

A Robot-Assisted Scenario Training for Students with ASD

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Abstract: Students with autism spectrum disorders (ASD) often feel insecure in new environments due to social challenges, unfamiliarity, and a lack of support or understanding. Despite considerable efforts dedicated to assisting students in adapting to new environments and understanding appropriate behaviours in public settings, there remains a lack of interactive and personalized learning systems. In this work, we developed a robot-assisted scenario training (RAST) system to facilitate inclusive learning and arouse students' learning interests. With the RAST system, we seek to identify effective interactions that can improve students' engagement. To this end, we invited 13 students with ASD to participate in an evaluation study. In the study, self-determination theory (SDT) measures students' learning engagement. Learning engagement and effectiveness are evaluated using variance analysis (ANOVA). Students also participated in interviews to report their user experience regarding the system. The results reveal that learning with the RAST system can significantly arouse students' intrinsic motivation and improve their behavioural, emotional, and cognitive engagement. Additionally, students with ASD increased their learning performance by 8.33%. Furthermore, students exhibited a high level of engagement in scenario training with certain types of interactions, including personalized functions, visual cues and sound quality. Overall, the RAST system demonstrates promising capabilities in enhancing students' learning engagement and proficiency with ASD.

Keywords: Autism spectrum disorders, Social Interaction, Behavioural Skills Training, Robot-assisted Learning, Engagement

1. Introduction

1.1 Problems encountered by individuals with ASD

Autism spectrum disorders (ASD) affect at least 1% of the world's population (Zeidan et al., 2022). Those with ASD exhibit distinct characteristics, including restricted and repetitive patterns of behaviour (Schaaf & Lane, 2015). Additionally, they often experience challenges in social interaction, such as difficulties comprehending and using gestures within a social context (Stone et al., 2019). Studying risk factors for specific language impairment and ASD involves examining shared demographics and behaviours, with language playing a crucial role, and individuals with ASD may struggle with interpreting vocal tones (Tager-Flusberg, H., 2016). Moreover, those with ASD lack adequate knowledge and understanding to effectively interact with others in social contexts, such as schools, public transportation, supermarket or dining (Roberts & Simpson, 2016). Furthermore, the manner of those with ASD in public is positively associated with parental depression and anxiety (Tso and Strnadova, 2017). These challenges affect individuals with ASD to engage with society and potentially hinder their social development. Therefore, it is essential to provide support and resources that facilitate social interaction for individuals with ASD.

1.2 Learning engagement

Students with ASD typically display low levels of learning engagement, especially in their social world (Keen, 2009). The cumulative effect of low engagement would further limit the opportunities for interpersonal, academic, and even life-long development (Howlin, 2021). With early intervention, the learning engagement of students with ASD can be improved (Bradshaw et al., 2015). Behavioural skills training (BST) with different scenarios could effectively address the difficulties in ASD intervention training (Palmen et al., 2012). Cotugno (2009) found that ASD intervention enabled significant improvement in anxiety management, joint attention, and transitions, and the approach could effectively improve core social deficits in those with ASD. On the other hand, self-determination theory (SDT) is widely used to measure students' learning engagement (Fung et al., 2024) in terms of cognitive, behavioural and emotional engagement and intrinsic motivation (Sorensen & Zarrett, 2014). Furthermore, SDT allows researchers to understand the perceived digital autonomy, competence and relatedness support students with ASD to improve the BST design.

1.3 Training for students with ASD

Previous studies revealed that robot-assisted training (RAT) has promising results in improving the emotional recognition of students with ASD (Holeva et al., 2022). Additionally, the robotic intervention program significantly enhanced social engagement among them, such as eye contact and verbal initiation (Roberts-Yates & Silvera-Tawil, 2019). On the other hand, RAT can strengthen the cognitive development of students with ASD, such as recognizing and producing gestures accurately (So et al., 2019) and reversal learning tasks (Costescu et al., 2015). Several intervention practices, such as cognitive behavioural strategies and social skills training, effectively support those with ASD (Babb et al., 2021). However, these programs heavily relied on efforts from parents, peers, and trainers. In contrast, technology-based training requires fewer human resources. However, there is a lack of research examining the effect of RAT on learning engagement for those with ASD who speak Cantonese and read Traditional Chinese.

This paper is organized as follows. Section 2 reviews the literature on robot-assisted learning, effects of system design on learning engagement, SDT, and training approaches for behavioural skills. Section 3 introduces the scenario training, i.e., scenario and system design, and presents the methodology employed in this study. Section 4 discusses the results and findings. Sections 5 and 6 summarize key insights, implications, and future works.

2. Related Works

With the rapid progress in technology, there is a growing recognition that robot-assisted systems (RASs) can offer innovative and practical training for students with ASD.

2.1 Robot-assisted learning

Many research efforts have been devoted to exploring the utilization of advanced interactive solutions for students with ASD, such as robots and children's literacy skills (Hsiao et al., 2015) and learning engagement (Fridin, 2014). As shown in Table 1, Girouard-Hallam et al. (2021) investigated the attributions made by children toward digital voice assistants, and the relationship between these attributions was explored. The result revealed that younger children perceived new interactive technologies as social partners more than older children.

On the other hand, Huijnen et al. (2019) investigated the potential of the robot KASPAR as a valuable intervention. They showed that the robots' appearance, voice and sound, operation, and behaviour and actions were essential to the students with ASD. Furthermore, previous research demonstrated that young children enjoyed interacting with robots (Huskens et al., 2015), and child-robot play interaction could engage and hold children's attention. In addition, Movellan et al. (2009) designed a RUBI-4 robot to investigate whether the robot could improve Table 1. Overview of RASs, interactive activities, and opportunities for social interactions.

1	McHugh et al. (2021)	Children	The study connected how families interacted with a robot to how children reasoned about the animacy of a robot.
2	Girouard-Hallam et al. (2021)	Children	The study examined what kinds of attributions made children toward digital voice assistants and explored the relation between children's attributions toward digital voice assistants.
3	Costescu et al. (2015)	Children	The study examined the cognitive flexibility of children with ASD in comparison to typically developing children.
4	Huijnen et al. (2019)	Children	The study explored the potential of the robot KASPAR as a valuable contribution to interventions.
5	Our study	Children	Our study examined (1) How can a RAST system impact students' learning engagement? (2) What are the effective interactions that can improve students' engagement?

children's learning performance. Children actively interacted with the robot by utilizing its dancing and singing functions, which captured children's engagement.

2.2 Effects of system design on learning engagement

System design is vital in influencing students' learning engagement with robots. Various aspects, such as physical embodiment, appearance, behaviour, interaction modalities, and ethical considerations of the robots, contribute to shaping the learning experience and outcomes (Baraka et al., 2020). Designing robots that can establish rapport, offer personalized feedback, and maintain a physical presence can enhance engagement and improve children's learning outcomes (Costescu et al., 2015). With a peer-like robot playmate, children were likelier to emulate the robot's actions and language, leading to improved language learning outcomes (Kory-Westlund & Breazeal, 2019). Also, children were found to be more engaged and motivated when interacting with a robot's physical embodiment compared to a virtual or screen-based robot, suggesting that system design should consider the robot's physical presence (Kennedy et al., 2015).

Previous research primarily focused on children's perceptions of new interactive technologies, learning engagement, and cognitive flexibility. However, the impact of a RAS on students' learning engagement in scenario training was under-examined and the necessary system improvements to provide a more enriching learning environment for students with ASD, especially those who speak Cantonese and read Traditional Chinese. Therefore, our work aims to fill the gaps by answering the research question: What effective interactions can improve student engagement?

2.3 Self-determination theory

Self-determination theory (SDT) is a psychological framework that underscores the significance of autonomy, competence, and relatedness in fostering intrinsic motivation and positive behaviours (Ryan & Deci, 2020). Using robot-assisted tools in scenario training can enhance learning engagement for students with ASD by offering personalized feedback, interactive activities, and opportunities for social interactions.

2.4 Training approaches for behavioural skills

BST has proven effective in teaching a wide range of skills among diverse populations, and it consists of a structured approach that incorporates instructions, modelling, rehearsal, and feedback (Hassan et al., 2018). Despite the evidence-based procedure of BST (Anderson et al., 2017), which has demonstrated success in teaching social communication (Gresham, 2015), task engagement (Palmen & Didden, 2012), safety skills (Gunby & Rapp, 2014), and



Figure 1. Kebbi is equipped with seven motors that govern different components of its body. These components include a neck (1), two shoulders (2), two elbows (3), and two fists (4).

serving as an instructional approach for individuals with ASD, there is limited research evaluating its application as scenario training combined with humanoid robots for Cantonese-speaking students with ASD.

2.5 The current study

Despite the wide recognition of early intervention in autism therapy, there is a dearth of research on learning engagement and system design enhancements for students with ASD who speak Cantonese and read Traditional Chinese. In this study, we developed a RAST system for students with ASD who speak Cantonese and read Traditional Chinese. We developed a scenario training application incorporating the BST approach, consisting of three scenarios: supermarket, restaurant, and transportation. The application is applied to humanoid robots. Students with ASD joined four training sessions, each lasting for one hour. The engagement level was measured in a pre-/post questionnaire adapted to the SDT. Students' learning performances were recorded, and interviews were conducted for user interface (UI) and user experience (UX) enhancement purposes. To our knowledge, this is the first effort to pursue studies on autism and developmental disorders and research on traditional Chinese and Cantonese learning environments in ASD training.

3. Scenario Training

3.1 Regulations

This study followed the following regulations: (1) Informed consent was obtained from the student's parents before running the experiment. (2) Participation was entirely voluntary and based on consent. (3) The Institutional Review Board approved the research, ensuring that ethical considerations were thoroughly addressed throughout the study's design, execution, and reporting.

3.2 Participants and inclusion criteria

The participants comprised eleven males and two females ($M = 9.16$ years old, $SD = 2.64$ years old), namely S1 – S13. A maximum of four students were in a group to conduct the training session in a classroom. Each student was allocated a table, and tables were separated three meters to reduce training interference, such as arousal or social comparison. The inclusion criteria for students to participate in this study were: (1) studying in K3 to grade 4; (2) the level of language comprehension and expression skills reached four years old; (3) having received relevant assessments prior to training; (4) being able to read traditional Chinese characters and speak Cantonese; (5) having no medical or physical disabilities that might interfere with their interaction with the robot and ability to read aloud; and (6) having prior experience using digital tools such as tablets.

3.3 Humanoid robot

In this study, we chose the robot Kebbi, which possesses a head, two hands, and four wheels (Fung et al., 2024). As illustrated in Figure 1, Kebbi has seven motors that govern its various

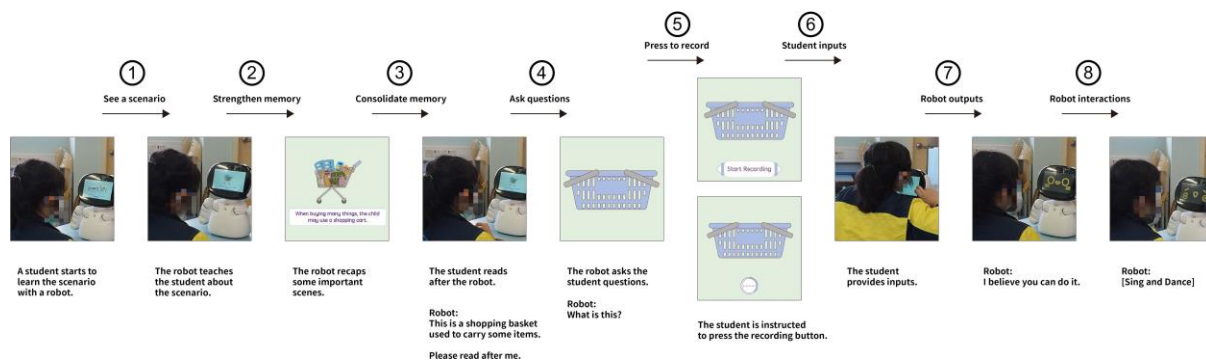


Figure 2. The whole interaction process of Kebbi.

body parts, including its neck, shoulders, elbows, and fists. Through these motors, Kebbi can rotate its head horizontally and adjust its head position vertically. Furthermore, it can exhibit a range of human-like hand movements, such as handshakes, fist clenches, cheering gestures, and expressions of agreement or disagreement. Using two swivel and auxiliary wheels, Kebbi can perform a captivating "dance". These features of Kebbi facilitate the incorporation of more humanoid interactive design elements, enhancing students' engagement.

3.4 Scenario design

The interfaces of the scenario-based training system were co-designed with a professional teacher specializing in traditional Chinese teaching and inclusive education, utilizing the BST principles. There are four steps in each training scenario. First, the training system provides students with instructions on performing in a relevant scenario (**instruction**). Second, the system presents the skills required for students to succeed in each scenario (**modeling**). Third, the system poses relevant questions to the students about the scenarios (**rehearsal**). Finally, the system offers feedback on the correctness of the students' answers and praises their efforts (**feedback**). All pedagogical materials are displayed in written Traditional Chinese, accompanied by voice prompts. Each instructional content is supported by voice assistance, which reads the content aloud to the students. The complete system comprises three training scenarios covering the topics of supermarket, restaurant and transportation, which are discussed in further detail below.

Scenario 1: Supermarket This scenario is divided into four parts. (1) Students learn the use of shopping carts and shopping baskets. The system assesses whether students can understand the usage. (2) Students learn how to use the shopping carts safely. The system assesses whether students can understand the safety of usage. (3) Students learn the proper manner of shopping in the supermarket. The system assesses whether students can understand the proper manner of shopping. (4) Students learn payment in shopping. The system assesses whether students can understand that they should pay for purchases. This scenario has 12 questions equally distributed to the four parts. Each question counts as one point.

Scenario 2: Restaurant This scenario is divided into three parts. (1) Students learn the steps of entering the restaurant, including lining up, making orders, having meals and making payments. The system assesses whether students can understand the steps. (2) Students learn how to use utensils properly. The system assesses whether students can understand how to use the utensil properly. (3) Students learn the table manners in the restaurant. The system assesses whether students can understand table manners. This scenario has nine questions equally distributed to the four parts. Each question counts as one point.

Scenario 3: Transportation This scenario is divided into four parts. (1) Students learn the setting in the railway station. The system assesses whether students can understand the setting in the railway station. (2) Students learn the steps to enter the station. The system assesses whether students can understand the steps of entering the station. (3) Students



Figure 3. A student with ASD was having the scenario training in the classroom.

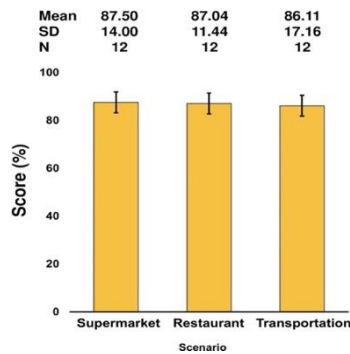


Figure 5. Performance of three sets of scenario training.

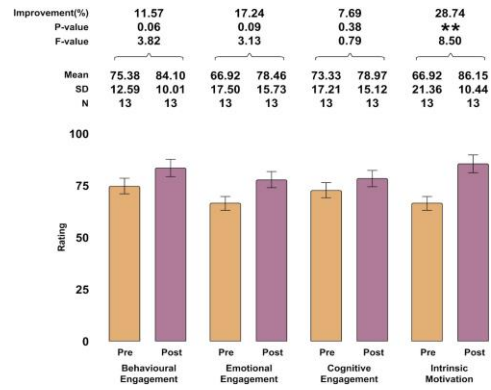


Figure 4. Overview of analysis of variance (ANOVA) for three engagements and intrinsic motivation. ** denoted that $p < .01$.

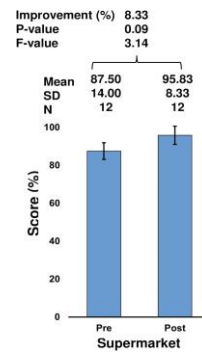


Figure 6. Overview of analysis of covariance (ANCOVA) for pre-/post-test.

understand the steps of taking a train. The system assesses whether students can understand the steps of taking a train. (4) Students learn the proper manner in the carriage. The system assesses whether students can understand the proper manner of the carriage. This scenario has 12 questions equally distributed to the four parts. Each question counts as one point.

3.5 System design

The RAST system was developed using Android Studio. The RAS utilizes automatic speech recognition (ASR), including speech-to-text (STT) and text-to-speech (TTS) functions, to facilitate the conversion of spoken language into text. This system can support Traditional Chinese (Cantonese) transcription and translation. The system is pre-programmed and compared with student input through transcription and translation.

As shown in Figure 2, students with ASD can follow eight steps to learn with the robot. Steps 1 and 2 teach students a specific scenario. Step 3 helps students consolidate their memory by asking them to recap the sentence again. Step 4 asks questions and evaluates students' memory-retaining ability. Steps 5 and 6 guide students in inputting their answers. Students have three chances to answer. Step 7 notifies students of the correctness of their answers and strengthens their memory by providing a recap function. Step 8 is to motivate students to learn, and the robot praises the students with singing, dancing and happy faces.

3.6 Setup

The experiments were conducted on the premises of a local school classroom in Hong Kong. Each student with ASD was assigned a well-trained instructor (with a degree in special education) to provide technical and emotional support, as shown in Figure 3. The instructor would also observe students' behaviour.



Figure 7. S1 was interacting with the robot by holding the hands of the robot.



Figure 8. S10 interacted with the robot by holding the hands to touch his face.

3.7 Procedure

Each student attended four sessions. The robot's possible actions were introduced to each student, including singing, dancing and automatic responses. The procedure of scenario training is shown as follows. In Day 1 Session 1, students first did a pre-questionnaire, which lasted for five minutes. Second, they took scenario training about supermarket (Scenario 1, pre-test), which took 20 to 30 minutes. Finally, they took a 15-minute break. In Session 2, students took scenario training about restaurants (Scenario 2), which took 30 to 60 minutes.

In Day 2, Session1, students first took scenario training about transportation (Scenario 3), which took 30 to 60 minutes. Then, they took a 15-minute break. In Session 2, students took scenario training about supermarket training (Scenario 1, post-test), which took 20 to 30 minutes. Second, they did a post-questionnaire, which lasted for five minutes. Finally, they did an interview, which lasted for 10 to 20 minutes.

3.8 Data analysis

A multi-analysis approach was conducted in the study, including quantitative and qualitative measures. For quantitative measures, we co-designed three training scenarios to measure children's understanding of the social contexts. The first author and a doctoral-level professional specializing in traditional Chinese teaching and inclusive education developed three sets of tests using the supermarket, transportation, and restaurant scenarios. The details can be found in the Section 3.4. For qualitative measures, interviews and observations examined students' learning engagement with the RAST system.

Descriptive statistics were employed, and SPSS version 29.0.1.0 was utilized. Specifically, we performed the analysis of covariance (ANCOVA) to investigate any significant improvement in learning engagement among students with ASD, as well as the understanding of social contexts. A p-value lower than 0.05 indicates a statistically significant difference. The qualitative measures were conducted based on interviews with parents and students and observations of students.

4. Scenario Training

4.1 Quantitative measures

The analysis demonstrated that the RAST system could significantly arouse students' learning interest in behaviour and emotional, cognitive, and intrinsic motivation. All questionnaire results follow normal distributions (i.e., skewness less than 2.3; kurtosis less than 7.0). As shown in Figure 4, students with ASD improved by 11.57% in behavioural engagement ($F_{1,12} = 3.82$, $p = .06$), 17.24% in emotional engagement ($F_{1,12} = 3.13$, $p = .09$), 7.69 % in cognitive engagement ($F_{1,12} = 0.79$, $p = .38$), and 28.74% in intrinsic motivation ($F_{1,12} = 8.50$, $p < .01$). Figure 5 shows students' performance in supermarket, restaurants, and transportation, which was 87.50, 87.04, and 86.11, respectively. Although the performance of the scenario training had no statistical significance in the pre-/post-test, the improvement had reached 8.33% ($F_{1,11} = 3.14$, $p = .09$), shown in Figure 6.

4.2 Qualitative measures

4.21 Students' interview. Students with ASD can concentrate well on straightforward content. Recap functions require prompts, and it takes time for the students to understand complex sentences. Also, continuous motivation is needed to engage students to keep up with learning.

4.22 Preference and experience. The students' responses revealed that they were happy and excited when playing games. Specifically, the students indicated that they enjoyed playing the game of scenario training, with some mentioning that they learned from it and others expressing a high level of enjoyment. For instance, S6 told us, "I like playing this game because I learn a lot from it." The overall sentiment towards the game was positive. Students found the RAS to be fun, engaging, and enjoyable.

5. Discussion

Students with ASD generally feel anxious in the community. Over 76% of students encounter different anxiety levels in new environments (Adams et al., 2019). With sufficient prior notice, they could reduce their anxiety (Green & Ben-Sasson, 2010). Implementing anxiety-reduction strategies, such as scenario training, that focus on enhancing tolerance towards everyday uncertain situations can enhance the well-being, quality of life, and participation of autistic children and their families.

The study results have several implications for supporting students with ASD. Quantitative and qualitative evidence for the efficacy of the RAST indicates that this robot-assisted approach can accommodate their diverse learning needs in various settings. For example, the RAST can be applied to real-world activities practice with slight modifications, such as attending a birthday party or playing games with friends. Additionally, our findings show that students with ASD enjoyed interacting with the RAST system, suggesting that the system can provide a happier school life for them. Improving school well-being and resilience for them is crucial because many students feel stressed when going to school with negative experiences (Tesfaye et al., 2023). This study provides some design hints on how to design RAT and make it more friendly to students with ASD. For example, human-like hand movements (i.e., handshakes, cheering gestures, and dancing) in the robot design may be an effective strategy to improve student engagement and enjoyment. During the training process, it is vital to make personalized adaptations (i.e., response time and lip-reading options) to fit the student's needs.

5.1 Impact of robot-assisted scenario training

Our system programmed and controlled the robot's responses and actions, providing a sense of stability and structure. Physical touch has positively affected emotional and social well-being (Holland et al., 2016). Interacting with a robot can provide a sense of predictability and consistency, which can be comforting for students with ASD. Holding hands with the robot can create a sense of personalization and connection, leading to increased cognitive engagement. In addition, the act can provide comfort and security, increasing emotional engagement. Moreover, the novelty of interacting with a robot can capture the attention and interest of students with ASD, leading to increased behavioural engagement. When students feel a personal connection to the robot, they may be more motivated to learn and engage with the content. Figure 7, S1 interacted with the robot by touching its hand and head. Additionally, S1 shook hands with the robot. In Figure 8, S10 also interacted with the robot by holding its hand to touch his cheek. Furthermore, S10 held the robot's hand and danced with it when the cheering animation appeared.

5.2 Flexible support for addressing varying digital learning abilities

Flexible support can be a beneficial solution to accommodate the diverse digital learning abilities and perspectives of students with ASD during scenario training, in line with Walton and Engelbrecht (2022). First, for students experiencing communication issues and struggling with pronunciation, integrating speech recognition technology and practice exercises can

enhance their language skills. Second, offering clear instructions and examples for answering questions can assist students who require help formulating responses. Adjusting the recording time for answers to a more manageable pace can alleviate pressure for students like S4, who find it too fast. Third, addressing audio/listening problems by ensuring high-quality audio and providing subtitles or transcripts can enhance comprehension. Regular teacher feedback and support are vital (De Boer et al., 2011) in addressing individual difficulties and creating a positive learning environment that fosters confidence and motivation.

6. Limitations and Future Research

There are some constraints in this study. First, the number of participants and training sessions limits the study. With more participants, the result will be more reliable. Second, the training duration was short. Longer training can provide a greater learning impact for students. Third, this study does not include any control group to compare the training results. In the future, we will evaluate retention and transfer the knowledge in a long-term evaluation. Fourth, the scenario design can focus on specific skills, such as communication, problem-solving, or social skills. These skills can help students gradually build their abilities and confidence in different areas. Also, to cater to students' abilities and learning needs, implementing customizable difficulty levels can provide various options for different scenarios, enabling students to select the level that aligns with their capabilities and learning requirements.

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