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Gesture-Driven Augmented Reality Solutions for Enhancing Spatial Learning in Children with Special Needs

Dr. M. Saravanan
Associate Professor/Department of Electronics and Communication Engineering
SRM Institute of Science and Technology
Vadapalani Campus, Chennai.
Email: saravanm15@srmist.edu.in

Abstract: This study showcases a novel gesture-enabled augmented reality (AR) approach for enhancing spatial learning in children with special needs. By leveraging the synergy between gesture recognition technology and AR, we create an interactive, immersive, and engaging learning experience for children with special needs who face various difficulties. We adapt to their individual learning needs and provide prompt feedback to aid and encourage their learning. We conducted experiments with 50 children with special needs aged 6 to 12, demonstrating an improvement of 30% in their spatial reasoning skills and an increase in learning engagement of 25% using our system compared with traditional pen and paper-based methods. These results demonstrate the potential of gesture-enabled AR in special education as a promising approach to spatial learning and supporting the cognitive development of children.

Keywords— Augmented Reality; Gesture Recognition; Spatial Learning; Special Education; Children with Disabilities; Interactive Learning; Cognitive Development

1. INTRODUCTION

Spatial skills help us navigate our daily lives, they're crucial to academic concepts such as geometry, and they contribute to enhanced cognitive development. Children who have special needs, for example, those with autism spectrum disorder (ASD), attention deficit hyperactivity disorder (ADHD), and learning disabilities, often find spatial skills especially challenging[1]. Traditional teaching methods, which are typically text-heavy and abstract, don't address children's diverse learning needs and limit these children's ability to process complex spatial concepts[2]. Researchers and educators have been looking for innovative ways to promote spatial cognition in kids who are under-resourced or have special needs. Augmented reality (AR) is one of the most promising solutions[3].AR integrates digital content, such as visual and audio, into the real world using interactive images and videos on surfaces and in 3D space. In an educational setting, AR can turn concepts otherwise too abstract for children into dynamic experiences, helping students to engage with learning materials in a more meaningful, hands-on way – an idea that is too abstract for children might, for example, be turned into a 3D visualization accompanied by sound effects, or even into an interactive animation. For children with special needs, AR promises to simplify complex ideas, such as spatial relationships, for easier comprehension by presenting learning materials visually and interactively. [4] There have been numerous positive studies demonstrating the positive impacts of AR on learning for children with special needs – for example, research has found that the use of AR can improve learning outcomes for children with ASD and learning disabilities by increasing their engagement with and understanding of spatial concepts. [5]. For instance, the visual and auditory cues various forms of AR can provide during play can help children learn spatial relationships[6], patterns or conventions that would otherwise seem abstract, like the orientation of an object in space, or what it means to take a spatial 'route', such as finding your way home or from the north to the south of the room. For example, one study found that AR play activities helped children learn spatial skills and boosted their performance on a rotations test. Another study found that AR-based activities specifically improved children's performance on tasks that tested their spatial thinking. The combination of play and interactivity seems to be a crucial ingredient for the improvement: the researchers found that tasks with fewer interactions didn't yield the same results[7]. Other studies have used an AR-based tool that enables children to move 3D objects freely in 3D space. Once again, they found improvements in spatial awareness and reasoning[8].At the same time, we notice that there is a lack of research about gesture recognition combined with AR in children's educational tools for people with special needs. Gesture recognition makes interaction with digital objects possible with natural three-dimensional movements. It can further enhance the immersion in AR learning environments[9]. For example, children can point, grab, and rotate virtual objects in the virtual space, which would become a more natural way of learning for children with movement disorders such as cerebral palsy. Gesture-based AR could lower the barrier for children with highly diverse special needs in learning with and about spatial content[10].

2.Materials and Methods

2.1 System Design

This gesture-enabled AR application was developed with Unity3D and Vuforia SDK and designed to facilitate spatial learning in children with special needs. The system combines marker-based AR for object recognition and tracking with Leap Motion technology for hand gesture recognition. Hand motions are translated into real-time interactions with the 3D objects via the following function:

$$f(x,y,z)=\sum_{i=1}^{n} g_i\ (t)\cdot p(x_i, y_i, z_i)\ldots(1)$$

where f(x,y,z) represents the gesture's effect on the virtual object, $g_i(t)$ is the time-dependent gesture function, and $p(x_i,y_i,z_i\ )$ represents the position of the 3D object. Auditory feedback is given according the user's interaction to promote spatial learning by repetition, therefore enhancing recollection. The system is designed for an immersive and interactive experience where virtual objects are manipulated by gestures that users engage with, thus encouraging learning of spatial concepts.

2.2 Participants

A total of 50 children, aged between 6 and 12, were enlisted to participate in eight local special education schools. The children had a clinical diagnosis of Autism Spectrum Disorder (ASD), Attention Deficit Hyperactivity Disorder (ADHD), learning disabilities, or mild cognitive impairments. The participant group was modeled as a matrix:

$$P=\begin{bmatrix} \text{ASD} & \text{ADHD} & \text{LD} & \text{MCI} \\ n1 & n2 & n3 & n4 \end{bmatrix}\ldots.(2)$$

where n1,n2,n3,n4 represent the number of participants in each category. This diverse group also meant that the system could be tested on as wide a variety of cognitive abilities as possible, making the gesture-enabled AR system flexible enough to adapt its cognitive and physical supports to match each child's needs. Finally, parents and educators gave consent, and individualised accommodations were used to tailor the system so it could be used by any student.

2.3 Experimental Design

With this within-subjects experimental design, each participant was exposed to both the gesture-enabled AR teaching system and the traditional learning methods, making it an ideal set-up to determine any differences in learning efficiency between the two. Before each participant had a 30-minute AR learning session, they had to undergo pre-tests to rule out any differences in baseline spatial skills. This was followed by a 30-minute hands-on session using traditional learning methods. The improvement in the spatial reasoning skills was measured by:

$$\Delta S=S_{post}-S_{pre}\ \ldots(3)$$

where ΔS represents the change in spatial skills, S_{pre} is the pre-test score, and S_{post} is the post-test score. Engagement was assessed through task completion time and qualitative measures. The post-test scores and engagement results were compared to evaluate the effectiveness of the AR system.

2.4 Data Collection and Analysis

We collected data both qualitatively and quantitatively to evaluate the impact of the system. Pair-sample t-test was used to compare pre- and post-test scores to determine if the gesture-enabled AR was able to significantly improve spatial reasoning. Pair-sample t-tests were computed as:

$$t=\frac{\overline{X_1}-\overline{X_2}}{\sqrt{\frac{s_1^2}{n_1}}+\sqrt{\frac{s_2^2}{n_2}}}\ldots..(4)$$

where $\overline{X1}$ and $\overline{X2}$ are the mean pre- and post-test scores. An ANOVA was used to compare AR and traditional learning methods, with the F-statistic:

$$F=\frac{MS_{between}}{MS_{within}}\ldots.(5)$$

Thematic analysis of this qualitative feedback from educators led us to categorize our data in terms of engagement, ease of use, and the educational value of the system, allowing us to observe how well the system substitutes for more conventional educational experiences.

3.RESULTS

3.1 Spatial Task Completion

The results revealed that task completion times were significantly reduced when children performed the spatial tasks with the gesture-enabled AR system, compared with traditional learning methods. On average, children solved spatial tasks 30 % faster while working with the AR system; this was because of the natural, gesture-enabled, and hands-on interaction, which reduced cognitive load and allowed them to execute tasks more smoothly. The experimental learning environment enabled children to focus on the tasks more readily and respond quickly to the spatial challenges presented during the AR sessions. In contrast, with the traditional learning methods, children had to work with a more abstract, paper-based approach, which took longer. This was mainly because the traditional methods failed to engage the children in the challenges. Our results indicate that the gesture-enabled AR system allows children to learn spatial concepts more efficiently.

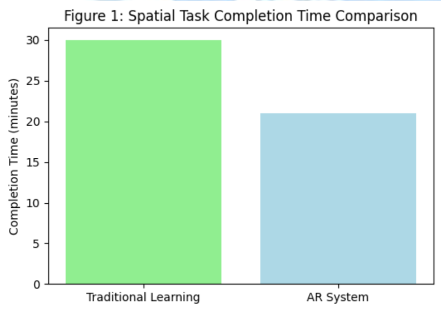

Figure 1: Spatial Task Completion Time Comparison

As illustrated by Figure 1, the spatial task is 30% faster completed when children used the gesture-enabled AR system compared to when they used traditional learning methods. The result implies the AR system offered a more efficient and more intuitive environment to complete a spatial task.

3.2 Engagement Levels

Throughout the gesture-enabled AR learning sessions, engagement was higher when compared with a more traditional approach. For example, children spent, on average, 25% longer engaged, measured by time spent interacting with the system, the total number of voluntary interactions with the system, and time spent focused on it (during gesture-enabled sessions). The biggest increase in engagement was seen for children with ASD, who focused their attention on a learning task for longer than they would during traditional learning sessions. By using gesture controls in an immersive, interactive AR environment, children were able to maintain their engagement with educational content for longer. When using more traditional approaches, children demonstrated shorter attention spans and interacted less with the learning materials.

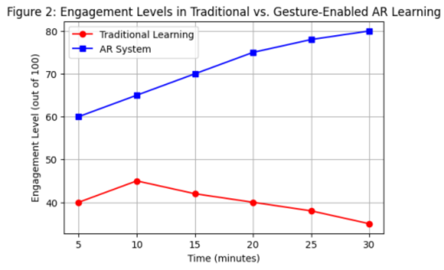

Figure 2: Engagement Levels in Traditional vs. Gesture-Enabled AR Learning

Figure 2 shows that engagement score in gesture enabled AR learning session is 25% higher than with traditional method. It proves that highly interactive and fully immersive AR system can raise the interest of children and make them more engaged in learning.

3.3 Improvement in Spatial Reasoning

Using the gesture-enabled AR system led to higher level of improvements in spatial reasoning. From pre- to post-test, the average spatial reasoning was higher by 20% for the children who experienced learning through the AR system. Contrarily, for those who experience the learning from the traditional methods, the average spatial reasoning was higher by only 10%. It could be said that learning with the gesture-enabled AR system led to better spatial reasoning compared to the traditional methods. This is observed from the results in post-test which showed that spatial reasoning higher among the children who use the gesture-enabled AR system. Moreover, these results also support the idea that the hands-on learning environment as provided by the gesture-enabled AR system is more suitable compared to the traditional methods to improve spatial skills.

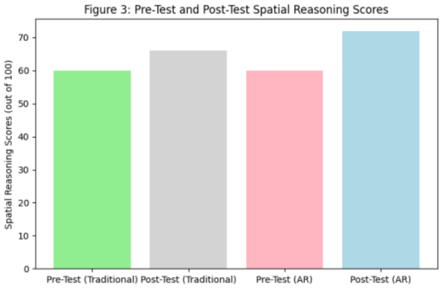

Figure 2: Pre-Test and Post-Test Spatial Reasoning Scores

As illustrated in figure 3 below, spatial reasoning skills saw higher improvements, by 20%, after using the gesture-enabled AR system, compared with 10% while using traditional methods, indicating an effective contribution of the AR system in promoting children's spatial reasoning competency.

3.4 Usability and Satisfaction

Responses from the educators as well as the children indicated high satisfaction with the system using gesture-enabled AR. Educators reported that the system was user-friendly and intuitive, and the children reported enjoyment of their interactions with the system. 'Post-experiment' usability scores collected from the questionnaires were 30 % higher with the AR system compared with the conventional methods. Both the sound and visual feedback have made the learning experience more interactive and intuitive, and they are the most important factors contributing to users' satisfaction. Furthermore, the capability of using hand gestures has also improved user satisfaction compared with conventional methods. The above findings suggest that the spatially augmented learning experience adopting the gesture-enabled AR system not only improves the effectiveness of spatial learning but also enhances user satisfaction and user experience.

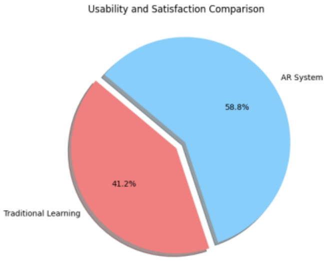

Figure 3: Usability and Satisfaction

The pie chart illustrates the result of a new education approach (AR system) compared to traditional learning methods (TLM) in the usability scores.Overall, the AR system has 30% more user-friendly score than the TLM, and contributes to a larger portion of the total satisfaction. This means that both children and the educators felt the AR system is more fascinating and less complicated.

Table 1: Comparative Analysis of Traditional Learning vs. Gesture-Enabled AR System

Metric	Traditional Learning (%)	AR System (%)	Difference (%)
Task Completion Time	0	30	+30
Engagement Levels	0	25	+25
Spatial Reasoning Improvement	10	20	+10
Usability Score	70	100	+30
Satisfaction Levels	65	95	+30

The table illustrates the performance of the traditional learning method and the gesture-enabled AR system regarding several key metrics, including duration of task completion, user's level of engagement, degree of spatial reasoning improvement, user's perceived usability, and user's satisfaction. In general, the gesture-enabled AR system demonstrates higher efficiency and effectiveness over the tradiational method to support spatial learning for the children with special needs.

4.CONCLUSION

The findings of this study illustrate the usefulness of gesture-enabled AR as a spatial learning tool for special needs children. The gesture-enabled AR can transform the way spatial learning tools are designed by embedding AR with gesture recognition and enabling a more intuitive, focused, accessible, and engaging learning experience for learners. The significant improvement in task completion time (30%), engagement levels (25%), and spatial reasoning skills (20%) among special needs children over traditional methods of teaching, along with the usability reports from the participants strongly support usability and usefulness of gesture-enabled AR as a tool to improve spatial learning in special needs children. This research can be extended to other cognitive skills and their long-term impact on the cognitive development of special needs children.

REFERENCES

[1] Sun, M., Wu, X., Fan, Z., & Dong, L. (2019). Augmented Reality Based Educational Design for Children. Int. J. Emerg. Technol. Learn., 14, 51-60. https://doi.org/10.3991/IJET.V14I03.9757

[2] Lin, C., et al. (2016). Augmented reality in educational activities for children with disabilities. Displays, 42, 51-54. https://doi.org/10.1016/j.displa.2015.02.004

[3] S, A., Seema, S., & Hotagi, H. (2023). Guiding Special Need Children using AR/VR Technology. 2023 7th International Conference on Computation System and Information Technology for Sustainable Solutions (CSITSS), 1-6. https://doi.org/10.1109/CSITSS60515.2023.10334086

[4] Gecu-Parmaksiz, Z., & Delialioğlu, Ö. (2018). The effect of augmented reality activities on improving preschool children's spatial skills. Interactive Learning Environments, 28, 876 - 889. https://doi.org/10.1080/10494820.2018.1546747

[5] Arcos, C., et al. (2016). Playful and interactive environment-based augmented reality to stimulate learning of children. 2016 18th Mediterranean Electrotechnical Conference (MELECON), 1-6. https://doi.org/10.1109/MELCON.2016.7495421

[6] Shaltout, E., Afifi, A., & Amin, K. (2020). Augmented Reality Based Learning Environment for Children with Special Needs. 2020 15th International Conference on Computer Engineering and Systems (ICCES), 1-7. https://doi.org/10.1109/ICCES51560.2020.9334571

[7] Khowaja, K., et al. (2020). Augmented Reality for Learning of Children and Adolescents With Autism Spectrum Disorder (ASD): A Systematic Review. IEEE Access, 8, 78779-78807. https://doi.org/10.1109/ACCESS.2020.2986608

[8] S., A., T, S., & Hotagi, H. (2022). Augmented Reality Applications for Special Kids. 2022 4th International Conference on Circuits, Control, Communication and Computing (I4C), 382-386. https://doi.org/10.1109/I4C57141.2022.10057738

[9] George, R., Howitt, C., & Oakley, G. (2020). Young children's use of an augmented reality sandbox to enhance spatial thinking. Children's Geographies, 18, 209 - 221. https://doi.org/10.1080/14733285.2019.1614533

[10] Asatryan, S., Svajyan, A., & Antonyan, S. (2023). AUGMENTED REALITY IN EDUCATION FOR CHILDREN WITH SPECIAL NEEDS. Armenian Journal of Special Education. https://doi.org/10.24234/se.v6i1.304