strengthen communication skills in verbally undermined ASD children.

**INDEX TERMS** Augmentative and Alternative Communication(AAC), Autism Spectrum Disorder(ASD), Mobile Applications, Machine Learning (ML), Artificial Intelligence(AI), Augmented Reality(AR).

## I. INTRODUCTION

ASD (Autism Spectrum Disorders) is a cluster of comprehensive neurodevelopmental disorders, and evolving as a significant public health complication that has extended beyond geographical, economic, and societal borders. In 2012, around the globe, 62 individuals per 10000 have been documented to prevail on the spectrum [1]. Considering the methodological variation in the estimation of the prevalence of ASD around the world, overall projections vary from 0.19 /1000 to 11.6/1000 [2]. This lower figure was, however, ascribed to a dearth of information from lower-middle-income countries like Bangladesh where alarming growth of Autism along with heavily dense population, making ASD one of the severest issues and the scenario of these developing countries is exceptional for its financial limitations and scarcity of awareness [3].

ASD is marked by speech difficulties, repeated activities, and social communication impairments [4]. Considering these differences, it is vital to emphasize that at the forefront of all impairments are communication; 25% of the individuals with autism are lacking natural speech as their fundamental means of communication corresponding to the National Institute on Deafness and Other Communication Disorders (NIDCD, 2010) [5]. It has been found that in 76% cases people diagnosed with autism will not strengthen eloquent communication and in 30% cases no advancement to vocal output [6]. Augmentative and Alternative Communication (AAC) systems have arisen as methods to better overcome the communication issues that many individuals diagnosed with ASD encounters. In compliance with ASHA (American Speech-Language-Hearing Association) [7], AAC is a comprehensive group of elements, including signs, communication assistance, methods, and techniques utilized by individuals to maintain communication. While AAC is commonly indicated as structured communication instruments and devices such as sign language, communication board, speech-generating devices, it also incorporates less profound communication modalities, for instance, articulations, facial manifestation, and distinctive gestures [8]. AAC involves more than one communication system so that individuals can utilize the most relevant one based on circumstances, communication partners, and involved activity. The utilization of images, like PECS (Picture Exchange Communication System), to facilitate individuals with language learning became the initial point for AAC approaches. But still, given PECS advantages, there were technical obstacles that need to be addressed. For Instance, printed images require time to produce and do not include a way to manipulate them according to user requirements and monitor language development. AAC devices, for example, Speech Generating Device (SGD), started to arise from this urge to make the system more efficient. Parents and Special Educators mention that AAC devices are feasible for training minimally verbal ASD children, yet additional resources and capabilities are required to utilize them [4,8]. AAC based mobile applications were developed out of this necessity to be capable of competing with these devices and have been cost-effective and user friendly.

The availability of handheld technology such as smartphones, iPad, iPhone along with apps permits a consumer-oriented delivery model which enable a dramatic shift in AAC for individuals with ASD [9]. Installation of an app on commercial mobile device enhance the accessibility of AAC solution to parents or caregivers of individuals with an autism spectrum disorder. Parents or caretaker can assess an app based on rating and this grant a perceiving of authority and participation to the family to recognize the voice for their child [10]. Moreover, apps are installed in a compact, lightweight, and handheld electronic devices and it is convenient for users as these applications can be employed anytime and anywhere. Apps are configured in all sorts of electronic devices which facilitate convenience for different data records. Therefore, a potential app with Artificial Intelligence (AI) and Machine Learning (ML) features will help family and caregivers to monitor autistic child's daily activities and other details. These data can monitor one's development as well as offer useful knowledge for autism child rehabilitation research [11]. Besides, compared with other devices, smartphones are simpler, quicker, more flexible, more user friendly, more compact, and advance in communication skills [12] is noted that mobile apps can be utilized as a means of contact between children and their surroundings.

Our research focuses on investigating the evolving trend in multimodal AAC strategy and advancement in features and functionality of the mobile application that contribute to fostering communication as well as social skills in ASD children with circumscribed verbal potentiality. By features, we refer to symbol scheme, navigation, speech output, customization, and context-based recommendation whereas functionality pertains to the integration of Artificial Intelligence (AI), Machine Learning (ML), Augmented Reality (AR) gamification properties in mobile applications.

To accomplish our research intent, we investigated a total of 60 research articles that were sorted via systematic search from five noteworthy databases- Springer, Scopus, ACM Library, Science Direct, IEEE Xplore, and one prominent journal- Augmentative and Alternative Communication. To comprehend the trend in AAC modalities and emerging intelligent technologies to improve communication and social skills in ASD children, we classified these articles under different themes. Our findings demonstrate that handheld technologies, especially mobile applications are becoming more prominent among ASD children as well as their parents, caregivers, special educators, physicians, and therapists. Moreover, the integration of AI, AR, and ML in mobile applications facilitate ease of monitoring and context-based communication and these particular areas require more research attention. Most of the research focused on developed countries. However, mobile applications can be culturally tailored to address the need for ASD children and their caregivers in developing countries. We recommend that the integration of personalization, intelligent analytics, a context-based recommendation system, and progress monitoring via handheld technology and associated websites as well as incorporating diverse stakeholders (parents, special educators, therapists, caregivers) will ensure a desirable enhancement of communication and social competence in ASD children.

## II. SYSTEMATIC REVIEW

A review is designated as a systematic study if it comprises the subsequent strategies which subsist of an affirmed research question, identification of proper studies, assessment of their quality, and empirical studies with precisely stated outcome [13]. A systematic review must be organized in a definitive procedure to concentrate on a coherent, explicit research question and pertinent studies must be incorporated on the premise of inclusion and exclusion criteria while embodying the sphere of investigation. After the selection of the relevant studies, quality assessment, delineating the evidence, and explication of the findings must be integrated to provide a critical lucid conclusion and future directions [13]. The focus of this investigation or research statement is to shed light on the existing AAC strategies or tools and

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advancement in AAC handheld technology that aims to foster the development of communication as well as social skills in Autism Spectrum Disorder (ASD) with limited verbal capability. This systematic review considered research articles/papers indexed by Scopus, Springer, ACM, Science Direct, IEEE, and by Augmentative and Alternative Communication Journal, published between January 2015 to October 2020. The commencement of systematic review begins with planning and formalization of the study protocol, designating the research problem, its objective or aim, relevant research questions, and related keywords. The following table delineates the study protocol.

**TABLE 1.** Study protocol

| |
|---|
| **Research Statement:** To investigate multimodal AAC strategy and advancement in AAC handheld technology to augment communication as well as social skills in ASD Children with circumscribed verbal potentiality. |
| **Objective:** To review research possibilities in AAC based mobile applications to support communication and communal skills in ASD Children restricted verbal ability. |
| **Generic Question:** What are current pragmatic solutions for supporting communication and social skills in ASD children via AAC mobile applications and what are the modalities of AAC that have been utilized ? |
| **Research Questions:**<br>**RQ1.** What type of AAC modalities are feasible for ASD children with limited verbal capacity?<br>**RQ2.** Are there certain proclivities towards AAC modalities by the ASD children?<br>**RQ3.** What are the limitations of AAC modalities that promotes widespread utilization of handheld technology, particularly mobile applications?<br>**RQ4.** What type of features and functionalities are prominent in mobile applications?<br>**RQ5.** What are the objectives of developed mobile applications and their corresponding features ?<br>**RQ6.** How Artificial Intelligence (AI), Machine Learning (ML) and Augmented Reality (AR) is incorporated in mobile applications to enhance communication ability in ASD children? |

### A. STRATEGY OF RESEARCH ARTICLE SELECTION:

Following the study protocol, selection criteria were outlined and employed as a 1st type screener on the extracted studies. Selection criteria were categorized into inclusion and exclusion criteria and employed to categorize the research articles based on their meta-data (title, abstract, and keywords). According to the guideline of Meline et.al [14], utilizing a critical evaluation approach that targets to include research studies that fulfilled the eminent methodological standard of quality. The inclusion criteria were not too extensive and not too brief. Research articles that complied with at least one of the inclusion criteria were listed and articles that fall under at least one exclusion criteria were precluded. The following table depicts the Inclusion and Exclusion criteria as the 1st type screener.

**TABLE 2.** Inclusion and Exclusion criteria as 1st type screener

| Specifications | Inclusion Criteria | Exclusion Criteria |
|---|---|---|
| **Type of Research Articles** | **IC1.** Research Articles issued in peer reviewed journals and scientific research. | **EC1.**Grey Literature,book review,thesis dissertation, Opinion articles,lecture notes papers. |
| **Objective or Aim of the Research Article** | **IC2.** Research articles that aim to enhance communication or language and social skills in ASD children with limited verbal ability with AAC strategy or application. | **EC2.**Research articles focus on development of other skills, screening process in ASD Children and not including AAC strategy as the research area. |
| **Language** | **IC3.** Research articles or scientific research papers utilizing English as the mean of writing. | **EC3.**Research articles or papers in any other language but other than English. |
| **Database** | **IC4.** Scopus, Springer, ACM, Science Direct, IEEE and Augmentative and Alternative Communication Journal and related references of selected articles. | **EC4.**Research articles foreign to the included database and journal as well as databases not available to the researchers. |
| **Publication Time Frame** | **IC5.** Research articles and papers focusing on communication or social skills in ASD Children and AAC based applications published from January, 2015 to October, 2020. | **EC5.**Research articles and papers focusing on communication or social skills in ASD Children and AAC based applications not published from January, 2015 to October, 2020. |

The selection criteria for 2nd type screener were specified and implemented on the comprehensive reading of the selected research articles that results from 1st type of screener.Table.3 delineates the selection terms.

**TABLE 3.** Selection criteria for 2nd type screener

| **2nd Screener-Selections Terms** |
|---|
| **AAC**: Augmentative and Alternative Communication |
| **PECS**: Picture Exchange Communication System |
| **SGD**: Speech Generating Device |
| **Comparison**: Comparative studies on multi-modal AAC modes. |
| **Apps** : Applications on Mobile, Tablets or handheld systems based on AAC themes. |
| **AI& ML**: Artificial Intelligence or Machine Learning based mobile applications focused on communication skills. |
| **AR**: Augmented Reality based handheld technologies related to AAC. |

### B. RESEARCH ARTICLE SELECTION

In the second phase of the systematic review, search keywords were determined, adjusted, and configured to the selected databases. The initial search comprised of 1547 research studies, after the 1st type screener application, 1442 studies were excluded which were followed by 2nd type screener results in the exclusion of 45 studies and finally a set of 60 research studies for review purpose.

**TABLE 4.** Instance of search keywords

| |
|---|
| **TITLE**( "ASD Children OR Autism Children" OR "AAC or augmentative and alternative communication" OR "Mobile Applications" AND "Communication or Language Skill" OR "iPad or Tablet" OR "Augmented Reality" OR "Artificial Intelligence") AND **Abstract**( "mobile app" OR "machine learning" AND "communication or social skill" OR "ASD children") |

**TABLE 5.** Achieved Results from Search Keywords

| Name of the Data-Base | Quantity of Research Articles | 1st Type Screener | 2nd Type Screener |
|---|---|---|---|
| Springer | 539 | 32 | 26 |
| Scopus | 170 | 25 | 13 |
| ACM Libary | 406 | 12 | 9 |
| Science Direct | 153 | 17 | 3 |
| IEEE Xplore | 49 | 9 | 3 |
| AAC Journal | 230 | 10 | 6 |
| **Total Number of Research Articles** | **1547** | **105** | **60** |

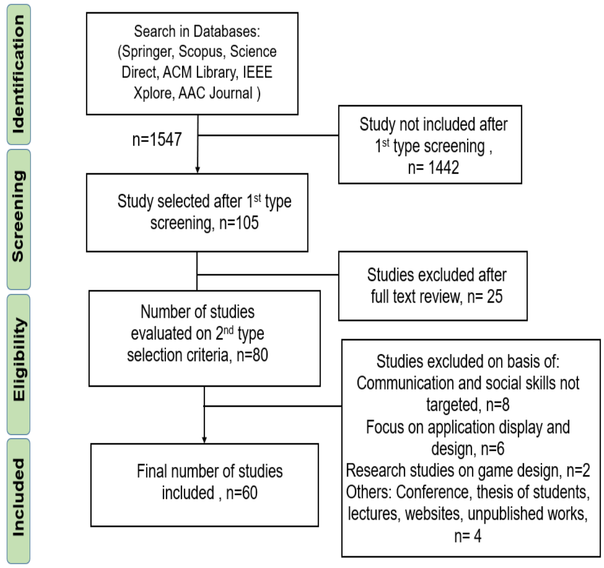


**FIGURE 1.** Flow Diagram of Selected Studies

**TABLE 6.** Data extraction format

| **Features** |
|---|
| Title of Research Article |
| Publication Year |
| Publication Source |
| Scope or Objective of the Research Study |
| Concise Description |
| Type of AAC modality or technology |
| Focus Area ( communication or social skill, mobile applications, features and functionality of proposed solution, comparison, picture exchange communication system, speech generating device, artificial intelligence, machine learning, augmented reality) |
| Evaluation process, number of participants, outcome/results |

### C. DATA EXTRACTIONS FROM SELECTED RESEARCH ARTICLES

A data extraction format is utilized to standardize data derivation from the selected research articles to lessen the biasness of results and generalize the process. The extraction was conducted by the first author and assessed by the second author by following back the data extraction format of each selected paper and reviewing their correctness. A dynamic outline was employed in categorization while the data were extracted. However, a pre-defined categorization might limit the possibilities of emerging categories that result from relevant data. As the goal of this study is systematically evaluates the selected studies, we prefer flexibility in generating themes that results from the data extraction format.

## III. FINDINGS

Subsequently, sorting and reading the selected research articles, the articles are grouped according to publication year (Figure.1). It is observed in the year from 2017 to 2019, the number (34 out of 60) of research articles focus on AAC strategies or applications to enhance language or social skills development in ASD children with verbal impairment, which indicates this particular research area capture the focus of the researchers and academia.

Selected research articles are categorized into seven distinct themes to acknowledge the trend of technological advancement in AAC which aims to develop linguistic or communal skills in ASD children with limited verbal capability. For instance, the themes are Picture Exchange Communication System (PECS), Speech Generating Device (SGD), Comparison between two AAC modalities and three modalities, Mobile Applications, Artificial Intelligence (AI) and Machine Learning (ML) based applications, Augmented Reality (AR) based applications and all of the aforementioned themes represent the articles that demonstrated AAC

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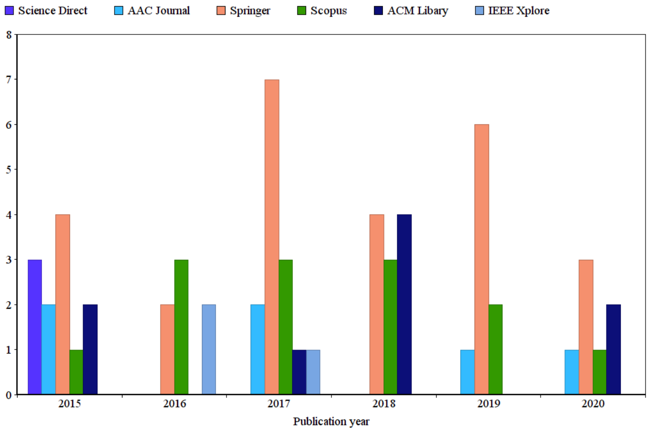


**FIGURE 2.** Selected research articles classified by year

**TABLE 7.** Theme based categorization of selected research articles

| Theme | Selected Research Articles |
|---|---|
| Picture Exchange Communication System (PECS) | [17] [18] [19] [20] [21] |
| Speech Generating Devices (SGD) | [24] [25] [26] [27] [28] [29] [30] |
| Comparison Between Two AAC Modalities | [32] [33] [34] [35] [36] [37] |
| Comparison Among Three AAC Modalities | [42] [44] |
| Mobile Applications | [12] [17] [45] [47] [48] [49] [50] [51] [52] [53] [54] [55] [56] [57] [58] [59] [60] [61] [62] [63] [64] [65] [66] [67] [68] [69] [70] [71] [72] [73] [75] [76] |
| Artificial Intelligence (AI) & Machine Learning (ML) Based Applications | [77] [78] [79] [80] |
| Augmented Reality (AR) Based Applications | [81] [82] [83] [84] |

strategies to augment communication or social skills in ASD children and are strongly relevant to the focus of this study.

The theme-based categorization commences with the data extraction phase and themes emerged while the review process of the articles by the authors. During the data extracting phase, the authors categorized the articles into a pre-defined theme. If the research article did not integrate into an existing theme, then a new theme is defined. Therefore, themes came out inherently during the extraction phase. After the theme-based categorization, the authors reviewed it and relevant modifications were made. Finally, articles are classified into themes delineated in Fig.2. and it is observed that the number of research articles focused on mobile applications was the highest (53.33%) followed by Speech Generating Device (SGD) (11.67%), Comparison of two AAC modalities (10.00%), Picture Exchange Communication System (PECS) (8.33%), Artificial Intelligence (AI) and Machine Learning (ML) based applications (6.67%), Augmented Reality Based mobile applications (6.67%), Comparison among three AAC modalities (3.33%).

### A. PICTURE EXCHANGE COMMUNICATION SYSTEM (PECS)

The Picture Exchange Communication System (PECS), designed by Bondy and Frost in 1985 [15], is an AAC tool for practical image exchange-based interaction. PECS incorporates Applied Behavior Analysis (ABA) guidelines that are formulated in a series of six stages, along with clear objectives, directions, and protocols for teaching. The child is initially instructed to launch requests by figures. Afterward, the child will begin to construct sentences, and address questions. In subsequent stages, the demand is that the child will communicate. The studies categorized under the PECS theme focus on different levels which is commensurate with the aforementioned six stages and highlights different factors that are notable, for instance, D. Hartzheim [16] demonstrated the importance of user preference, therapists skill, portability of AAC system whereas P. Zlatarov et al. [17], underscored the importance of personalization and monitoring of the progress of child development. On the contrary, several studies focused on designing PECS based computer software with different level and introduced peer manding utilizing PECS in natural circumstances. The study conducted by M. Benkherrat [18], developed a computer application consists of four-level which will assist children with autism to exchange and communicate, to understand the certain social-life situation, and to ascertain events by the usage of timetable. Each of the levels has a different purpose where the first level aims to acknowledge and learn new words through image and speech synthesis and the final level permits the child to construct longer sentences composed of several complements. The outcome of the research by A. Doherty et al. [19] demonstrated that PECS mands can be implemented to prepare numerous trained peers and generalization to diverse conditions and children can be taught PECS by applying time delay and positive reinforcement. Besides, the result of the study by A. L.Greenberg et al. [20] support that the visual nature of PECS is effective for children with autism who own visual strengths and support that even though PECS training was conducted in isolated training sessions, generalization can occur in distinct situations and across different people whereas the research by Karena S. Rush et al. [21] examine the impacts of PECS on the verbal response for children who have had intelligible limited vocal skills and utilize PECS as their main communication mode. This study concerned four children with ASD, age range between 5 to 13 in the clinical setting. In two trials, the effects of PECS on vocal responsiveness were tested using a reversal method. Results showed that when vocal response and PECS along with the same reinforcement schedule, PECS was used more often by all four participants with slight to no verbal reaction. When

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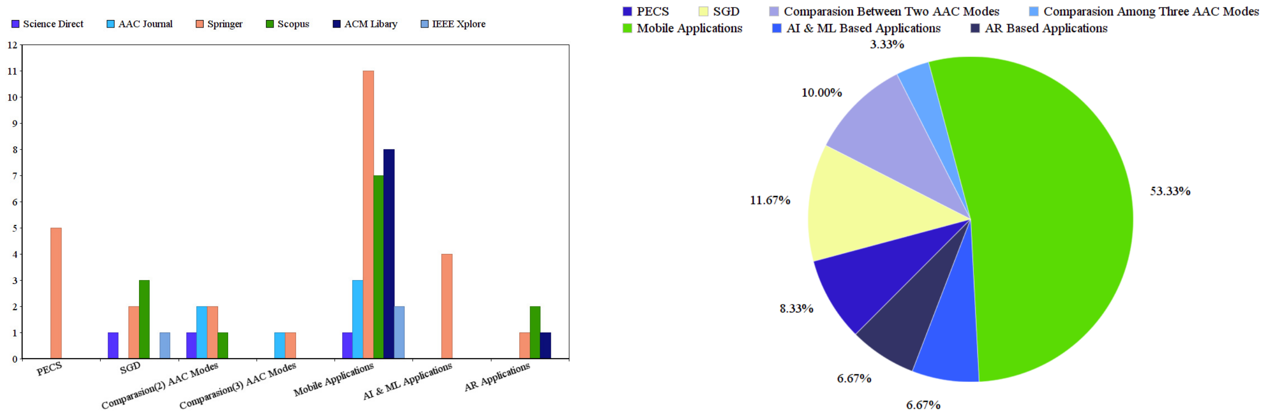


(a) Research Articles categorization by theme

(b) Percentage value of each theme

**FIGURE 3.** Theme Based Categorization

PECS place on extinction or inaccessible vocal response elevated significantly. The inference is that once vocal responses are identified, the utilization of image communication can restrict the use of voice communication. Future research is required on how to efficiently modify response efforts and how to effectively adjust schedules for reinforcement to minimize the use of PECS while maintenance of functional voice expression.

### B. SPEECH GENERATING DEVICE(SGD)

SGD is an electronic device that comes with a speech-generating application or software and capable of incorporating a considerable volume of vocabulary for the user and synthesized voice output is generated by tapping on the icons [22]. As mentioned by M. C. Boesch et al. [23], the benefits of SGD are: speech signal from SGD is accessible to others within reception distance, no instruction is appropriated for a communicative partner to comprehend message like PECS, the user achieves communication independence and an untrained individual can understand the conveyed message. The included research studies in this systematic review focus on investigating the effectiveness of SGD as well as the integration of prompting, like textual promoting, and manding, like asking questions to train ASD children to elicit verbal communication skills. The investigation conducted by E. R. Lorah et al. [24] intended to advance evidence-based research concerning the effectiveness of iPad based SGD with Proloqu2Go$^{TM}$ application to promote intraverbal communication and one of the findings of the analysis is on average four training sessions were required to acquire intra-verbal statement. Similarly, the purpose of the investigation by C. Gevarter et al.[25] is to demonstrate whether individuals with ASD along with limited vocal imitation skills can apprehend selected vocalizations (whole word or approximation of words) while utilizing SGD and the overall findings indicate that additional procedure (echoic prompt or delay in prompt) that targeted vocalizations might augment SGD interventions. Moreover, both A. Carnett et al. [26] and A. Carnett, E. T. Ingvarsson et al.[27] focus on utilizing SGD for communication augment in ASD with textual prompt and madding (question manding) respectively. The results of the former studies indicate that prompting and manding serve as a reinforcement along with SGD to train minimally verbal ASD children. Likewise, the goal of the research by Elizabeth R. Lorah et al. [28] was to assess the efficacy of an interrupted chain process, continuous-time delay with maximum physical prompting in the procurement of peer manding at an art preemptive scheduling, utilizing the tabled-based SGD. In all, four children with ASD, aged between three and five, participated the pre-school educational environment where the study was conducted; three participated as speakers in the study; the fourth child served as the listener for the other three children and one significant result is a comparatively fast rate of skill development. Whereas, the study by Sarah E. Frampton et al. [29] assesses the effectiveness of utilizing Direct Instruction (DI) for ASD students who use speech-generating devices. (SGDs); three ASD students whose main communication mode was SGD were introduced to the Language for Learning Curriculum. The average time to accomplish an activity, frequency of iterations, frequency of discontinued sessions, and student effect were measured. The students displayed enhanced performance, constructive effects, and efficient execution of exercises in general. Taken together these results indicate that for certain ASD students who use SGDs, DI could be feasible. However, all the aforementioned studies are implemented in developed countries but the study conducted by M. N. R. Khan et.al [30] took place in a developing country with two different versions of SGD. The first version is comprised of twelve buttons where each button contains a ten-second long audio file and square sized one-inch picture. The second version is dedicated to ASD children who have prior knowledge of PECS and there

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are four modes where each mode has twelve buttons and a specified button to alter the modes. The outcome of the case studies with the devices demonstrates that participants requesting skills were developed compared to PECS and the overall cost of the designed device was lower than a similar type of device. Overall, minimally verbal ASD children can convey their requirements via SGD provided that the individual has the minimum motor skill to handle the device and assistance of caregivers, parents are required for prompting and manding.

### C. COMPARISON BETWEEN TWO AAC MODALITIES

According to the Department of Health and Human Services (DHHS), Interagency Autism Coordinating Committee's Strategic Plan for Autism Spectrum Disorder Research [31], there is a necessity for comparative research as it is important in promoting rational decision-making in the context of one-to-one comparisons of approaches. The incorporated studies encompass comparison between low tech (PECS, Exchange Based Communication (EBC), Picture Communication Board) and high-tech ( SGD, Visual Screen Display(VSD), iPad Based SGD) AAC interventions. The outcome of such kind of studies S. P. Gilroy et al.[32] indicates that high-tech AAC generates notable improvements in social and communication skills which is analogous to low-tech AAC for school-aged ASD children; however, there is no explicit implication that high-tech should replace low-tech AAC. Besides, a research study by J. B. Ganz et al. [33] concentrates on exploring preference of participants in managing two techniques of AAC ( EBC, VSD) and it is demonstrated that participant who uses VSD frequently has milder ASD and have prior knowledge in identifying skills. The study by M. M. Agius and M. Vance [34], investigated the comparative efficacy of iPad as SGD and PECS to develop request and navigational skills in pre-schoolars with ASD where follow-up data recommend that requesting using PECS was higher than iPad based SGD and indicate a possibility that preference shifts and it only becomes static when proficiency is obtained for any specific communication mode. Similarly, K. M. Tonsing [35] compared SGD with Picture Communication Board but the objective is to correlate the effectiveness of intervention of communication Board or SGD while children with severe motor disorder generate multi graphic symbol during shared storytelling and results demonstrate that after the commencement of intervention all the participants increase the generation of two symbol combinations with both the AAC modes. Likewise, the purpose of the study by Nouf M. Alzrayer [36] to expand the scope of the relevant literature by (a) studying the results of the implementation of enhanced PECS Phase IV improved protocol on the acquisition of random requesting, define the influences of gradual time delay and synthetic production of speech on vocal request and evaluate the preference of the AAC after achieving mastery with both PECS and SGD. Three boys and one girl, age between 2 and 5 years old, with minimal echoic repertoire and no experience with SGD participated within a clinical setting. The outcome of the analysis reveals that all of the participants chose the SGD for requesting when accessible to both modalities. The production of synthetic speech that was generated by triggering symbols on the iPad improved the willingness of the participants to use the app for requesting. In contrast to the aforementioned research studies, the investigation by K. E. Barlow et al.[37] concentrate on the comparison of effectiveness and efficacy of Selection Based (SB), selection topography means speaker attend multiple stimuli and perform verbal conduct by selecting specific stimuli, and Topography Based (TB), topography based communication consists of voice or sign language, based alternative communication while appropriating the training procedure of M. K. Gregory et al.[38] and results demonstrate that three participants with six-mand instruction reached mastery criteria with SB instruction while none of them reached mastery criteria with TB based instruction.

### D. COMPARISON AMONG THREE AAC MODALITIES

Several studies [39] [40] [41], demonstrate that children with ASD and development delay exhibit preference of one AAC mode over others that have been taught to them and the initial preference might be based upon the presentation of the system (such as iPad) but as the proficiency improves, there is a possibility of transition in preference and some other factors, for example, ease and efficiency of use might also affect the preference. Following the research thread, the study by L. McLay et al et al. [42] extends the previous works [40,41,43], in which comparison of acquisition, preference, and maintenance among three AAC modes (PECS, Manual Sign(MS), SGD) took place among four new children with the generalization of new contexts and new communication and provide a tentative inference that acquisition rate might not be the crucial value for the election of AAC option for children with developmental defects and other factors (maintenance, generalization, preference) need to be considered. Subsequently, the replication [44] of the former study and the focus of the study is to answer the succeeding questions: whether the intervention consists of interruption, time delay, and less physical supervision and differential reinforcement can be effective to teach children to request continuation of play with three distinct AAC modes, whether maintenance will sustain over time and preference of AAC for each child and whether such preference sustains over time. The result of the replication study is coherent with previous studies.

### E. MOBILE APPLICATIONS

App, a concise form of application, is a set of instructions that are only designed for electronic devices to perform one or more functions [11]. Applications allow users with speech impairments to articulate their object desires efficiently via images, convey their own particular needs, feel and experience, answer queries, pose easy questions, and create basic sentences. A major benefit of smart devices loaded with apps is the prospect of non-stop operation (reinforcement) relative to human abilities and, in particular, the capacity to

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**TABLE 8.** Primary studies under comparison themes

| Citation | Publication Year | AAC intervention | Participants | Outcome |
|---|---|---|---|---|
| [32] | 2018 | PECS vs SGD | 35 school-age children with ASD | Data indicated that both "high-tech" and "low tech" interventions were effective for improving behavior and that there was not a significant difference between the two approaches. |
| [33] | 2015 | Computer based PECS vs Traditional PECS | Three preschoolers with ASD | Two showed preference for PECS App, two for PECS Communication book. |
| [34] | 2016 | PECS vs iPad based SGD | Three pre-school aged children with ASD | The data indicates that all three participants reached mastery criteria within approximate time and suggest that two AAC systems are equally effective and no clear preference pattern. |
| [35] | 2016 | SGD vs Communication Board with two symbols combination | Four Children Age within 6-11 year with severe motor speech disorders and a variety of developmental disabilities | All participants preferred SGD. |
| [36] | 2020 | PECS vs SGD | Three boys and one girl, age between 2 and 5 years old, with minimal echoic repertoire and no experience with SGD | Analysis reveals that all of the participants chose the SGD for requesting when accessible to both modalities. |
| [42] | 2015 | Manual Sign vs Picture Exchange vs SGD | Four children with autism spectrum disorder | Participants preferred SGD and the acquisition level with each AAC interventions was comparable. |
| [44] | 2017 | SGD vs MS vs PE | Two children with ASD | Both children choose more often the SGD, which indicate preference for SGD. |

track and concentrate on multiple signals, their patterns, etc [45]. As outlined by J. Gosnell et al.[46], it is necessary to align the learning objectives of the user with the features in the mobile app, that's where it is valuable to have a set of communication-based attributes. Several features of the app are essential but there are four features relevant in the case of applications that contribute to verbal communication: "symbol system", "navigation features", "voice and speech output", and "customization". The opportunity to configure the system with icons, navigation functions, and speech output to meet the learning target of the child is necessary to support the child from the AAC approach. The utilization of personally customized and contextually meaningful words improves attention, self-expression, and communication [47]. If the learner is not interested in or inspired by the predefined material in an application, could set a learning barrier. Therefore, in this systematic review, we investigated the features and relevant factors of mobile applications that have an impact on ASD children's communication, social, emotional, and learning skills and particularly focused on those applications which were research-based and evaluation results were presented in case of children with Autism.

The frequently observed features of mobile applications are customization, communication protocol, multimedia presentation, multiple outputs, and progress report generation and the objective behind these mobile applications is to enhance emotional, monitoring, communication, social, learning skills in verbally challenged ASD children and overall creating communication and social competence to improve their quality of life. The detailed description of mobile applications based on their objective is presented in the following sub-sections.

#### 1) Emotional Skills

The features of mobile applications that were frequently identified during the review of research articles are customization, feedback or progress report, multiple modules, gamification or video representation, connectivity to multiple devices, and built-in database. Apps like "Krisha" [48] have four modules of activity in its user interface and progress report generated in 21 days intervals as a pop-up application and request feedback from parents and this type of app aims to support autistic children in improving emotional skills and becoming mentally independent. Similarly, an Android App "Express Your Feelings" presented by P. Sharma et al. [49] through which children with ASD can exhibit their feeling or emotions using emoji with their family or friends and result indicates that the application is implementable to users with autism and recommend the usage of the app to aid gap of communication among people.

#### 2) Monitoring

On the other hand, the study by N. Soomro and S. Soomro [50] focuses on the development of android applications based on PECS principles intending to assist teachers, parents, caregivers, and doctors to monitor autistic children's progress. Moreover, the application involves a progress chart and user function for the addition of images and integrated technologies which had been proven to improve communication skills. Similarly, a mobile application named "Yuudee" was developed by S. An et al. [51] based on PECS with a built-in database of a picture with categories and facilitate customization and alternation of layout and the results indicate improvement in requesting skills in children with 50% accuracy. At the same time, the ePECS system [52] suggests including a fully scalable and cost-efficient, contextually expandable, integrated PECS framework with augmented sensing and IoT aids technology and a bit better interaction

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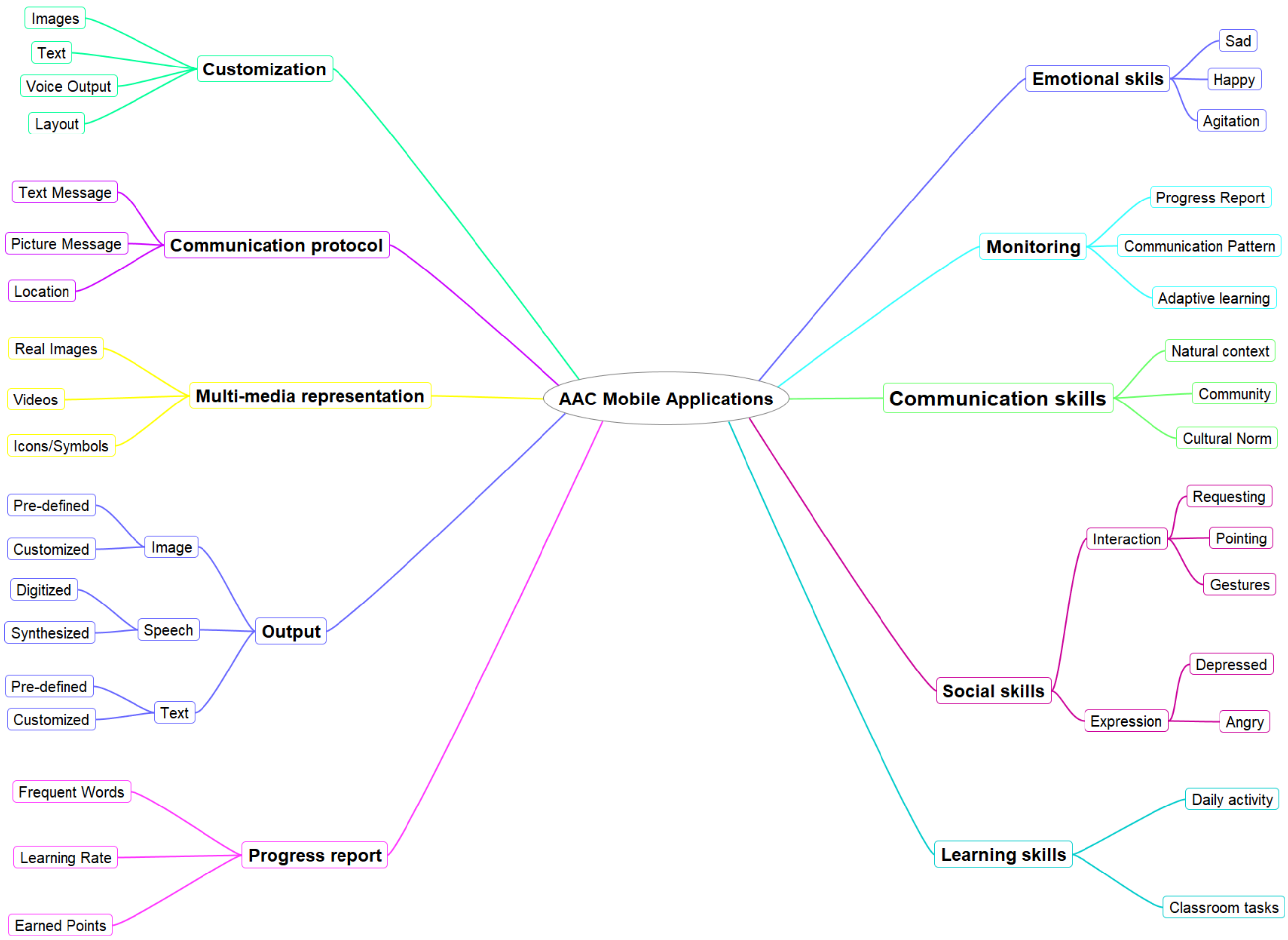


**FIGURE 4.** Features & objectives mind-map of selected mobile application based research articles

capability. Similarly, Adaptive ePECS [53] utilized three contextual information: place, period, and communication pattern. Rather than transmitting images in a static folder, the framework will estimate the place/folders most possibly used at any given time display adaptively. It can also regroup or build any pictures in additional files to store often-used pictures for a particular moment. Besides, another two yielding and independently adaptable word-learning image-based mobile apps [54]; lightweight regards to utilized technology which are Swipe-N-Tag, and SnapN-Recognize. Particularly, both of the applications require caregivers and educators to create an image database based on child progress in learning in the classroom and objects accessible at home (or outdoor activity).

### 3) Communication Skills

To improve communication and social skills in a natural environment, the study by O. Wendt, G. Bishop, and A. Thakar [55] discuss evidence-based mobile applications "SPEAKall" and "SPEAK-more" that was developed to enhance the learning of language, development of speech, generalization skills and expansion in social circles and the results indicate that participants can acquire action-object symbol combination and generalize to new combination with the assistance of the application. Similarly, to augment speech perception in a noisy environment "L2F" application was developed by J. Irwin, J. Preston, L. Brancazio [56] to improve audiovisual perception in children with ASD. Some notable features of the application are training children via video representation and for keeping them motivated, video with fireworks or animated animals appear after six non-consecutive trials. Furthermore, the study by N. H. Voon et al. [57] focus on the development of an application, "Autisay", a communication tool which can be utilized between autistic children and their parents/caregivers/ teachers and notable features of the application are, customization, three modules in user interface and designed according to the cultural norm. Likewise, the aim of the study by C. Y. Sng et al. [58] was to investigate if an application administered on an iPad could educate students to describe 'on-topic' reactions. Three boys diagnosed with autism disorder, aged between 8 and 10 years participated in this study. From the findings, it is clear that training on

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**TABLE 9.** Primary studies under mobile applications themes

| Citation | Publication Year | Application Name | iOS /Android Platform/System | Objective of the Application |
|---|---|---|---|---|
| [12] | 2019 | My Voice | iOS | An iOS-based application developed for UAE autistic children to be activated on an iPad device to enable them to interact utilizing their indigenous Arabic language. |
| [45] | 2017 | Let's Play | Android and iOS | The application is built in such a manner that autism children use it for enjoyable and educational purposes. |
| [47] | 2018 | My Word | iOS | My Word was not devised specifically as an AAC or tool for learning but rather to be used as a working model in the context of mobility and transparent execution classrooms unique to autism. |
| [48] | 2019 | Krisha | Android | To improve emotional skills in children with autism and make them mentally independent. |
| [49] | 2019 | Express Your Feelings | Android | To assist autistic children to express their feelings based on emoji in order to interact with family and friends. |
| [57] | 2015 | AutiSay | iOS | A customizable communication tool between autistic individual and teacher/caregiver with focus on social communication. |
| [61] | 2019 | AIA | Android | The framework was developed to provide an immersive learning experience that includes vibrant pictures, enticing voices, and insightful and encouraging videos. |
| [65] | 2017 | Tell Your Day | Developed System | A prototype to improve communication of ASD children with others while adaption of multimodality. |
| [66] | 2015 | DISSERO | Developed System | The proposed application framework and architecture fits the circumstances and expectations of the autistic children who are seeking to overcome some of the social communication challenges. |
| [68] | 2015 | iCanLearn | iOS | A mobile flashcard application to create social stories for children with ASD in order to improve autism education and interventions. |
| [69] | 2015 | iCAN | iOS | To mitigate disadvantages of traditional PECS and an educational interface management for interaction and recovery with appropriate content. |
| [70] | 2015 | MyCalendar | Prototype | To facilitate teacher's function in communication modeling through images and videos on MyCalendar application was essential to obtaining day-to-day interaction. |
| [75] | 2017 | Bolte Chai | Android | To provide ease in the learning cycle and the instruction process for autistic children through the opportunity to add other existing objects such as images, voice, and recording, that accessible in smartphones. |
| [76] | 2018 | Duronto Sishu | Android | The philosophy of research is to make use of the strength of emotional commitment to develop communication skills in autistic child. |

the iPad by itself is not adequate to educate participants to distinguish on-topic reactions and more specific teaching techniques were needed. A potential explanation for this might reside in the special profile of an individual child, but more research is required to determine individual factors influencing reactions to the interventions. However, some mobile applications incorporate indigenous language along with English languages, for instance, "My Voice"[12] is an iOS-based application developed for UAE autistic children to be activated on an iPad device to enable them to interact utilizing their indigenous Arabic language with the facility of customization of category, pictures, and audio and notifications feature for altering parents/caregivers. In a similar manner with profound features, another application proposed by M. S. A. El-Seoud et al.[59], which facilitates integration, exchange of data via speech processing server, connectivity, and communication via mobile application by keeping communication available and cost-effective and primarily tailored to satisfy the desires of nonverbal people in countries where the Arabic language is utilized as a means of interaction. Similarly, Tap-to-Talk [60] is a Filipino based mobile application that will involve Tagalog language and Filipino custom apart from the English language. In this mobile application, the functions of Picture combined Exchange Communication System(PECS), Augmented and Alternative Communication (AAC), and Text To Speech are amalgamated to assist children with level 1 autism in interactive communication. The subjects used in the Android application are Hygiene, Activities such as Dietary, Plan, Chores, and Leisure. Likewise, "Autistic Innovative Assistant (AIA)" [61] is an android application devoted to Arabic children with autism. The framework was developed to provide an immersive learning experience that includes vibrant pictures, enticing voices, and insightful and encouraging videos with the potential to evaluate the success of the child and produce feedback that can be used to tailor the pattern of usage of the application and obtain improved performance. Similarly, "Suara Saya" [62] mobile App is a relatively cheap AAC communicator application that involves customization of categories, icons that promotes communication in all aspects of life, and thus offers voices for children with language development problems. The focused group of users includes instructors, therapists, teachers, parents, autistic children, and children with language impairments. In a similar direction, a solution demonstrated by Pavel Zlatarov [17], which includes an efficient and responsive user interface, supported by a database of uniquely tailored details for individual use, a personalized vocabulary and performance statistics are stored

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and maintained within each child's account, allowing for the accurate and unbiased monitoring and review of their subsequent progress whereas the research by K. T. Johnson et al. [63] addressed the layout and eight-month duration case study on a platform called "ECHOS (Enhancing Communication using Holistic Observations and Sensing)" for communicative interaction which consists of Phase I and II. In Phase, I the utilization of numerous physiological sensors with adhesive electrodes was inefficient for long-term usage whereas in Phase II an affordable audio recorder contributed to efficacious and communicative data while maximizing simplicity, ease of utilization, and possible scalability. In-moment tagging with customized Android application, enable active participation of elementary caregivers, who offered distinctive observations into the significance of non-verbal communication. Outcomes of each research phase demonstrated the ability of the ECOHOS platform to promote and facilitate more practical connections between minimally verbal ASD individuals and the wider community while working efficiently on a scale.

#### 4) Social Skills

Interaction consists of different modalities with the support of multiple languages can be beneficial to train and stimulate the capability of a child with ASD in a diverse social context. The mobile social application's [64] goal to support the children of autism mastering essential abilities in social communication comes in the form of introducing oneself, expressing feelings (happy, depressed, angry), and simple gestures. The application utilizes a visual approach as a method of teaching children by presenting a variety of video modules that involves social situations performed by child performers. One of the goals of the study by S. S. T. Diogo Vieira et al. [65] is to provide the children an assistant for communication with others as well as acknowledging family and teachers about the daily activities of the students which will enable them to participate and providing feedback. The developed application "Tell Your Day" targeted the children with ASD to assist them in improvement in communication while adapting multimodality as a basic feature. Similarly, the proposed application, "DISSERO"[66] framework and architecture fit the circumstances and expectations of the autistic children who are seeking to overcome some of the social communication challenges such as interaction, the process of learning, and time supervision while ensuring motivation and the application incorporates expectable features, such as GPS service in connection cloud data server, multimodal loader and database to store information of each child. In a similar direction, "Autism Social-Aid" [67] is a smartphone application designed to concentrate on social interaction for children with autism. Autism Social-Aid's purpose is to support individuals with autism with acquiring and implementing essential social expression techniques and findings suggest that children in the younger demographic are more active and willing to seek out all the tasks in the application.

#### 5) Learning Skills

However, some applications focus on the development of learning skills along with communication ability, such as, "iCanLearn"[68] is a flashcard based educational app that enables users to produce flashcards with pictures, audio, and text and the distinctive feature of the app is connected to multiple devices over a Wi-Fi network for teacher-learning environment whereas a PECS application in an android platform, iCAN, designed by M. E. Chien et al.[69],target at the improvement in children motivation in learning along with the stimulation of senses and communication skills and the application has a built-in feature to read aloud the composed sentence as well as saving to reuse familiar sentence for children. Likewise, "MyCalendar" [70] has assisted children with Autism and deficiency in linguistic skills to easily communicate their everyday activities via images and videos, supported by parents and teachers. The in-depth understanding of child everyday activities enabled teachers to model affirmative behavior and to generate more related and practical learning resources by relating them to the live of the children whereas "MyWord" [47] is a personalized iPad App featuring an online audio-visual dictionary. It works by letting the user build individual entries words and connect images and voice files of their own to every single word. MyWord was not devised specifically as an AAC or tool for learning but rather to be used as a working model in the context of mobility and transparent execution classrooms unique to autism. In a similar direction, the "Let's Play" application [45] is built in such a manner that autistic children use it for enjoyable and educational purposes where on the smartphone, users interact with the application by pressing a cartoon picture or a video projected on the screen if a recognized beacon (small embedded sensors) is identified within the neighborhood. The rate of learning per session reflects the learning speed.

$$\text{Learning rate} = \frac{\text{Number of learned words}}{\text{Toal Number of Let's play sessions}} \times 100\% \qquad [40]$$

The meaning of this function (the greater the better) indicates what portion of a word a child could recall after a session of Let's Play, or what portion of a word remained in mind after a session, e.g. a learning rate equivalent to 20 percent(1/5) implies the child required five 30-min interventions to acquire a new word.

Incommensurate with research trend, several research studies evaluated mobile application, for instance, the purpose of the research by J. H. Meeks [71] is to determine the effect of AAC application on requesting skills in students with a communication disorder and whether the students with ASD can be taught to use commercial AAC application and the results indicate that both of the student exhibit increase in communication while using iPad based "GoTalk" application and one of the participant demonstrated more occurrence in spoken language. Similarly, the objective of the research by M. N. Novack et al. [72], is to evaluate the efficacy of the "Camp Discovery" of responsive language learning in children with

ASD, across several contexts. "Camp Discovery" mobile application is accessible to both iOS and Android smartphones and tablets. The feature includes modified discrete-trial (DTT) training processes and other ABA standards of behavior to educate responsive communication goals in a different context and results indicate that participants showed relatively strong learning levels in the short term. However, the key purpose of the study by S. Holt and N. Yuill et al.[73], is a detailed study of the social behavior of learning disabled children with autism (LDA) children along with two separate technical aids to decide what environmental factors are the efficient engagement of LDA children and development of desired habits and it had been shown that dual tablets are especially successful in promoting active sensitivity in LDA children when accompanied by adults.

In contrast to the abovementioned applications which were designed for developed countries, several mobile applications were developed in the context of developing countries, for instance, Bangladesh, as there is a lack of clinicians and rehabilitation facilities available for ASD children, solutions that depend on non - expert caregivers, particularly parents, have emerged to be feasible and realistic alternatives for developing countries [74]; therefore, deployment of reasonable rate of Information and Communication Technologies (ICT) resources (mobile phone applications) which are tailored culturally to address specific needs of ASD children as well as their caregivers regarded as significant initiative. For instance, "Bolte Chai" [75] is an Android mobile application developed for verbally challenged ASD children and some notable features of the application are distinct modes for parents and children, customization of image, text, audio in user-defined categories and subcategories as well as an employed communication protocol to deliver message between children and parents or caregivers. The application offers parent assistance in two perspectives: regularly reinforcing the learned word and showing the corresponding image, as well as gathering details like quantity of actions that can be utilized for evaluation and further training preparation. The case study results indicate ease in the learning cycle and the instruction process for autistic children through the opportunity to add other existing objects such as images, voice, and recording, that accessible in smartphones. Similarly, the application titled "Duronto Sishu" [76] can provide a generic collection of details, along with customized options for attaching elements and vocal details. It helps children to recognize familiar things and speech. That means the caregiver has the freedom to assign priority to the items that need to be recognized. This autonomy opens up the directions that the teachers and parents should work together as a group to achieve optimal performance for children.

### F. ARTIFICIAL INTELLIGENCE (AI) & MACHINE LEARNING (ML) BASED APPLICATIONS

Mobile technology provides a systematic approach and accessibility in contrast to computers. But there is also a pay-off between the flexibility of communication, constrained by the number of pictograms accessible, and the spatial requirement on the device to view the pictures in a manner compatible with an individual's unique motor and cognitive abilities. To overcome this restriction, pictograms are typically grouped into categories, which may be reached by dynamic navigation via item hierarchies or by "pages" presented on the screen. This, however, presents another obstacle: the "deeper" and farther away an element is located upon on hierarchy, so more physical actions are made by the user because of the additional amount of interactions required to achieve the final element. In this scenario, applying a machine learning (ML) algorithm and artificial intelligence (AI) lessen the amount of coordination required to get to the requested element. For instance, LIVOX [77] is the very first "Augmentative and Alternative communication" based on pictograms "Android" mobile application adapting "Artificial Intelligence" to the requirements of individuals with physical abilities and the difficulty of informal communication. For example, the application integrates a broad variety of algorithms to allow flexibility in the creation of personalized items for presentation to the user with disabilities. Second, the application could adjust to the diversified motor and cognitive difficulties via algorithms like "IntelliTouch" and "Livox Natural Conversation". In a similar direction, a recommendation based Android application [78] targets to facilitate coordination among therapists, children, and parents; along with helping the children pleasantly perform their activities; and a recommendation system for proposing suitable, essential, and enjoyable activities using Case-Based Reasoning (CBR) for each child where "Diary" interface ease therapist's task of record-keeping and parents can monitor their child progress and to comprehend child development "Analytics" interface provide statistical information to parents and therapists. Moreover, to save special educators time of creating content and comply with the requirements of each child, "VITHEA-Kids" [79] builds on the framework of "VITHEA" [80], it represents a specific kind of exercises: multiple choice activities promoting the development of vocabulary and/or the improved generalization capabilities, most used in applications for children with ASD. Creating numerous exercises will be a time-intensive task for caregivers, a module is incorporated supporting automatic exercise content formation (e.g., query, stimulus, right answer, including distractors). The consequent exercise will be submitted to the caregiver, who will decide to accept this as it is, omit it or alter it. Afterward, the exercise will then be stored in the database and made available for the child module. Overall, the integration of intelligent algorithms and analytics ease content creation, progress monitoring, context-based communication, data storing, decision-making process which eventually lessen the rigorous task of educators or caregivers and demand less cognitive, motor skills from ASD children.

### G. AUGMENTED REALITY (AR) BASED APPLICATIONS

Augmented Reality (AR) will either be an explicit real-time application or a graphical representation distant from its actual object by incorporating a digital object lead to additional knowledge about the existing object whilst AR aim to improve the real object by integrating the online object, so the knowledge is not just for the user interface, but also for the user who could not link immediately to the interface form the actual entity. For instance, Brain Power System (BPS) [81], is automated behavioral assistance to gather qualitative data and notifying features. The BPS involves personalized smart-glasses, offering targeted customized mentoring experiences via a family of artificial intelligence-based, gamified "augmented reality applications". It involves gamified apps and it has sensors onboard which are employed for the acquisition of real-time data in various categories; for instance, "motion", "physiology", "in-app efficiency", "video", and audio. Mobile data collection from smart glasses built-in gyroscope and accelerometer allow for real-time measurement monitoring of direction and motions of the user's head. Another approach [82] which relates AAC elements and Applied Behavior Analysis (ABA), to implement AR in speech and language intervention strategies with children with ASD to alleviate the problems induced by communication impairments and inadequacy in creativity. The application strengthens the symbols of communication that superimpose virtual elements and animations over response to real screen environment where functions of the application involve designing AR Graphics activities and audio to deepen the sense of the symbol, both with visual and auditory reinforcements. The program is capable of adapting to each particular child, requiring several variations of activity. In the same direction, the multimedia framework had developed augmented reality systems as the therapy for ASD children. The application [83] built can run in the android version of the device. The evaluation method was performed by the teacher to ASD child, where the teacher can use android-based device media to render the intervention to ASD child. Based on the outcome analysis of the communication capacity of ASD child before and after the therapy cycle using PECS based multimedia-based augmented reality, it was demonstrated that cognitive skills enhanced from the requester level to the early communication phase. Moreover, a system like KinToon [84] utilizes Kinect to extract main points from the external contours of a human face, and change them to the appropriate focal points on the face of a cartoon character. The communicator's face is presented with a tweaked cartoon mask face to accomplish a complex "make up" impact. Lastly, children with ASD will communicate dynamically with the communicator cartoon makeup that will reduce the burden on them to communicate with people and to make them more understandable of emotions.

## IV. DISCUSSION

Unlike other research studies on AAC interventions for ASD children, this systematic review yields to investigate the evolving trend in AAC strategies, as well as features and functionalities of research-based AAC mobile applications which aim to foster communication and social competence in ASD children while considering emotional, learning, social skills enhancement as these, eventually contributes to improving communication and communal capabilities. Several research studies focus on high-tech AAC systems for speech impaired individuals, which include imaging methods, touch-enabled technologies, electromechanical approach, breath-enabled techniques, and brain-computer interfaces to point out a selection of signal detecting and acquisition strategies [85]. S.B Sievers et al. [86] investigates the factual basis of AAC interventions by evaluating possible factors that provide insight on how and why ASD children respond to and between the various AAC approaches, and also the focus on the requirement to discuss these factors further. In contrast to these research studies, we aim to explore the trend of AAC modalities and focus on emerging intelligent technology in mobile applications that will contribute to enhancing the communication and social skills of children with limited verbal skills, particularly, autistic children. A further pertinent theme of research centralized on a comprehensive analysis of the literature on the approaches utilized in computer-based interventions (CBIs) and the effect of such treatments on the development, generalization, and maintenance of linguistic ability and interaction skills in ASD children [87] and systematic mapping [88] of the research study to identify study projects on the usage of the mobile device as a method to strengthen or encourage interaction between individuals with some sort of speech impairment. As distinct from these research investigations, we aim to concentrate on the features and functionality of mobile applications and associated outcomes on language and communal skill development in autistic children. We consider a profound understanding of trends in AAC modalities and integrated features of mobile applications is mandatory to apprehend the opportunities that can offer to enhance linguistic skills in autistic children and facilitate their social participation.

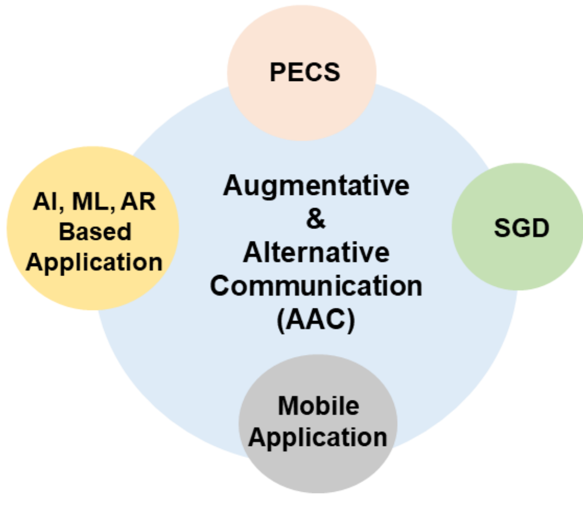


FIGURE 5. Observed trend from PECS to AI, ML, AR based AAC modality

Autism is classified as an omnipresent, life-long neurological condition in which the affected person perceives severe and omnipresent deficiency in several developmental areas. Communication is one of the standards in life describing skills which is inadequate in autistic children. According to B. O. Gudu [89], children with autism experience language impairments, which makes it difficult for them to articulate what they need. Hence, it is crucial to assist them in developing inter-relational skills. In particular, for those who can not consistently rely on functional communication, Augmentative and Alternative Communication (AAC) has been incorporated for children and adolescents. It is a set of practices that broaden, consequently improve communication skills for autistic non - verbal children. AAC is also used to address the lack of functionality speech, necessitate adaptive tools, and materials. Therefore, the AAC system needs to be evolved to accommodate the user's capabilities. Considering, the necessity of evolvement in the AAC system, a trend is observed in this systematic review. It is perceived from the systematic review of the selected research articles that PECS is considered as an early approach to motivate ASD children in communication but considering the limited opportunities, the utilization of SGD is considered effective by parents and caregivers. However, financial burden, cognitive skills demand, and lack of customization in SGD galvanize the necessity of portable, personally customized mobile applications. Hence, several research studies [12] [17] [45] [47] [48-73] [75] [76] concentrate on developing mobile applications and systems that incorporate some notable features which are customization, multiple modules, gamification, or video representation, communication protocol, and built-in database. Besides, it is imperative to monitor the progress in ASD children and provide the opportunity for context-based communication and this leads to the integration of machine learning (ML) and Artificial Intelligence (AI) in the mobile applications (both Android and iPad/iOS) to facilitate remote monitoring, analytics in representing communication development whereas Augmented Reality (AR) based representations motivates children to communication and overall, employing additional resources in AAC interventions assist therapists in their speech training sessions [82]. Moreover, parents emotional relationship with their child plays a vital role and the customization of mobile applications provides them the autonomy to focus on their child's preference. Considering all the aforementioned evolvement in AAC strategies and evolvement, it is essential to acknowledge that cultural norm and surrounding environments plays a vital role in developing AAC based mobile applications and hence some applications or systems [54] [61] [62] [64] are designed in a specific language considering the preference of ASD children. On the contrary, it is observed that most of the developed systems or applications are in the context of developed countries compare to lower-middle-income countries. However, some applications [75] [76] are devised in the context of developing countries and the incorporated features fulfill the necessity of ASD children as well as the expectations of parents or caregivers as well as commensurate with the cultural, structural, and financial context, of the country. This systematic review explored the evolvement in AAC strategies and acknowledged the importance of mobile applications with intelligent analytics to augment as well as monitor communication, social competence in ASD children. Based on this systematic analysis, we recommend incorporating intelligent machine learning algorithms and artificial intelligence to facilitate personalization, ease of monitoring, and generation of recommendation. Moreover, compared to the traditional approach in AAC interventions, interactive mobile application interface motivates ASD children, and therefore, augmented reality representations or gamification may accelerate their language, learning, social acquisition. However, this systematic review does not focus on games as they are similar and standardized [17], making much less customization possible where there is a requirement of an innovative and scalable user interface, supported by a database that contains information about each user. In addition to tailoring feasible AAC based applications according to ASD children's preference, collaboration among parents, caregivers, special educators are imperative as they provide reinforcement focused learning opportunity to children with the assistance of AAC interventions and applications. Finally, it needs to be considered that each ASD child is idiosyncratic and one particular invention might not fit all and there is a need to further explore the causal effects of AAC-based mobile application features in developing speech, communal skills in ASD children.

## V. LIMITATIONS

While this review concentrates on the classified studies that fall under the specified inclusion and exclusion criteria but some limitations might prevail. At first, the Augmentative and Alternative Communications (AAC) approach for ASD children is itself a broader area, and research articles included in this systematic review originated from a limited set of databases and journals. Moreover, several mobile application-based research studies concentrate on the diagnosis of ASD children but these studies are not relevant to the focus on this systematic review. Secondly, AAC interventions or applications are also applicable to individuals with other impairments, such as, cerebral palsy, intellectual disability, developmental disability, stroke patients, but this systematic review particularly concentrates on research articles that incorporate ASD children. One of the limitations might be related to keywords utilized because search strings of keywords might have synonyms and the keywords themselves limit the possible outcomes. Finally, to overcome any limitations related to data extraction and theme categorization, discussions on disagreements are conducted among the authors and reiterated until there are no differences and devices or system developed for the individual case study is not included.

## VI. CONCLUSION

This systematic review acknowledges the evolving trend in AAC interventions as well as integrated features of AAC based mobile applications for ASD children to enhance their language, learning, emotional skills which are linked to communication and social competence development. To achieve the research goal, 60 research articles were categorized and investigated. The findings of this systematic review can be beneficial to further explore the potential of AAC interventions or mobile applications to augment communication ability in ASD children. Moreover, it has been identified that embedded machine learning (ML) algorithms and artificial intelligence (AI) processes in mobile applications or systems have substantial potential to facilitate adaptability, contextual flexibility, data analysis, storage, and dissemination of information for advanced research.

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