

# ICT-Based Learning Solutions for Children with ASD: A Requirement Engineering Study

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## ABSTRACT

This research explores the explicit requirements to design and develop ICT-based learning solutions for children with Autism Spectrum Disorder (ASD). A requirement elicitation study has been conducted for six weeks of the study's in Pune, India. The study sample size is fifteen (N=15), with an age limit between five to twelve years old. All the participants have been diagnosed with ASD and undergoing a skills development process in the same institution for at least six months. The outcomes of this research are tri-fold. Firstly, identify the twelve explicit requirements to design and develop ICT-based learning solutions considering the challenges due to autism. Secondly, conformity to the existing Multi Agent based Persuasive Education (MAPE) model with revealed requirements. Thirdly, propose an Internet of Things (IoT) based framework to observe and record the learning performance of ASD-affected children. The unique contribution of this study is to develop a Level-5 IoT framework to incorporate the requirements revealed through the participatory design approach for implementing ICT-based learning solutions. The proposed framework forms the basis for developing a dataset to identify the learning patterns and new requirements for ASD-affected children through Artificial Intelligence (AI) and Machine Learning (ML).

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**Keywords:** ASD, ethnography, ICT, IoT, requirement engineering study.

## INTRODUCTION

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder, which can be identified within the first two years of age (Zwaigenbaum et al., 2013). Autism creates a deficit in the cognitive development of the children which hamper their regular learning process (Constantino et al., 2021). The common symptoms of children with ASD are: social communication difficulties, restricted and repeated behavior, not understanding other's emotions, cannot concentrate on a particular task, not responding while calling their name, difficulties in coping with a new environment, and not focusing on the surroundings (Jones et al., 2018; Jadhav & Schaepper, 2021). The ICT-based education system has emerged all over the world (Ferede et al., 2022; Perez & Masegosa, 2022; Guo et al., 2022). During the COVID-19 pandemic, the role of ICT in education has become increasingly important (Vergara et al., 2022; Belousova et al., 2022; Yang et al., 2021; Gerard et al., 2022). Technological interventions for children with ASD also provide up-skilling in several areas like academic, social behavior, daily living skill, and communication skill (Chen & Yakubova, 2021; Fletcher-Watson, 2014; Jdaitawi & Kan'an, 2022; Chadwick et al., 2022; Chadwick et al., 2022; Grossard et al., 2018; Alotaibi & Almalki, 2016; Zaki et al., 2017). Different technologies like video modeling, computer-based intervention, mobile technology, virtual reality, and augmented reality have been applied in the intervention process for the skill development of individuals with ASD (Syriopoulou-Delli & Stefani, 2021).

The usability of the technologies is one of the essential factors in performing the task effectively, which can influence or guide the users to achieve the target goal (Scholtz et al., 2016). The usability of the technologies can be ensured if the requirements are identified and addressed accordingly (Sabariah et al., 2019). Requirement engineering study (Raghavan et al., 1994) concerns the requirements elicitation, analysis, specification, and validation process. The requirements elicitation study aims to collect the requirements directly from the stakeholders (Jakkaew & Hongthong, 2017). The purpose of requirements analysis is to examine the collected requirements in terms of interrelation, gaps, and modeling (Mylopoulos et al., 2001). The requirements specification is the formal way to represent the analyzed requirements in various forms which is understandable to all stakeholders (Abdalazeim & Meziane, 2021). Requirements validation is the process of approving the requirements by the

stakeholders to be incorporated into the system (Maatuk et al., 2021).

The motivation of this research is to explore the explicit requirements to design and develop ICT-based learning solutions to upskill children with ASD considering their limitations.

The scope of this research is to explore the requirements to be included in the ICT base learning solutions for academic and cognitive development skills of ASD-affected children. The focused group of this research is specialized school-going individuals with ASD, having an age limit between five to twelve years old.

The rest of the paper is organized as follows. The problem statement of the study is presented in Section 2. Section 3 highlights the existing recent related research. The study methodology is illustrated in Section 4. The procedure of the requirements elicitation study is described in section 5. Section 6 describes the requirements analysis, specification, and validation process. An overview of the previously developed MAPE model (Hasan & Nene, 2022) is presented in Section 7. Conformity to the MAPE model with revealed requirements is shown in Section 8. Section 9 presents the proposed IoT-based network framework, and lastly, discussions and conclusions are presented in section 10.

## Problem Statements

The deficit areas due to autism have been classified into two following categories by DSM-5 (Diagnostic and Statistical Manual of Mental Disorders, 5th edition) (*Autism Case Training...*, 2013): Social Communication and Restricted Interests & Repetitive Behavior. Each of the areas is classified into three severity levels: Level 1 (requiring support), Level 2 (requiring substantial support), and Level 3 (requiring very substantial support). DSM-5 states the common challenges faced by individuals with ASD. Among those, the followings are the challenges that hinder the academic and cognitive development of individuals with ASD: severe deficit in communication, minimal response, difficulty coping with the change, less attraction towards surroundings, difficulty in changing actions, and concentration deficit. This research aims to identify the requirements to address these challenges and enhance the ICT-based learning mechanisms for the said group of children.

## Related Works

A good number of research efforts have gone in recent years to identify the requirements for the effective design of learning tools for children with ASD.

A User-Centered design approach has been followed by (Marti & Giusti, 2010) to identify the design requirements to develop a robot that performs social communication with ASD-affected children. Another requirement elicitation study has been performed (Al-Khalifa et al., 2017) to develop Toilet Training Sequencing (TTS) wearable watch for children with ASD. The study comprises with semi-structured interview and field observation approach. The researchers developed the prototype of the tool and measured the effectiveness of the design. The therapists, teachers, and parents were interviewed to collect the requirements for designing robotic toys for individuals with ASD (Robins et al., 2007). A therapeutic game named “Pico’s Adventures” has been designed and developed based on the requirement elicitation study (Malinverni et al., 2017). The purpose of this therapeutic game is to develop social initiation among children with ASD.

Interview script and canvas-based artefacts have been developed for effective requirement elicitation study to develop software for individuals with ASD (Melo et al., 2021). The researchers have proposed a separate set of questionnaires and evaluation patterns of scripts and canvases for caregivers, specialists, and clients. Eleven design considerations have been explored (Hasan & Islam, 2020) by requirement elicitation study to design and develop tabletop learning tools for children with ASD. The researchers applied ethnography and a

semi-structured interviewing approach for the requirements elicitation.

Moreover, a good number of research works have been conducted to develop behavioral datasets for various ICT-based therapies and learning mechanisms for children with ASD (Billing et al., 2020; Liu et al., 2017; Simões et al., 2020; Colombo-Dougovito & Reeve, 2017; Carette et al., 2018). However, requirements elicitation study-based research to form an IoT framework for the development of behavioral datasets to explore the learning patterns, identify the new requirements, analysis of the effects of using technologies, and performance evaluation are yet to be unfolded, which have been addressed in this study.

## METHODS

Requirements engineering study (Raghavan et al., 1994) specification, and validation approach has been followed to reveal the requirements to design and develop ICT-based learning solutions for children with ASD. Fig. 1 illustrates the methodology of this study. Field notes for various observations have been taken during the ethnographic study along with photographs of the sessions to understand the environmental effects. Afterward, the thematic approach was applied to transcribe the recorded data into information. Both qualitative and quantitative approaches have been applied to analyze the data.

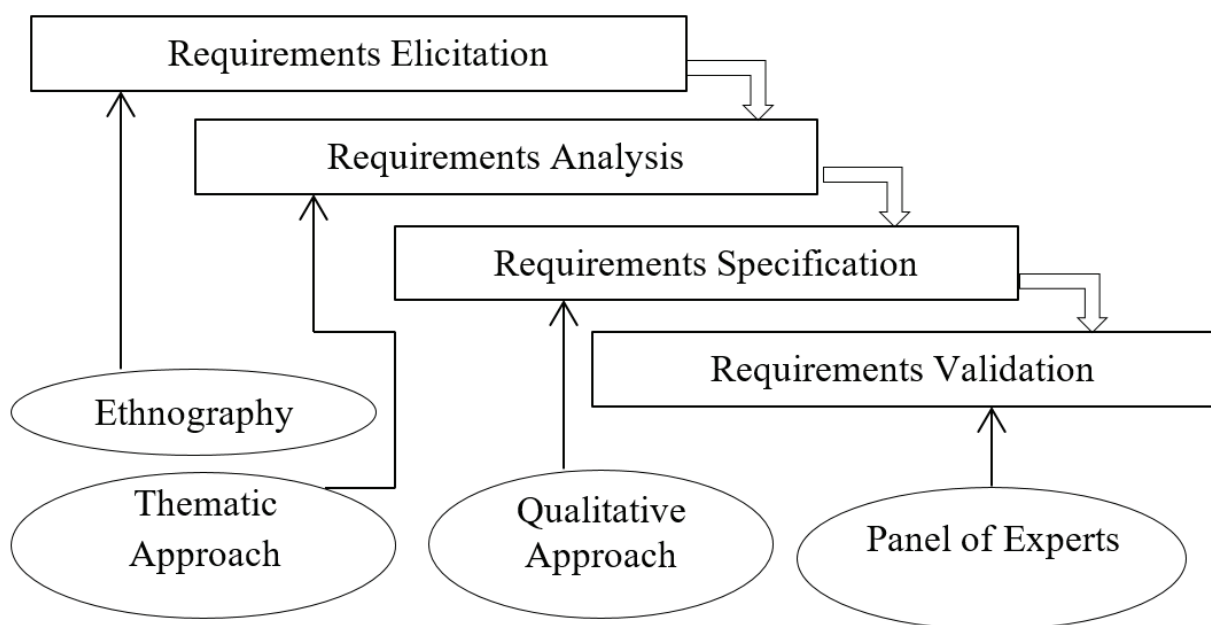


Fig. 1. Methodology of the Study

### Requirements Elicitation Study

The empirical research approach (Gupta et al., 2006) has followed in conducting the requirements elicitation study. In this study ethnographic study has been conducted to reveal the requirements.

### Institutional profile

A school for special children located in Pune, India, has been selected for the Ethnographic study. This institution started its journey in 2000. Children with ASD within the age limit of three to thirteen years old are undergoing a skill development process in this institution. At present, thirty-eight ASD-affected students and fifteen trained teachers and staff are there in this institution. This special school offers academic learning, speech therapy, occupational therapy, and behavioral therapy. This institution also conducts regular counseling for the parents of children with ASD to make them able to take good care of their special children.

### Participants' Profile

Participants in this study are fifteen ASD-diagnosed children undergoing skills development processes at the selected specialized school for at least six months. The age limit of the participants is five to twelve years old. Among the fifteen children, twelve are male and three are female. The purpose of selecting specialized school-going children is to explore the gaps between existing facilities and the new requirements in a structured way. Five students have been selected from each of three specialized class levels (elementary, moderate, and advanced) to validate the collected data from all variations.

### Ethnographic Study

The first step of the Ethnographic study was to define the objective and find an appropriate institution to conduct the study. Necessary permissions from the appropriate authority of the institution have been taken. The researchers of this study visited five days a week and observed the activities for two to three hours a day for six consecutive weeks. The following issues have been observed during the visit:

- the operational procedure of the institute
- way of conduct of the therapists to individuals with ASD
- methods of teaching
- tools/ equipment used for teaching
- communication modes of the teacher to student, student to student
- the reaction of the students in various situations

- challenges faced by the teachers to teach and reasons
- challenges faced by individuals with ASD to learn and reasons
- performance evaluation procedure

The field data have been recorded very meticulously with date, time, situation, number of teachers & students involved, and the incident details. Photographs of different sessions have also been taken.

### Requirements Analysis, Specification, and Validation

Content analysis has been done on the study data received through an Ethnographic study. Afterward, the thematic analysis approach (Braun & Clarke, 2012) was applied to analyze the requirements. A qualitative approach has been followed for the specification of the requirements, which means only the requirements which are specific, expressible, and can be addressed through ICT are specified. Lastly, the requirements were validated by multiple discussion sessions with the experts. The panel of experts consisted of one behavioral therapist, one occupational therapist, one speech therapist, and two academic teachers. All the experts are from the same specialized school where the Ethnographic study was conducted. The researchers have chosen a panel of experts from the same institution as the ethnographic study to justify the data collected during the field study. Because this panel of experts knows the deficiencies of all fifteen ASD-affected children who participated in the field study, it was possible to evaluate whether any field data was misinterpreted. A total of twelve requirements have been revealed through this study.

**Finding 1 - Initiation of conversation:** Conversation indicates the reciprocity of each other. Without establishing the conversation, it is difficult to start any learning process. Starting the conversation with ASD-affected individuals is a challenge. On 16 February 2022 at 1020 hour the researcher observed that students A, B, C, D & E had entered the corridor. The therapist exchanged greetings with them by saying, "*Good Morning*". Students A, B, D & E also exchanged greetings with the therapist by saying "*Good Morning*", but C did not say anything. The therapist then addressed him separately by saying '*Good Morning C*'. After repeating the third time, C replied with "*Good Morning*". The speech therapist opined that this is a common problem for almost all the students here. The therapists mostly face this issue at the beginning of any session. She said, "*...it is just like ice breaking session...when they reply back to our call, it reflects that they are ready to go with this session....*".

**Finding 2 - Picture Exchange Communication (PEC):** PEC is an effective medium for functional communication with individuals with ASD. Because ASD affected children mostly suffer from communication issues. On 25 February 2022 at 1005 hours, it was observed that student F was learning the identification of patchy items from a set of given items drawn on a page. For example, in a group of five photos, four are different-shaped windows, and one is a reading table. F needs to mark the reading table as a patchy item. F learned the process quickly and felt interested in solving all the problem statements. He solved seven out of ten problems correctly. The behavior therapist augmented that *“PEC is not only helpful for communication but also helps to improve the cognitive development. The individuals need to learn the meaning and purpose of the symbols on the card and when to use those. Normally we start our session for the beginners by using different flashcards to introduce with the surroundings”*.

**Finding 3 – The attractiveness of the colorful objects:** Colorful objects/ tools/ learning materials attract the children with ASD the most. Colorful objects help to address the concentration deficit of individuals due to ASD. On 17 February 2022, at 0945 hours, it has been observed that students G, H, and I were introduced to different kinds of fruits and flowers in this session. The mentors began by showing colorful pictures from a book to introduce the names and colors of various fruits and flowers. A set of Lego blocks of fruits and flowers was given to students. One of the mentors showed the students a picture of either a fruit or flower and asked the students to pick up a Lego model of the same fruit or flower. Students G and H became interested in the process and felt motivated to continue. The occupational therapist stated that *“...we use different Lego blocks, matching tools, trampoline, stepper for the cognitive and physiological development...we have observed that students are attracted towards the tools having more color, sound, vibration...”*.

**Finding 4 - Persuasiveness or provocation factor:** The provocation factor or persuasiveness is essential to attract individuals with ASD towards learning solutions. A persuasive learning tool interacts with the user and guides them to the next step. This property addresses the attention deficit and concentration deficit factors due to ASD. On 17 March 2022 at 1030 hour, the researcher observed that student J was given a page where ten pairs of sequential numbers needed to be written. In each pair, either the first or second number remained blank. Student J was asked to write the missing numbers in the appropriate place. J was facing difficulty understanding the problem statement. The academic teacher cited some ex-

amples to make him understand, even though he was unable to understand. Later, the academic teacher changed the learning sheet and gave one page where various symbols were printed with different frequencies. J was asked to count the individual item and write down the total number of frequencies. There were five different objects (ice cream, umbrella, pen, clock, and butterfly) having six frequencies each. J successfully counted for three items and miscalculated for two items. The academic teacher added with this observation, *“...students are more attracted to the tools where the actions are predictable like there is a magnetic board where for each alphabet there are appropriately shaped slots to place magnetic alphabet blocks and kids like it very much...”*.

**Finding 5 - Pictography:** Pictography is the form of symbolic representation of any behavior (Hasan & Islam, 2020). As children with ASD suffer much with verbal communication, thereby pictorial representation of the message/ instruction is more effective for them. The researcher observed on 16 February 2022, at 1005 hours that, while entering the classroom, the behavioral therapist showed three pictures on the wall to the students where the first picture is a pair of untied shoes, the second picture is about picking up the shoes and the third picture is a shoe rack having some pair of shoes on it. By observing the pictures, all the students removed their shoes and kept them on the shoe rack, which was placed just outside the classroom. The behavioral therapist opined *“Our students grasp the meaning of those instructions quickly which are given through some images/ photos. They face extreme difficulty with the verbal instructions...”*.

**Finding 6 - Motivation through reward/ appreciation:** Reward or appreciation after each successful task motivates the target users. Appreciating words like “good job”, “well done”, “congratulations”, or appreciating with action like clapping has a significant impact on users’ behavior. On 18 February 2022, at 0930 hours, the researcher observed that students K and L were learning to place an object in the right place. Both of them were given separate boards where various-shaped slots were there to be filled with similarly shaped objects like rounds, rectangles, triangles, squares, etc. At first, the mentor showed them how to find the appropriate place on the board for any particular shaped object and place it. Student K was focused during the learning session, whereas L had less concentration. After the demonstration, K and L were asked to do the same. Student K placed all the objects correctly and remained seated without showing further interest in this event. Whereas initially, L was facing trouble placing the objects, the mentor guided him

all the way and appreciated L by saying “*Good Job*” and clapping after each successful placing. After completion, L became interested in starting the same event again. In the second round, L successfully placed all the objects correctly by himself. The panel agreed with the observation unanimously. The behavioral therapists added, “*Reward or appreciation is most common for cheering the students. We follow this approach regularly*”.

**Finding 7 - Repetitive demonstration:** Most of cases individuals with ASD fail to understand the learning at the first go. Repetitive demonstration of the process is more effective in learning for them. On 21 February 2022, at 1000 hours, it was observed that there was a one-to-one session where one mentor was engaged with one student. Student M was given a page where various geometrical shapes were drawn in different positions with a pencil. The geometrical shapes are interconnected with lines of various types. Some are straight, some are curved and some are dotted, etc. At first, the student was asked to color the objects with some colors, like he was asked to color the triangles with yellow, the ovals with red, etc. Afterward, he was asked to connect the geometrical shapes with colored pencils according to their types. For example, the triangle is connected with the rectangle with a curved line. The student needs to color the connector line with brown color, as the instruction was all the curved lines would be colored with brown, all the straight lines will be colored with black and all the dotted lines will be colored with pink. Initially, student M struggled to get the problem statement, and the mentor guided him again and again. In the second round, student M could catch the idea and successfully solve most of the tasks. When M was facing problems in the first round, he seemed to be less interested in the process. But the repetitive demonstration of the actions shown by the mentor helped him to understand the problem statement. The academic teacher stated that “*...the academic learning process like learning alphabets, words constructions require the number of sessions. And the sessions should be arranged after a fixed interval for refreshing the memories of the students...*”.

**Finding 8 – The capability of applying classroom knowledge to the real world:** ASD-affected children are capable of applying classroom learning to the real world. The observation recorded on 21 March 2022, at 1000 hours, stated in this regard: student N was learning the alphabet with some flashcards. When she came across “S” in the flashcard, it was mentioned “S for spectacle” and an image of a spectacle. N then pointed towards this researcher sitting in front of her and wearing a spectacle.

This reflects their ability to co-relate classroom learning with the real world. The speech therapist said: “*The students always try to copy and apply the actions that we behaved with them*”.

**Finding 9 - Involvement of caregivers:** The main challenge due to autism is communication and social behavior. These two challenges affect other learning processes. Active involvement of the caregivers like parents / teachers / therapists will make the learning process an effective one. Their involvement increases the collaboration, sharing, and emotion recognition skill development along with academic and cognitive skills. On 07 March 2022, at 1030 hours, it was observed that the mentor was checking the tasks done by the students, which were given as homework. Student O was assigned a task on numeracy. The mentor drew stars in different frequencies in different slots and wrote three numbers in each slot. O was asked to count the frequency of the stars in each slot and encircle the correct number. The parents of O were involved in the learning process and commented on the task sheet, “O has done the task by himself. We have just made him understand the action set”. The behavioral therapist said, “*The role of the parents in the learning process for this group of children is very important. Because parents spend most of the time with them and they need to teach them daily living skills like using the toilet, making beds, doing laundry, setting up the school bag and, etc. That’s why we arrange parents’ counseling sessions each and every week. In the counseling session we receive feedback from the parents regarding the student’s progress. We also apprise them about our evaluation. We provide guidelines/ directions to the parents regarding what & how they should behave with their special child*”.

**Finding 10 - Evaluation of performance / Progress tracking:** The researchers observed during the Ethnographic study that the teachers / therapists are evaluating or maintaining the individual’s progress report manually. Most of the cases they endorse the performance record based on their observation. There is no fixed scale of evaluation of the performance. Hence, the level wise transformation of the problem statement is not justified. While discussing this issue with the panel of experts, the behavioral therapist stated that, “*When a new student comes to us, we conduct an interview to observe his/ her limitations in terms of eye gaze, eye contact, responsiveness, concentration level, motor neuron skill, verbal and non-verbal communication skill. Afterwards, we set a six months goal for that particular student. We follow that goal chart while conducting the learning process for that individual*”. The occupational therapist stated that the observations might

vary from individual to individual. Moreover, manual evaluation may not always be accurate, whereas daily evolution is sensitive to achieving the goal for the individuals. Lastly, all the members of the panel opined that it would be effective to have a systematic and automatic performance record and evaluation pattern which can generate the report as per the requirements for individual students by analyzing the performance.

**Finding 11 - Database for future research:** The researchers have not found any existing dataset to validate the collected data. Moreover, at present, no dataset exists containing the performance evaluation based on any ICT based learning solutions. The existing dataset facilitates only the Applied Behavior Analysis (ABA) like motor skills patterns, social skills patterns, body motion, eye gaze or responses upon calling their name (Billing et al., 2020; Liu et al., 2017; Simões et al., 2020; Colombo-Dougovito & Reeve, 2017; Carette et al., 2018). Thereby, a dataset containing the evaluation of learning performance based on ICT based learning solutions needs to be developed to facilitate future research through which academicians and physicians can explore further on ICT based effective solutions to upskill individuals with ASD.

**Finding 12 - Physical and psychological effects of using technology:** The researchers have not seen any use of technology in the teaching process of children with ASD in this institution. This issue has been highlighted in the discussion session with the panel of experts. The academic teacher said, *"...earlier I used an app on a tablet to teach alphabets. That app is developed for the normal children. I have found that app is not intuitive enough for special children"*. The behavioral therapists added, *"...as the children with ASD suffer mostly in communication, then if we make them used to with smartphone or tablet, then I think it will have a more negative impact. But it would be great if there is any learning app available where simultaneous participation of the students and teachers are there"*. The occupational therapist said, *"Again we are not aware of the blue screen effect on this group of children. It must be analyzed whether any psychological impact is there or not of using the smartphone/ tablet for this special kid. Most importantly, the apps or digital learning tools which are developed for this group of people must get certification from physicians or psychologists stating that the digital learning tools are effective and not hazardous for ASD affected children"*. Thereby, it is imperative to analyze the impact of using the technologies on individuals with ASD before their skill development process is implemented. Evaluation criteria should include physical indicators such as

eyestrain, dizziness, sleeplessness and psychological indicators such as addiction, anxiety, depression and solitariness (Westby, 2020) a framework for choosing appropriate digital media for children with autism is described. The 3-component framework considers the characteristics of the child, the context in which digital media are used, and the content of the media. Key Message: Using the framework, the speech-language pathologist will be better able to select appropriate digital media content for children with autism that is engaging (while not being distracting).

The revealed twelve requirements led to the development of a new model to design and develop technology-based learning tools for children with ASD. In this study, instead of developing a new model, the existing MAPE model from the previous study (Hasan & Nene, 2022) has been evaluated to measure conformity to the revealed requirements.

### Overview of MAPE Model

The Multi Agent based Persuasive Education (MAPE) model (Hasan & Nene, 2022) has been developed for the cognitive and basic academic skills development of children with ASD having an age limit between five to eight years old. MAPE model mainly addresses the concentration deficit issue due to autism. The architecture of the MAPE model is illustrated in fig. 2. MAPE model consists of three intelligent software agents: student agent, teacher agent and supervisor agent. This model uses persuasive technology to design the interaction pattern of the three agents. The student agent of this model interacts with the user just like another partner, which helps to attract the concentration of individuals with ASD. The teacher agent demonstrates the correct answer and appropriate procedure when the user gives the wrong answer. It helps to develop the interaction behavior of children with ASD. Lastly, the supervisor agent keeps the progress track of the user and generates reports for appraisal to the caregivers. This ensures the engagement of the caregivers in the learning process. The supervisor agent provides access to higher-level learning modules only when the user attains a specific benchmark at the current level. The MAPE model consists of two data repositories. Performance recording repositories store the evaluation parameters of the individual user. The data repository holds the learning modules' data. Both repositories are accessed by the supervisor agent only. The unique property of this model is to have chronological learning modules that can be revealed based on the users' learning performance. The provision of adding new learning

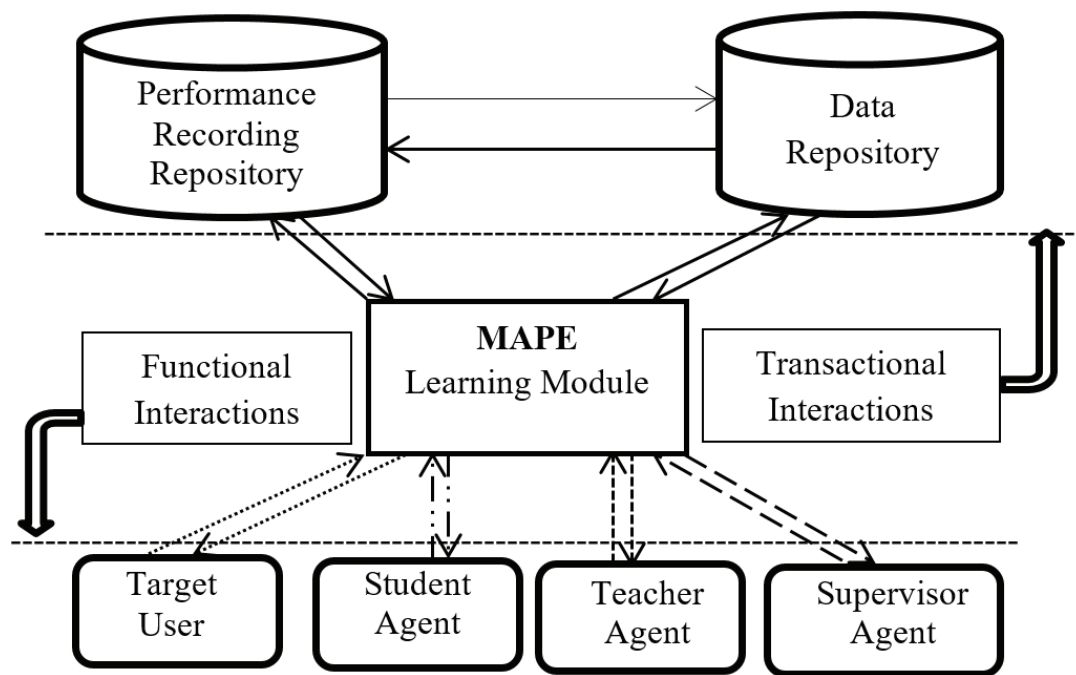


Fig. 2. Architecture of MAPE Model (Hasan & Nene, 2022)

modules is available in the MAPE model. AI & ML need to be applied to generate the metadata to analyze the individual user's performance report, which will be recorded in the performance recording repository.

### Conformity to MAPE Model with Revealed Requirements

This section aims to analyze the MAPE model against the revealed requirements in this study. The analysis results are shown in Table 1. The evaluation results depict that the MAPE model satisfies a total of ten requirements out of twelve revealed requirements of this study. Now, the MAPE model needs to be expanded to accumulate the following two not-satisfied requirements: a database for future research; analysis of the physical and psychological effects of using technology.

### IoT Based Framework

The IoT is a technology whereby individually identifiable devices can automatically communicate with each other according to requirements (Shafique et al., 2020). At present, IoT is mainly used to monitor the activities and evaluate the cognitive development progress to identify the behavior pattern and explore the therapeutic requirements of children with ASD (Sula et al., 2014; Shi et al., 2017; Tang & Winoto, 2018; Lavanya et al., 2019). Table 1 illustrates that the MAPE model satisfies this study's ten out of twelve revealed requirements. This study proposes a three-tier IoT Level-5 (Bahga & Madiseti, 2015)

network framework to incorporate the eleventh and twelfth requirements. The layout of the proposed framework is illustrated in fig. 3.

### Tier-1: Body Area Network (BAN)

Body Area Network (BAN) mainly monitors the users' physiological parameters and generates reports accordingly to inform stakeholders like users themselves or physicians or therapists (Chen, 2014). Wireless Body Area Network (WBAN). The first tier of the proposed network framework is a BAN. The user and the ICT-based learning solution exist in this tier. The number of users determines the number of BAN in Tier-1. The BANs are independent of one another. There will be three following analyses in this tier to fulfil the twelfth requirement of the findings.

**EEG Signals Analysis:** Neurons are the human brain units that receive signals from the surroundings and pass the reactions to the relevant parts of the body (Woodruff, 2019). Electroencephalogram (EEG) effectively analyzes the brain signals in different situations (Kumar & Bhuvaneswari, 2012). EEG analyzes the signal bands from low frequency to the high frequency of the Frontal lobe, Parietal lobe, Occipital lobe and Temporal lobe of the human brain to understand the cognitive capabilities (Wang et al., 2013). Physiological aspects like the prediction of epilepsy in children with ASD also can be monitored through EEG (Rossi et al., 1995). Analyzing these signals will provide the idea about the responses

Table 1. **Conformity to MAPE model with revealed requirements**

Revealed Requirements	Conformity to MAPE model
Initiation of conversation	Student agent of MAPE model initiates the conversation to persuade the users to involve with the system.
Picture Exchange Communication (PEC)	Student agent and teacher agent communicate with the target user with figures/ symbols which are easily understandable. For example, the student agent shows two placards in its two hands - one is showing '1 2 3' and another one is showing 'A B C', which demonstrate options to explore either numeracy or alphabets.
Colourful objects attracts more	For all type of demonstrations, the agents use colourful objects to attract the user.
Persuasiveness or provocation factor	MAPE model satisfies three criteria of persuasiveness. Firstly, eight step design process to create persuasive technology (Fogg, 2009). Secondly, incorporation of five social cues into the three software agents to be persuasive (Fogg, 2003) and lastly, satisfying the Fogg Behaviour Model (FBM) (Fogg, n.d.).
Pictography	MAPE model demonstrate the learning session with pictography. For example, for addition: '5+3=?', MAPE model will demonstrate five apples in one basket and three apples in another basket. The student agent will put all the apples all together by counting '1 2 3 4 5 6 7 8', At the same time '8' on the virtual keyboard will change its colour to attract the user to press it.
Motivation through reward/ appreciation	For successful answers, student agent will respond by saying 'correct answer.... congratulations. And for wrong answer it will say 'wrong answer.... try again'. Along with voice annotation, score will be added for correct answer and deducted otherwise.
Repetitive demonstration	Learning modules are classified into different levels in MAPE model. The upper level will only be revealed when a certain point will be achieved in the lower level. Otherwise, the same level but with different problem statements will continue.
Capability of applying classroom knowledge into the real world	MAPE model mainly focuses the concentration deficit factor which hampers the learning process of ASD affected children. Thereby, the interaction pattern of the MAPE model is designed to develop the concentration level of the user which can be applied into the real world.
Involvement of caregivers	Caregivers like parents or teachers are actively involved in the MAPE model. They can select the suitable learning modules for the user. They are also able to see the performance report generated by the supervisor agent.
Evaluation of performance/ Progress tracking	The supervisor agent evaluates the performance of individual user. Points added for each correct answer and deducted for each wrong answer. This agent also reveals the advanced learning levels based on the users' performance.
Database for future research	Not Addressed
Analysis of the physical and psychological effects of using technology	Not Addressed

in various situations, like when the user is comfortable and when s/he feels disturbed (Oberman et al., 2005). EEG signals need to be analyzed before and after using the learning solutions to compare the data and understand the effects of task specific information processing (Catarino et al., 2011).

*Analysis of Facial Expression:* Understanding the emotions of individuals with ASD by observing their facial expressions is difficult (Harms et al., 2010; Gordon et al., 2014). ASD-affected individuals display less frequent facial expressions, less accuracy, and less time with lower quality to be evaluated (Trevisan et al., 2018). Microsoft Kinect is a motion sensor camera that identifies the user through expression and body gestures, and it allows it to be operated without any controller (Zhang, 2012).

Microsoft Kinect evaluates the parameters considering multiple facial expressions at a time like eye gaze, eye-ball movement, hand movements, body coordinates, and open or closed mouth (Pour et al., 2018; Al-Jubouri & Ali, 2020). Existing research supports identifying seven basic emotions (happiness, anger, sadness, surprise, fear, disgust, and neutral) of individuals with ASD in real time with Microsoft Kinect (Jazouli et al., 2017). Thereby, the evaluation of the facial expression is placed in Tier-1 of the proposed framework to evaluate the emotions of children with ASD while using the ICT-based learning tool.

*Analysis of Physiological Parameters:* Several chronic disorders, neurological disorders, and mental health issues can be managed and treated using wearable sensors (Fletcher et al., 2010). Wearable sensors kits in the form

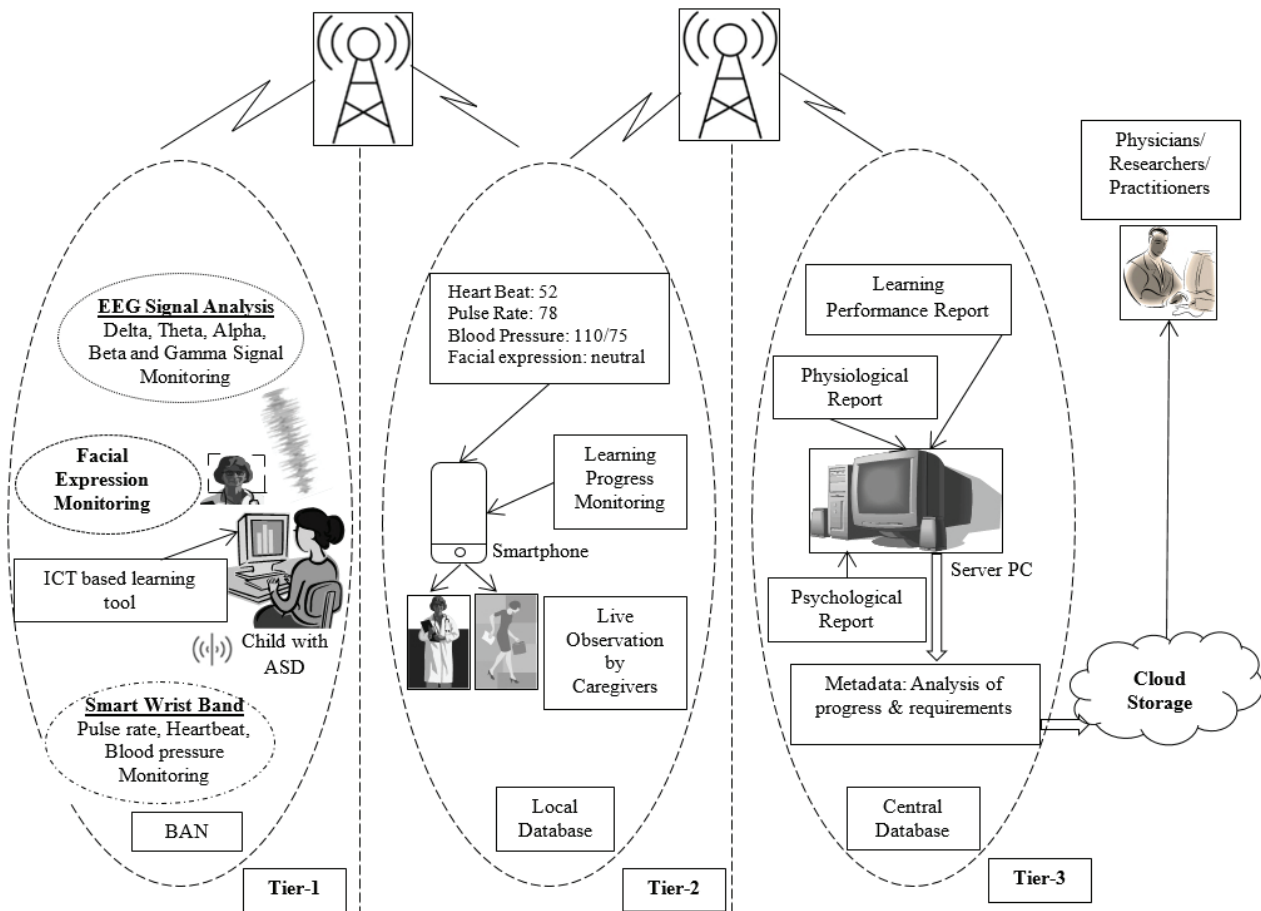


Fig. 3. A 3-Tier IoT network framework of ICT based learning solution

of a wristband, chest strap, and headband continuously monitor the users' physiological parameters like blood pressure (BP), pulse rate (PR), body temperature, heart rate variability (HRV), and provide early warning during serious physiological situations to the caregivers or the users themselves (Clifton et al., 2014). Present research supports evaluating the physiological parameters like BP, PR, HRV and body temperature by using smart, comfortable and harmless wearable gears of individuals with ASD during the learning process with ICT based learning solutions (Taj-Eldin et al., 2018). The inclusion of the analysis of physiological parameters in the proposed framework will explore the physiological impacts of using the technologies for children with ASD.

### Tier-2: Local Database and Performance Monitoring Through Mobile Technology (MT)

To fulfil the eleventh requirement of the requirements engineering study, the second tier of the proposed framework consists of a local database. The caregivers of children with ASD, like teachers or therapists or parents will have access to this server through MT. The network will

have multiple local databases (Tier-2), considering each institution will have a separate one.

*Local Database:* Data from the first tier will be stored on a local database (*Types of Databases*, 2015) which will be hosted within the institutions. Multiple BAN from Tier-1 will be connected to the local database. This local database will host individual user learning performance through ICT-based learning tools and physiological & psychological parameters during learning sessions.

*Performance Monitoring through MT:* The caregivers of individuals with ASD will access the local database through MT. A mobile app will facilitate the caregivers to fetch the information about the concerned ASD affected children. Individuals' performance will be reported to the concerned caregivers only. By analyzing the metadata through AI & ML (Gorai & Nene, 2019), the report will also project the requirements for the individual's development for any particular aspect.

### Tier-3: Central Database and Cloud Storage

Having a central database for a specific purpose has the following advantages: accessible communication and co-

ordination to get the target information, less duplication of the data, more secure and more efficient to manage, access points that can be added or discarded easily, portability of data is hassle-free and cost-effective to maintain (Akhtar, 2021). The last tier of the proposed network framework consists of a central database to fulfill the eleventh requirement revealed in the requirements engineering study.

*Evaluation reports in Central Database:* The central database will store the reports on performance evaluation and physical & psychological effects parameters of using the ICT-based learning solutions of all the institutions' participants. Empirical data will be accumulated to develop heuristics by employing AI & ML. Learning patterns and new requirements will be identified through the heuristics and available in the cloud storage for future research avenues for academicians, physicians, and practitioners. The central database will be connected to multiple local databases from Tier 2.

*Database as a Service:* The second part of Tier-3 is a cloud-based database. Databases that run on cloud platforms are known as cloud databases and they provide access to the databases as a service (Abourezq & Idrissi, 2016). Database as a Service (DaaS) is the recent inclusion in the services of Cloud Computing (Al Shehri, 2013; Khan et al., 2022). In the proposed framework, researchers/ academicians/ therapists/ physicians can access the cloud database where the metadata of all the performance evaluations and physical & psychological effects analysis of using technologies will be hosted. By analyzing the metadata, they will be able to explore the new requirements to facilitate the effective learning process of children with ASD with the leverage of ICT.

## DISCUSSIONS AND CONCLUSION

The ICT-based learning tools like computer-based instructions, computer-assisted instruction, mobile technology, video modeling, virtual reality, augmented reality, robot-based intervention is used in various skills development process of children with ASD (Syriopoulou-Delli & Stefani, 2021; Heng et al., 2021). The requirements for the intervention process for this group of children are to disjoint to another, which is the barrier to develop common learning tools for ASD-affected children (Grossard et al., 2018). By considering these, this study has revealed the requirements for the design and development of ICT-based learning solutions through a participatory design approach. Based on the revealed requirements, a framework is developed which will form

the basis to track the learning patterns of individuals with ASD and reveal the new requirements particularly applicable for that individual only. The stakeholders of the ASD-affected children like their parents, teachers, therapists, and academic researchers are considered as a part of the proposed framework to observe the progress and comply with the new requirements. The implication of this study is to design and develop usable ICT based learning solutions for ASD-affected children with performance evaluation capability, individual's new requirements identification process, and the generation of the dataset for the development of the learning pattern to incorporate new heuristics through AI & ML.

The outcome of this study is an IoT Level-5 based three-Tiered network framework for developing ICT-based learning solutions for children with ASD. This network framework aims to evaluate the performance of the learning outcomes and analyze the effects of using technologies on individuals with ASD. The requirement for this framework has evolved from the requirements elicitation study through ethnography at a school for special children in Pune, India. There are twelve requirements validated in this study that can be addressed by ICT. The revealed requirements are: *initiation of conversation, PEC, attractiveness of the colorful objects, persuasiveness or provocation factor, pictography, motivation through reward/ appreciation, repetitive demonstration, the capability of applying classroom knowledge to the real world, involvement of caregivers, evaluation of performance/ progress tracking, a database for future research, and analysis of the physical and psychological effects of using technology*. Ten out of twelve requirements are addressed in the previously developed MAPE model for the cognitive and basic academic development of individuals with ASD. The rest of the two requirements are addressed in the proposed IoT framework. The unique contribution of this study is the IoT based framework to design, and develop the ICT-based learning solutions and a cloud-based database model for future researchers to enhance the ICT-based learning mechanism for children with ASD.

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