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Need Analysis for Developing a Semiotic-Based Augmented Reality Media to Enhance Numeracy Literacy Among Deaf Children

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Abstract

This study aims to analyze the needs for developing a semiotic-based Augmented Reality (AR) learning medium to enhance numeracy literacy among deaf students. A qualitative descriptive method was employed through open-ended questionnaires and interviews involving teachers at Sekolah Luar Biasa Negeri Branjangan, Jember Regency, Indonesia. The findings indicate that although 50% of teachers are familiar with AR technology, all participants expressed a strong need and enthusiasm for its implementation in numeracy instruction. Teachers perceived that the visual, interactive, and semiotic features of AR can transform abstract mathematical concepts into concrete and meaningful learning experiences that align with the visual learning strengths of deaf students. The study also revealed that color, animation, and three-dimensional visualization significantly enhance students' attention and conceptual understanding. The integration of semiotic principles—icons, indices, and symbols—into AR design enables the representation of mathematical meaning through visual signs that are easily accessible and interpretable. This approach bridges the gap between symbolic understanding and experiential learning in mathematics. The findings highlight the significant potential of AR not only as a technological innovation but also as a semiotic learning environment that supports inclusive education for students with hearing impairments. Moreover, these results provide a theoretical and practical foundation for teacher training programs on the use of AR-based technology in special education contexts.

Keywords: *augmented reality, deaf learners, inclusive education, numeracy literacy semiotics.*

Abstrak

Penelitian ini bertujuan menganalisis kebutuhan pengembangan media pembelajaran Augmented Reality (AR) berbasis semiotik untuk meningkatkan literasi numerasi di kalangan siswa tuna rungu. Metode deskriptif kualitatif digunakan melalui kuesioner terbuka dan wawancara yang melibatkan guru di Sekolah Luar Biasa Negeri Branjangan, Kabupaten Jember, Indonesia. Temuan penelitian menunjukkan bahwa meskipun 50% guru familiar dengan teknologi AR, semua peserta menyatakan kebutuhan dan antusiasme yang kuat untuk menggunakan AR dalam pembelajaran numerasi. Guru merasa bahwa fitur visual, interaktif, dan semiotik AR dapat mengubah konsep matematika abstrak menjadi pengalaman konkret dan bermakna yang selaras dengan kekuatan pembelajaran visual siswa tuna rungu. Penelitian ini juga menemukan bahwa warna, animasi, dan visualisasi tiga dimensi secara signifikan meningkatkan perhatian dan pemahaman konseptual. Mengintegrasikan prinsip-prinsip semiotik ikon, indeks, dan simbol ke dalam desain AR memungkinkan representasi makna matematika melalui tanda-tanda visual yang mudah diakses dan diinterpretasikan. Pendekatan ini menjembatani kesenjangan antara pemahaman simbolik dan pengalaman dalam matematika. Temuan ini mengindikasikan adanya potensi besar untuk mengembangkan dan mengimplementasikan media AR sebagai inovasi teknologi tetapi sebagai lingkungan belajar semiotik yang mendukung pendidikan inklusif bagi siswa dengan gangguan pendengaran sekaligus menjadi dasar bagi pelatihan guru dalam pemanfaatan teknologi berbasis AR di sekolah luar biasa.

Kata kunci: *augmented reality, siswa tuna rungu, pendidikan inklusif, literasi numerasi, semiotik.*

INTRODUCTION

In the 21st century, the rapid advancement of Information and Communication Technology (ICT) has significantly influenced various aspects of life, including the teaching and learning process. An effective learning process must be interactive, engaging, challenging, and motivating, while also providing opportunities for students to develop creativity and independence according to their individual talents and interests. Although teachers now primarily serve as facilitators of learning and students are expected to take a more active role, teachers still play a crucial part in creating an enjoyable and stimulating learning environment that encourages active participation (Mustaqim & Kurniawan, 2017). In this era, teachers are required to adopt a visionary approach by developing students' communication and collaboration skills, integrating technology and problem-solving competencies, and fostering innovative and creative thinking (Hidayatullah et al., 2021).

However, several challenges related to creativity remain. These include (1) students' inability to think creatively because previous learning activities did not provide sufficient opportunities for creative expression and (2) teaching practices that fail to stimulate students' creative potential (Hidayatullah et al., 2021). Consequently, students' low creativity levels are largely attributed to instructional approaches that neither facilitate nor encourage creative thinking throughout the learning process. To address these challenges, the integration of innovative learning media is essential to foster students' creativity and engagement in the 21st

century. One promising approach is the use of Augmented Reality (AR), which combines real and virtual elements to create immersive and interactive learning experiences. AR can help visualize abstract concepts, stimulate students' curiosity, and provide multisensory learning environments that encourage exploration and creative problem-solving. By leveraging AR-based instructional media, teachers can design learning experiences that are not only enjoyable and motivating but also capable of enhancing students' critical, creative, and independent thinking skills.

One of the learning approaches that can foster students' creative thinking skills is digital-based learning. Learning media that utilize mobile technology through the concept of mobile or digital learning allow students to construct dynamic and visual representations of real-world situations they encounter (Wangid et al., 2021). Augmented Reality (AR) has the ability to change how we interact with computers and digital content. It makes the impossible possible, and its educational potential is only beginning to be explored, as this technology enables the integration of virtual elements into real-life environments (Marougkas et al., 2023). AR provides seamless interaction between the real and virtual worlds, allowing learners to engage with three-dimensional information, objects, and events in diverse and meaningful ways (Hakim, 2018).

Deaf children, who experience partial or total hearing loss, face barriers in verbal communication (Putri et al., 2019). These communication and socialization challenges often hinder their learning development (Setyaningsih et al., 2024). In formal educational settings, deaf students receive the same learning content as hearing students; however, the delivery process differs as it relies heavily on sign language (Natasya et al., 2019). Maintaining communication with deaf students requires strong visual support, primarily through the use of signs and symbols (Wainscott & Spurgin, 2024). Their communication system functions as an educational tool that incorporates oral, written, and predominantly nonverbal communication, including gestures, body language, and visual symbols that convey meaning (Yati et al., 2023).

Literacy refers to an individual's language competence—including listening, speaking, reading, and writing—used to communicate effectively for various purposes (Bintoro et al., 2023). Andini et al. (2025) identifies six core literacies: reading and writing literacy, numeracy literacy, scientific literacy, digital literacy, financial literacy, and cultural-civic literacy. The literacy and numeracy levels of deaf students remain significantly lower than those of their hearing peers (Supena & Muskania, 2020). In general, deaf learners have not yet demonstrated the ability to utilize learning media as tools for literacy enhancement or as sustainable learning resources. Numeracy literacy is particularly important for deaf students, as it enables them to communicate using numbers and mathematical symbols while solving real-life problems. However, developing this competence remains challenging due to the abstract nature of mathematics. This issue can be addressed through the use of innovative learning media that integrate signs and symbols, allowing deaf learners to visualize and interpret mathematical concepts more effectively.

Integrating semiotic principles into Augmented Reality (AR) provides a powerful conceptual framework for supporting the development of numeracy literacy among deaf learners. Semiotics, as the study of signs and meaning-making processes, emphasizes the role of symbols, icons, and indices in constructing understanding (Suryaningrum et al., 2020a).

When applied to AR, these principles enable the creation of learning environments where mathematical concepts are represented through meaningful visual and spatial cues rather than abstract verbal explanations. This multimodal approach aligns with the dominant visual learning modality of deaf students, allowing them to interpret mathematical relationships through the interaction of signs, gestures, and three-dimensional visual representations. Moreover, semiotic-based AR facilitates meaningful learning by connecting symbolic mathematical representations with real-world contexts, thereby strengthening comprehension and retention. Thus, combining AR technology with semiotic theory not only enhances accessibility and engagement for deaf learners but also redefines how abstract mathematical ideas can be visualized, experienced, and understood within inclusive education settings.

Semiotics is the study of signs and how meaning is constructed through them. In mathematics education, semiotics refers to the use of symbols or signs to represent mathematical concepts (Suryaningrum et al., 2023). Semiotic theory is closely associated with logical reasoning, emphasizing the cognitive processes underlying human thought (Atkin, 2023; Colapietro, 1988). Peirce's theory of signs, which integrates logic and metaphysics, offers a comprehensive theoretical foundation for understanding meaning-making within cultural and social contexts (Suryaningrum et al., 2020b). According to Peirce, humans think through signs, which enable them to communicate and assign meaning to phenomena in their environment (Atkin, 2023; Brier, 2018).

Findings from a survey conducted at SLB Negeri Branjangan Bintoro and Muhammadiyah Elementary School Tanggul, Jember Regency, East Java, Indonesia revealed that teachers still rely on traditional learning media such as two-dimensional flashcards. As a result, students often lose interest and show low participation, which negatively affects learning outcomes. These findings suggest that deaf students require learning media that use animation to visualize abstract mathematical concepts in concrete, perceptible forms. Such media can serve as effective tools for improving numeracy and literacy skills by helping students construct meaningful mathematical understanding through visual experience.

In the context of special education, Augmented Reality (AR) has been shown to enhance learning outcomes by providing richer and more engaging content representations (Iqbal et al., 2022). AR delivers concrete visual stimuli beyond what two-dimensional media can offer, making it highly effective for teaching abstract concepts (Kurniawati et al., n.d.). AR combines physical and virtual environments, allowing users to manipulate perspectives and interact with three-dimensional content, thereby increasing engagement and conceptual understanding (Liono et al., 2021). Furthermore, AR promotes learner autonomy and generates positive emotional responses by enabling active exploration of abstract concepts (Gómez-Rios et al., 2022).

A well-designed AR system can also be adapted for students with special needs, including those with hearing impairments (Ahuja et al., 2022; Andriyani & Buliali, 2021; Buliali et al., 2021; Iqbal et al., 2022). Prior studies (Mu'minah, 2021; Sudiarta & Sadra, 2016) have demonstrated that applications integrating animation, imagery, text, and video can make mathematics learning more enjoyable and interactive. Similarly, Suryaningrum et al. (2021) found that semiotic-based mathematical play effectively stimulates children's understanding of mathematical concepts. Thus, semiotic-based augmented reality represents a powerful educational medium that merges the virtual and real worlds, allowing students to

experience abstract mathematical symbols as tangible, manipulable virtual objects within their learning environments. This approach provides immersive and meaningful visualization experiences that can significantly enhance both literacy and numeracy learning for deaf students.

Previous studies have not yet conducted a systematic needs analysis to determine the most effective features, content formats, and semiotic approaches for enhancing numeracy literacy among deaf learners. Although numerous studies have demonstrated the effectiveness of augmented reality (AR) in improving learning outcomes and visualizing abstract concepts, as well as the effectiveness of semiotic approaches in facilitating children's understanding of mathematical ideas, no research has integrated these two domains. Specifically, there has been no study focusing on the development of semiotic-based AR media aimed at improving numeracy literacy among deaf students. Furthermore, no systematic analysis has been carried out to explore the characteristics, features, and design requirements of semiotic-based AR media tailored to the needs of deaf learners.

The primary objective of this needs analysis is to identify the features and content structures of AR that most effectively support mathematics learning for deaf students through a semiotic framework. The analysis seeks to determine which semiotic elements, including icons, indices, symbols, gestures, and visual signs, are most accessible and meaningful for deaf learners. It also aims to examine factors such as accessibility needs, learning context, technological constraints, and the readiness of teachers and parents. The findings are expected to provide a foundation for designing a semiotic-based AR prototype with appropriate functional and non-functional specifications, ultimately contributing to the improvement of numeracy literacy among deaf students.

The components analyzed in this study encompass various aspects related to the development and implementation of Augmented Reality (AR) technology in enhancing numeracy literacy learning for deaf students. The analysis focuses on several key elements, including participants' understanding of AR technology, their perceptions of using images and virtual objects in the learning process, and their views on how AR can assist students in comprehending numeracy concepts and making learning more engaging. In addition, the study examines the need for semiotic-based AR media as an innovative tool to facilitate more meaningful numeracy learning experiences. The technical aspects analyzed include the use of audio narration, visually appealing designs, bright colors, and interactive animations that help convey mathematical concepts visually and contextually. Furthermore, the study takes into account the learning context, including teachers' readiness, training needs, and technical limitations that may arise in implementing AR media. Overall, the analysis aims to provide a comprehensive understanding of how semiotic-based AR can effectively and sustainably improve numeracy literacy among deaf learners.

METHODS

This study serves as the initial phase of a broader project aimed at developing semiotic-based Augmented Reality (AR) learning media to enhance the numeracy literacy of deaf learners in constructing mathematical concepts. The research adopted a qualitative descriptive design through a needs analysis approach. This method was chosen to gain a deep

understanding of classroom realities, teachers' experiences, and the pedagogical as well as technological requirements for AR integration in mathematics learning for deaf students.

The participants were chosen using purposive sampling, ensuring that each informant met the study's specific inclusion criteria. Eligible schools had to include deaf or hard-of-hearing students, while participating teachers were required to have current teaching experience with those students. Headmasters involved in the study were those who directly supervised special or inclusive education programs. In total, eight teachers and one headmaster participated, representing SLBN Branjangan in Jember Regency. The teachers had more than five years of experience working with deaf students and were familiar with both traditional and technology-supported learning environments.

Two main instruments were employed: an open-ended questionnaire and semi-structured interviews (Saglam, 2024). The questionnaire was designed to obtain preliminary insights into the learning challenges encountered by teachers in developing deaf students' numeracy skills; teachers' familiarity and engagement with technology-enhanced learning tools, particularly augmented reality; teachers' expectations regarding AR features and semiotic components (icons, indices, gestures, symbols, and visual markers) that could facilitate students' understanding of mathematical ideas.

The questionnaire underwent expert validation by specialists in special education and instructional media to confirm its content and face validity. After collecting the initial responses, the researchers conducted individual interviews to explore teachers' answers in greater detail, particularly regarding current classroom practices, accessibility considerations, and potential AR design requirements.

The collected data were examined using a descriptive qualitative approach, referring to the interactive analysis model by Miles and Huberman (1984, cited in Sugiyono, 2019). The process included 1) data reduction—filtering and organizing relevant information into categories such as user characteristics, learning needs, and semiotic preferences; 2) data presentation – compiling summarized data into descriptive narratives and tables to visualize relationships among themes; 3) drawing and validating conclusions—interpreting the findings to identify essential needs and implications for AR media design.

The validity of findings was strengthened through method and source triangulation, comparing responses from questionnaires, interviews, and expert evaluations (Campbell et al., 2018). The results of this phase provide a solid empirical foundation for designing a semiotic-based AR prototype that addresses the real learning contexts and cognitive characteristics of deaf students in numeracy learning.

RESULTS AND DISCUSSION

This study aims to analyze the need for developing a semiotic-based Augmented Reality (AR) learning medium to enhance the numeracy literacy of deaf children. The analysis was conducted through open-ended questionnaires and interviews with teachers at SLBN Branjangan, Jember Regency. The findings indicate that teachers demonstrated high enthusiasm toward the use of AR in instruction, primarily because this technology presents numerical concepts in a visual, interactive, and meaningful manner that aligns with the learning characteristics of deaf students.

Teachers' Knowledge of Augmented Reality (AR) Technology

The questionnaire results show that 50% of teachers were familiar with AR technology, while the remaining 50% lacked sufficient knowledge. Teachers who were already familiar with AR had generally acquired their understanding through educational seminars or social media, whereas those unfamiliar expressed strong interest in learning how to use AR in classroom practice. Teachers still lacked a profound understanding of how to apply AR effectively in pedagogical contexts. This condition reflects a diverse level of technological literacy among special-needs teachers that requires improvement to ensure effective AR implementation. According to Belda-Medina & Calvo-Ferrer (2022), teachers' knowledge and readiness are key factors determining the successful integration of AR in learning, as they influence how immersive learning experiences are facilitated.

Similarly, Köroğlu (2024) emphasizes that teachers' preparedness and comprehension play crucial roles in successful AR adoption; without adequate understanding, such innovative media may remain underutilized. Supporting this, Iqbal et al. (2022) found that AR-based technology training significantly improves teachers' pedagogical competence and confidence in applying interactive digital tools. Teacher readiness, therefore, is essential: educators serve as facilitators bridging deaf learners with visually meaningful experiences. With sufficient technological understanding, teachers can design more engaging and contextual lessons, helping students grasp numerical concepts through concrete visual exploration.

Teachers' Perceptions of Using Images and Virtual Objects in AR

Teachers expressed positive perceptions of using images and virtual objects in AR to support learning. They reported that these visual elements effectively help explain abstract mathematical concepts. Visualization enables deaf students to connect numerical symbols with tangible representations, thus fostering deeper conceptual understanding rather than rote memorization. According to Glaser & Schwan (2020), combining verbal and visual representations enhances conceptual comprehension because information is processed through two distinct cognitive channels. For deaf learners, the visual channel becomes dominant due to limited auditory access (Andriyani & Buliali, 2021).

AR allows for the concrete representation of concepts like addition, subtraction, and patterns in three-dimensional visualizations, making them easier for students to understand. Yanuarto and Iqbal (2022) showed that the incorporation of 3D objects in AR enhanced students' spatial and visual comprehension of geometric concepts. Similarly, Latif, W. B., et al. (2017) concluded that AR enhances conceptual understanding through interactive integration of real and virtual worlds. In the case of deaf children, AR's primary strength lies in its ability to reinforce visual perception, the main modality through which meaning and symbolic comprehension are constructed.

AR as a Medium for Enhancing Numeracy Literacy

All participating teachers agreed that AR can help improve deaf students' numeracy literacy. According to the Cognitive Theory of Multimedia Learning (Vu et al., 2021), integrating text, images, and kinesthetic interaction in a single medium facilitates dual-channel information processing (visual and verbal). AR allows learners to manipulate mathematical objects directly, thereby constructing understanding through hands-on

experience. Aldeeb et al. (2024) found that AR use enhances students' motivation and academic performance by providing more engaging and meaningful learning experiences.

Teachers observed that AR bridges the gap between the real and symbolic worlds of mathematics through immersive visualization. By presenting numerical concepts visually and contextually, students can more easily associate meanings among numbers, shapes, and operations. Suryaningrum et al. (2021) likewise found that semiotic approaches in mathematics instruction effectively help children interpret the meaning behind numerical symbols. AR functions as a semiotic medium because it presents visual signs, icons, indices, and symbols that correspond directly to the taught concepts. Peirce (1931) proposed that meaning arises from the interaction between signs and their interpreters; AR enables this interaction to occur visually, making abstract concepts more accessible to deaf learners. Altmeyer et al. (2020) further confirmed that AR improves both conceptual understanding and long-term knowledge retention. Thus, semiotic-based AR can serve as an effective strategy for building stronger and more meaningful numerical understanding among deaf students.

AR as an Engaging Learning medium.

All respondents stated that AR-based learning is more engaging and enjoyable for deaf students. Teachers noted that 3D visualization, animation, and direct digital interaction increase learners' focus and motivation. Learning, once abstract and difficult, becomes concrete, engaging, and easier to comprehend (Du et al., 2024). The cognitive theory of multimedia learning asserts that students' attention and motivation improve when instruction combines text, images, and animation effectively. AR provides active and interactive experiences that encourage students to experiment with concepts rather than passively receive information. Booyoesen (2023) found that AR enhances students' engagement and promotes exploratory learning, while Humam et al. (2024) observed that deaf learners show greater motivation when interacting with visually dynamic and colorful media. So, AR can help people get over motivational barriers and improve their focus when they are learning how to read and write numbers.

Teachers' Need for Semiotic-Based AR Media

Survey results revealed that all teachers expressed a strong need for semiotic-based AR media for teaching numeracy to deaf students. Teachers emphasized that visual symbols and signs play a crucial role in helping students understand abstract mathematical meanings. Peirce's (1931) semiotic theory defines a *sign* as consisting of an icon, index, and symbol, each serving as a bridge between representation and meaning. Integrating these semiotic principles into AR allows numerical symbols to be directly linked with 3D visual representations, reinforcing conceptual understanding of numbers and operations. Pavithra & Shanthi (2025) found that interactive visual media enhance logical thinking and numeracy skills among deaf learners.

Teachers further explained that students with hearing impairments require strong sign systems for visual messages to be translated into conceptual meaning. Semiotic-based media are thus essential to bridging mathematical symbols with real-world experiences. Stephan & Akyuz (2021) emphasized that semiotic approaches in mathematics learning improve students' understanding of symbolic relationships among numerical concepts. By combining semiotic principles with AR, instructional media can display meaningful connections between

visual signs (images, colors, and movement) and the mathematical ideas they represent, enabling deaf children to perceive mathematics not merely as abstract symbols, but as an interpretable system of signs grounded in visual experience.

The Role of Narration and Sound in AR

Most teachers agreed that auditory narration is not a crucial element for deaf learners. Instead, they highlighted the importance of strong visual cues such as contrasting colors, animated movements, and sign-language integration. Visual presentation is considered more effective because it aligns with the primary perceptual modality of deaf students. Farhan & Razmak (2020) demonstrated that visually oriented instructional design enhances accessibility and comprehension for students with hearing loss.

Nonetheless, teachers suggested that subtitles or textual narration should be provided to support learners with partial hearing. This finding corresponds with Rajabani & Juhana (2025), who found that text and sign language are more effective than audio narration in AR-based instruction for deaf students. In semiotic terms, text serves as a symbol that connects visual representation and conceptual comprehension. Therefore, AR design for deaf learners should prioritize visual and textual elements rather than sound. This approach aligns with the Universal Design for Learning (UDL) framework, which emphasizes accessibility for all learners. By integrating text, images, and interactive animation, AR can be inclusively applied to students with varying degrees of hearing impairment.

Visual, Color, and Interactive Animation Needs in AR.

All teachers agreed that visually appealing elements, bright colors, and interactive animations are essential for numeracy learning among deaf students. Contrasting colors act as semiotic markers that set apart important learning parts. According to Mayer (2009), visual cues such as color and motion reduce cognitive load and facilitate attention. Interactive animations allow learners to explore objects directly, consistent with Piaget's (1973) constructivist view that conceptual understanding emerges from active interaction between learners and their environment (Stupiansky, 2022).

Teachers emphasized that deaf children rely heavily on visual perception; thus, engaging media design enhances attention and comprehension. Elaf Alajmi (2021) reported that color and motion strengthen concept perception in children with special needs, while Tong & Chan (2023) found that interactive digital elements stimulate both cognitive and affective engagement. (Qasserras, 2024) The visual learning style theory further supports that visually oriented individuals learn more effectively through color, imagery, and form than through text alone. Hence, semiotic-based AR emphasizing visual elements is an ideal choice to support numeracy instruction for deaf children.

Overall, the study demonstrates that teachers possess a high awareness of and strong need for semiotic-based AR media. AR is viewed not merely as a technological aid but as a *semiotic medium* that helps deaf learners construct meaning through interactions among symbols, objects, and real-world contexts. This approach integrates visual, gestural, and symbolic dimensions to foster more meaningful and inclusive learning experiences.

These findings are consistent with Jdaitawi et al. (n.d.), who found that AR enhances autonomy, motivation, and conceptual understanding among students with special needs. Integrating semiotic theory into AR design strengthens both cognitive and affective aspects of

numeracy learning. Therefore, this needs analysis provides an empirical foundation for subsequent development phases, namely the design of a semiotic-based AR prototype aimed at significantly and sustainably improving deaf children's numeracy literacy.

The results confirm that semiotic-based AR represents an innovative approach that can enhance numeracy comprehension among deaf learners. From a theoretical perspective, the findings reinforce Peirce's semiotic theory and Mayer's multimedia learning principles, which suggest that combining visual, symbolic, and interactive signs fosters deeper meaning construction. From a practical standpoint, AR enables teachers to connect mathematical symbols with three-dimensional visual representations, helping students grasp abstract concepts more effectively. Moreover, this study opens opportunities for developing teacher-training models focused on designing and implementing AR-based media for special education contexts.

CONCLUSION

The findings of this study demonstrate that semiotic-based Augmented Reality (AR) holds substantial potential to enhance numeracy literacy among deaf learners by aligning instructional design with their dominant learning modalities: visual, symbolic, and interactive. Teachers in special education schools exhibited strong enthusiasm toward the use of AR in the classroom. Teachers perceived that visual objects, color schemes, animation, and interactive elements in AR can transform abstract mathematical concepts into concrete, meaningful learning experiences. The use of AR helps bridge the gap between numerical symbols and real-world representations, promoting deeper conceptual understanding and greater motivation among deaf students. Moreover, the integration of semiotic principles, including icons, indices, and symbols, reinforces students' capacity to construct meaning through accessible and interpreted visual experiences. This study concludes that AR serves not merely as a technological innovation but as a semiotic learning environment in which meaning is co-constructed through the interaction of visual signs, gestures, and authentic learning contexts. The integration of Peirce's semiotic theory and Mayer's cognitive theory of multimedia learning provides a robust theoretical foundation for designing inclusive learning media that respond to the cognitive and perceptual needs of deaf learners.

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