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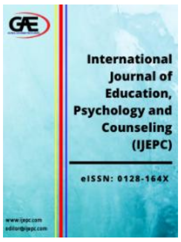

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EFFECTIVENESS OF TANGIBLE TEACHING AIDS IN ENHANCING LEARNERS' VISUALIZATION SKILLS: A STRUCTURED LITERATURE REVIEW

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Abstract:

This systematic literature review (SLR) investigates the effectiveness of Tangible Teaching Aids (TTA) in developing students' visualisation skills across different educational settings. Visualisation skills play an important role in the conceptual understanding, spatial reasoning, and abstract thinking. However, many students struggle to develop these abilities because they have limited access to concrete, interactive, and technology-supported learning materials. This challenge creates a need to synthesise existing research on how tangible and technology-enhanced instructional tools influence visualisation-related learning outcomes. The review followed the PRISMA framework to maintain a transparent and systematic study selection process. A structured search was conducted in the Scopus and ERIC databases using terms such as "visualisation skills," "teaching aids," and "tangible,". The search covered studies published between 2016 and 2026. After the inclusion and exclusion criteria were applied, 27 primary studies were retained for the final analysis. The findings were organised into three major themes. The first theme, Tangible and Physical Learning Tools for Conceptual and Spatial Understanding, covers hands-on manipulatives and physical models that support cognitive mapping and spatial comprehension. The second theme, Digital Visualisation, Simulation, and Immersive Educational Technologies, includes augmented reality, virtual reality, simulations and interactive visualisation platforms that strengthen engagement and conceptual understanding. The third theme Multisensory, Inclusive, and Accessibility-Oriented Educational Aids, focuses on adaptive and assistive resources designed to support learners with different needs, including students with disabilities. The findings show that tangible teaching aids and related technologies consistently enhance students' visualisation performance, conceptual retention, and

International Journal of Education, Psychology and Counseling
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engagement across different academic disciplines. The review concludes that combining tangible, digital and multisensory approaches provide a more inclusive and effective framework for strengthening visualisation skills in contemporary education. It also identifies a need for further empirical research involving varied educational contexts and learners' populations.

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Keyword:

Instructional Materials, Spatial Visualisation, Tangible Teaching Aid (TTA), Visualisation Skills

Introduction

Tangible teaching aids play a vital role in sharpening students' visualisation skills by bridging the gap between abstract concepts and hands-on manipulation. By supporting multisensory learning, these tools help students translate complex 2D and 3D representations more effectively. According to Ishikawa & Newcombe (2021) & Lowrie et al. (2019), spatial ability is deeply intertwined with success in mathematics and the broader STEM fields. Many learners struggle with diagrams and models when instruction relies too heavily on verbal or symbolic methods. The gap makes visualisation a critical educational priority. Abdo et al. (2024) and Azzam et al. (2024) stated that limited spatial skills can hinder a student's progress and persistence in science and engineering. Therefore, researchers are increasingly looking at how manipulatives, 3D models, and robotics. The digitally enhanced objects can help students better perceive, rotate, and organise information mentally. In addition, the theoretical foundation is solid. The principles of embodied and multisensory learning suggest that we learn best not just by listening or watching. According to Hsieh et al. (2022 and Kuhn (2021), through touching, moving, and interacting with physical materials. In the classroom context, this concept is translated into using everything from fraction bars and pattern blocks. The purpose is to improvise resources that ignite active discovery rather than passive listening (Ojating & Ojating, 2022). The approach is particularly helpful for students who find verbal instruction alone insufficient. (Ojating & Ojating, 2022) emphasised that physical objects can often clarify ideas that words cannot.

Studies involving different age groups and academic subjects support these findings. In mathematic the use of spatial visualisation tools has produced notable improvements. One study found that the experimental group achieved a 25% increase, while the control group improved by only 5% (Herrera et al., 2024). Teacher-led visuospatial instruction has also strengthened elementary students' spatial reasoning and mathematics performance, particularly

International Journal of Education, Psychology and Counseling
IJEPC
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in mental rotation and numerical skills (Hawes et al., 2017; Lowrie et al., 2017, 2019). Research further indicates that students who use 3D models gain a stronger understanding of concepts by connecting two-dimensional and three-dimensional representations (Abdo et al., 2024). Digital interfaces have produced positive effects. Students who used digitally supported materials to learn fractions achieved better results and greater enjoyment. Tangible computing tools have likewise supported learning in geography and artificial intelligence education (Fokides & Alatzas, 2022; Kim & Kwon, 2024; Millar et al., 2018). Robotics and other hands-on learning activities have also improved students' academic achievement without increasing their cognitive load (Hsieh et al., 2022; Nwankwo et al., 2024). However, it is important to note that the tool itself isn't a "magic bullet"; success still depends heavily on how the lesson is designed, the quality of teacher guidance, and the resources available. Further research is needed to determine how long these improvements can be sustained (Daodao, 2025; Herrera et al., 2024; Patahuddin et al., 2020).

Literature Review

The current body of research offers clear evidence that tangible teaching aids (TTAs) are effective at boosting visualisation skills in many different settings. Tools like 3D models, physical manipulatives, and augmented reality (AR) significantly sharpen spatial reasoning, critical thinking, and conceptual depth. For example, tangible programming tools and 3D models help students simplify complex problems and mentally manipulate objects, reducing cognitive effort and promoting more interactive learning (Gong et al., 2025; Ha & Fang, 2013). Whether physical or virtual, using manipulatives in math and geometry has been shown to improve both immediate understanding and long-term memory of the material. Manipulating 3D models in physical or digital form encourages greater and engagement and promotes a more inquiry-oriented approach to learning (Guan et al., 2024; Ochugboju & Díez-Palomar, 2025). These findings highlight the potential of TTAs to bridge the gap between abstract concepts and practical understanding, making them particularly effective in STEM education.

When TTAs are paired with digital tech like AR or 3D simulations, their impact is even stronger. For instance, augmented reality applications allow students to manipulate virtual shapes within three-dimensional environments, leading to greater improvements in spatial ability and motivation than conventional teaching methods (Chao, 2026). In apparel design, 3D simulations enable students to see how two-dimensional patterns fit and appear on a three-dimensional body, highlighting the usefulness of these tools across different disciplines (Park et al., 2011).

However, the effectiveness of these tools depends on how they are introduced. Too many visual aids or poorly designed materials can hinder learning, as excessive visual content in videos has been linked to lower student satisfaction (Fish et al., 2016). Ultimately, while TTAs are powerful for visualisation, their success depends on being carefully woven into the curriculum, ensuring teachers are well-trained, and matching the tools to the students' cognitive needs.

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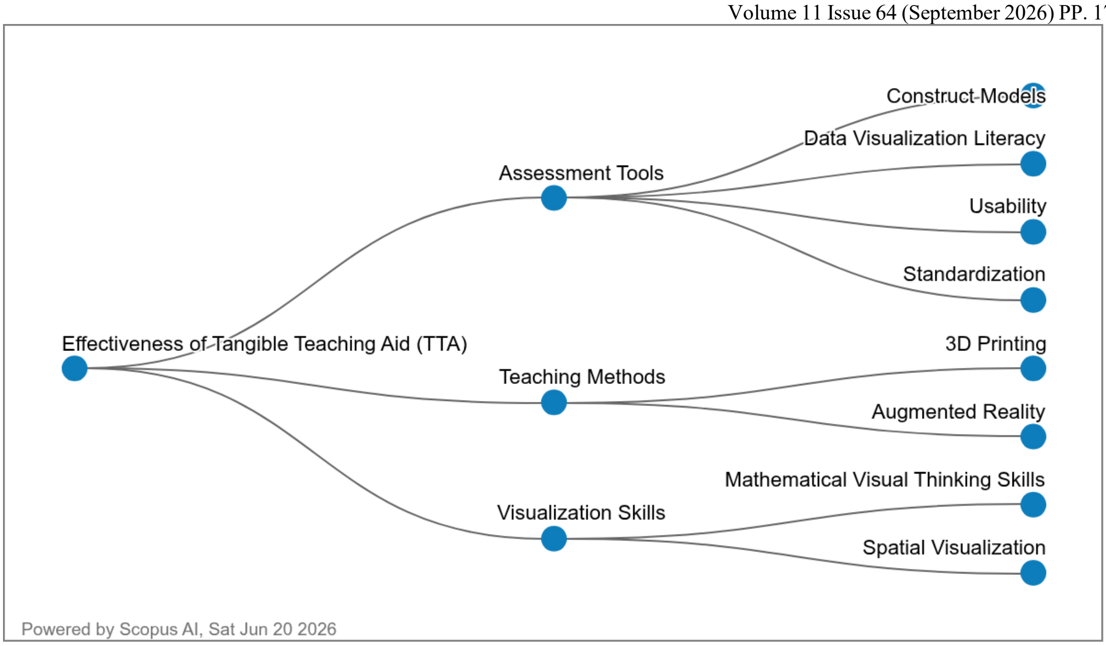

Figure 1: Linked Concept on Effectiveness of Tangible Teaching Aid (TTA)
Source: Scopus AI

Material And Methods

Identification

The identification stage of this Systematic Literature Review (SLR) followed the PRISMA framework to support a broad and systematic search for relevant studies. The search focused on SCOPUS and ERIC because both databases provide extensive coverage of research in education, technology and related interdisciplinary fields. Keywords such as “visualisation skills”, “teaching aid” and “tangible” were combined to identify suitable publications. The initial search produced 262 records from SCOPUS and 86 from ERIC, giving a total of 348 records. This large number suggests increasing research interest in the use of tangible teaching aids to develop visualisation skills. Searching more than one database also allowed the review to include studies from different disciplines, including education technology, engineering and cognitive science. SCOPUS generated more records, possibly because of its wider interdisciplinary coverage. At this stage, the search aimed to be a comprehensive as possible, although the initial results still contained duplicate records and studies that did not meet the final inclusion criteria.

Table 1: The Search String

Scopus	TITLE-ABS-KEY (("visualization skills" OR "visual skills" OR "visualization" OR "visual") AND ("teaching aid" OR "instructional aid" OR "educational tool" OR "learning aid" OR "tangible aid") AND (tangible OR "hands-on" OR "physical" OR "concrete")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (PUBYEAR , "2016") OR LIMIT-TO (PUBYEAR , "2017") OR LIMIT-

International Journal of Education, Psychology and Counseling
IJEPC
EISSN : 0128-164X
Volume 11 Issue 64 (September 2026) PP. 170-185

	TO (PUBYEAR , "2018") OR LIMIT-TO (PUBYEAR , "2020") OR LIMIT-TO (PUBYEAR , "2021") OR LIMIT-TO (PUBYEAR , "2022") OR LIMIT-TO (PUBYEAR , "2023") OR LIMIT-TO (PUBYEAR , "2024") OR LIMIT-TO (PUBYEAR , "2025") OR LIMIT-TO (PUBYEAR , "2026")) AND (LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "ARTS") OR LIMIT-TO (SUBJAREA , "MATH") OR LIMIT-TO (SUBJAREA , "MULT") OR LIMIT-TO (SUBJAREA , "PHYS") OR LIMIT-TO (SUBJAREA , "SOCI")) Date of Access: June 2026
Eric	("visualisation skills" OR "visual skills" OR "visualisation" OR "visual") AND ("teaching aid" OR "instructional aid" OR "educational tool" OR "learning aid" OR "tangible aid") AND (tangible OR "hands-on" OR "physical" OR "concrete") pubyearmin:2016 pubyearmax:2026 Date of Access: June 2026

Screening

The second stage involved screening the identified records to retain only studies that were relevant to the review. Of the 348 records initially retrieved, 256 were excluded because they were not written in English, were published before 2015, consisted of conference papers or book chapters rather than peer-reviewed journal articles, or did not fall within the selected subject areas, including Social Science, Engineering and Mathematics. English-language studies were selected to maintain consistency in the analysis, while the publication period was limited to the most recent decades to reflect current developments in educational technology and teaching practices. The review also focused on original studies to establish a more reliable evidence base. Following the screening, 92 records remained, comprising 66 from SCOPUS and 26 from ERIC. Six duplicate records were then removed, resulting in 86 unique studies for further assessment. This systematic screening process helped ensure that the retained studies were relevant, suitable, and aligned with the objectives of the review.

Table 1: The Selection Criterion is Searching

Criterion	**Inclusion**	**Exclusion**
Language	English	Non-English
Timeline	2016 – 2026	< 2015
Literature type	Journal (Article)	Conference, Book, Review
Publication Stage	Final	In Press
Subject	Social science, Engineering, Arts and Humanities, Mathematics, Multidisciplinary, Physics and Astronomy	Besides Social science, Engineering, Arts and Humanities, Mathematics, Multidisciplinary, Physics and Astronomy

International Journal of Education, Psychology and Counseling
EISSN : 0128-164X
IJEPC
Volume 11 Issue 64 (September 2026) PP. 170-185

Eligibility

During the eligibility stage, the full texts of the remaining 86 articles were examined in detail to determine whether they directly explored the relationship between tangible teaching aids and visualisation skills. The presence of the relevant keyword alone was insufficient, as the main focus and evidence presented in each study had to align with the review objectives. Following the full-text assessment, 59 articles were excluded. Some did not fall within the scope of review despite having relevant titles, while others provided limited evidence on visualisation skills or tangible materials. Several studies were also excluded because their full texts were unavailable. The reduction from 86 to 27 studies highlights the importance of full-text assessment, as title and keywords may not accurately represent the actual focus in the study. The final 27 studies were considered relevant, methodologically suitable and sufficiently robust for inclusion in the synthesis.

Data Abstraction and Analysis

An integrative analysis approach was used to systematically examine and synthesise findings from studies employing different quantitative research design. The analysis aimed to identify recurring patterns, themes and subthemes related to the tangible teaching aids and their influence in educational outcomes. The process began with data extraction, during which relevant information was collected from the selected studies. As illustrated in Figure 2, the 27 eligible publications were examined in detail to identify findings and evidence that addressed the research objectives. The analysis focused on the ways tangible teaching aids were implemented, their main characteristics, and their effects on students' learning. The methodological approaches used in each study were also critically examined to provide a broader understanding of the existing body of research. The extracted data were then coded and organised into relevant categories. Through repeated comparison and interpretation, themes and subthemes were developed based on the available evidence. An audit trail was maintained throughout the analysis to document analytical decisions, reflections, and challenges, encountered during the coding process. The themes were repeatedly reviewed and compared across the studies to ensure consistency. Differences in interpretation were discussed among the researchers until agreement was reached. This collaborative process enabled the themes to be refined and reorganised for greater clarity and closer alignment with the research objectives. The systematic analytical process provided a strong basis for addressing the following research objectives:

1. How do tangible and physical learning tools influence students' conceptual understanding and spatial visualisation skills in structured learning environments?
2. How do digital visualisation, simulation, and immersive educational technologies affect students' visualisation skills and learning engagement in technology-enhanced educational environments?
3. How do multisensory and accessibility-oriented educational aids support inclusive learning and enhance visualisation skills among diverse learners in educational settings?

International Journal of
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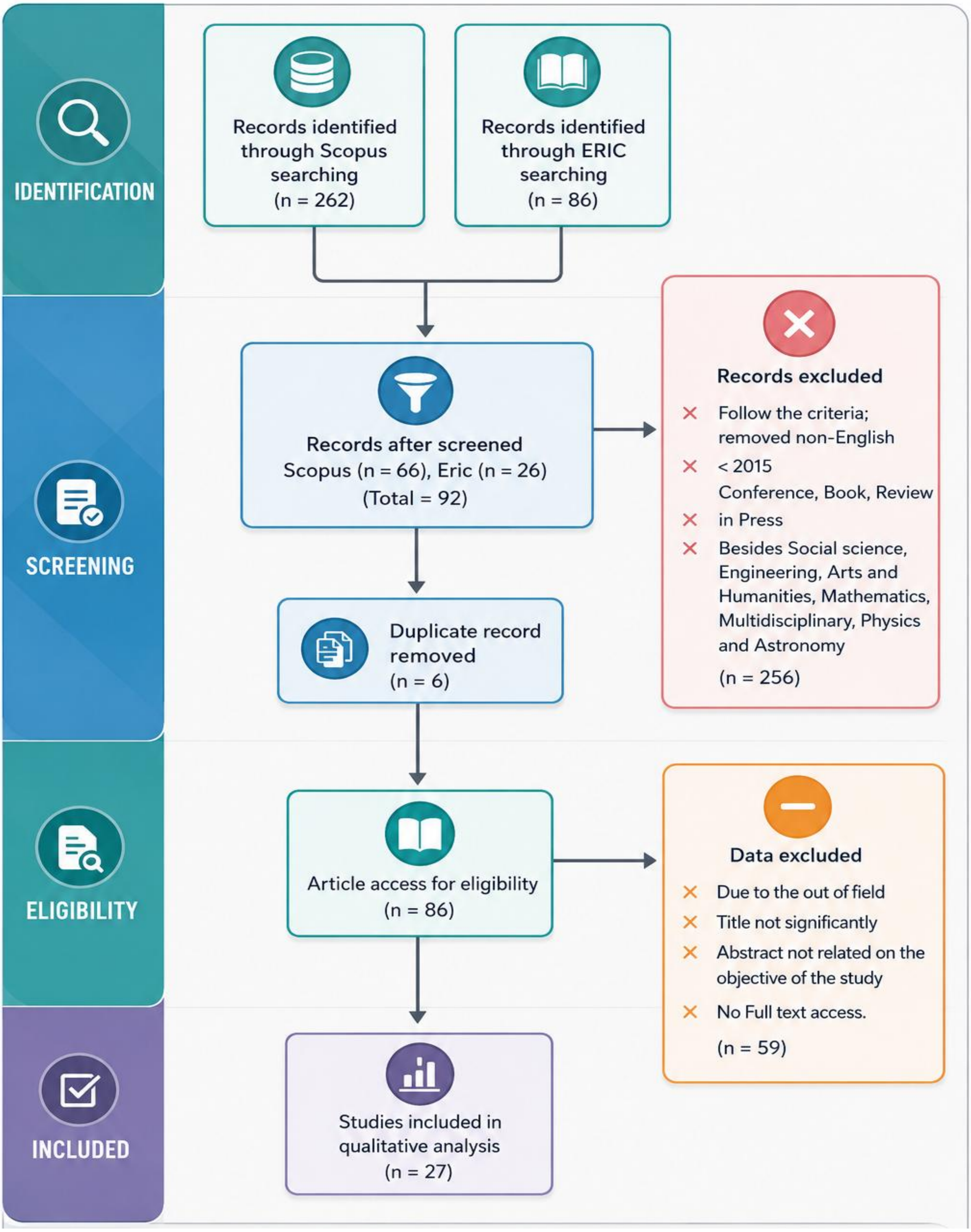

Figure 2: Flow Diagram of The Proposed Searching Study

International Journal of Education, Psychology and Counseling
EISSN : 0128-164X
IJEPC
Volume 11 Issue 64 (September 2026) PP. 170-185

Results and Discussion

Theme

Theme 1: Tangible and Physical Learning Tools for Conceptual and Spatial Understanding

The research consistently shows that tangible teaching aids (TTAs) help students visualise abstract scientific ideas by turning them into something they can physically touch and move. Across fields like engineering, science, and medicine, these tools are praised for making complex concepts clearer and easier to remember. For example, in electromagnetic studies, abstract ideas like magnetic field distribution are much easier to grasp when students use simulation tools to see them in action (2021). Similarly, interactive tools for electrical machines help students understand internal structures by letting them manipulate parameters and see diagrams change in real-time (2025). When physical computing is combined with digital simulations, students get a better handle on electricity by seeing how virtual models react to physical circuits (2025).

In engineering and mechatronics, hands-on training kits let students observe system behaviour directly, linking theoretical math to real-world electrical outputs (2025). Using motion tracking and visual feedback also helps students see how theoretical models match up with actual physical movement (2023). These systems aren't just for watching; they allow students to actively test and refine their understanding. In biology and chemistry, 3D-printed models are a gamechanger for spatial cognition. Being able to touch a molecular model helps students understand atomic shapes and interactions in a way that self-guided learning becomes much more effective (2025). Studies also show that students using 3D-printed anatomical models understand complex structures much better than those using 2D diagrams (2018). Modular models for proteins also make it easier for students to grasp how these building blocks fold and fit together (2020).

For young children, tangible visual aids are great for developing fine motor skills and spatial awareness. Activities that combine hands-on movement with visual aids help kids better understand their environment (2024). Overall, the evidence suggests that the power of TTAs lies in their ability to "externalise" abstract thoughts, making them something you can see and touch, which reduces the mental effort needed to learn and makes the whole experience more engaging.

Theme 2: Digital Visualisation, Simulation, and Immersive Educational Technologies

Digital tools and simulations are proving to be just as effective as physical ones for bringing abstract concepts to life. Whether it's using Minecraft to teach math or AR to show the inside of a computer, these technologies lower the barriers to understanding complex spatial ideas (2025, 2024). They make invisible structures visible and let students interact with them, which greatly boosts engagement and makes learning feel more intuitive. Dynamic visual systems, like those that combine animation with sound to explain natural phenomena (like geyser eruptions), help students spot patterns that they might otherwise miss (2021). In robotics, virtual simulations turn invisible programming errors into visible paths on a screen, making it much easier for students to find and fix mistakes (2023). However, the research also warns that

International Journal of Education, Psychology and Counseling
EISSN : 0128-164X
IJEPC
Volume 11 Issue 64 (September 2026) PP. 170-185

these tools need to be carefully guided. Without proper support, students can sometimes get overwhelmed or confused by the complex visuals (2017).

In professional education, mixed-reality and AR are transforming training. They provide realistic simulations of anatomical structures and medical procedures, giving students a safe place to practice and visualise complex systems like the human brain (2025). While some students still prefer the tactile feel of physical models, these digital tools are closing the gap between theory and practice in a major way.

Theme 3: Multisensory, Inclusive, and Accessibility-Oriented Educational Aids

Current research into multisensory and inclusive education shows a clear and steady trend: we are moving toward learning environments that truly cater to every student's needs. Instead of treating accessibility as an afterthought or a 'special feature,' modern educators are building it directly into the heart of their lessons through the integration of sight, sound, and touch. We see this shift happening across almost every field, from language learning and medical training to special education and STEM. The real power of these multisensory tools lies in their ability to take abstract, difficult concepts and turn them into physical, 'hands-on' experiences. For instance, studies on mixed-reality systems, digital blocks, and adaptive physical aids highlight just how much these tools can boost a student's engagement and depth of understanding (Zeng et al., 2025; Samala et al., 2024; AlAli et al., 2018). Along the same lines, Manasa et al. 2020) and Ibarra-Cabrera et al. 2025) emphasise that multisensory approaches are key to breaking down learning barriers for students with cognitive, sensory, or physical disabilities. Looking at these results together, it's clear that inclusive technology is most powerful when it offers several ways to engage, helping to bridge the gaps where traditional teaching methods might fall short for some students.

One of the most striking findings in the research is how multisensory design can truly transform the learning experience for students with sensory impairments, especially those with visual or hearing disabilities. The studies repeatedly show that by blending touch, sound, and sight, we can significantly boost both comprehension and engagement. This approach is especially vital for students who often find it difficult to keep up when lessons rely on more traditional, one-dimensional teaching methods. Two concurrent independent studies indicate that (Ibarra-Cabrera et al., 2025) found that a braille multisensory system can boost engagement among visually impaired learners (Manasa et al., 2020) and that audiovisual assistive devices can improve the reading ability of individuals with reading disabilities. A 2018 study by (Chou et al., 2018) shows that physical-digital blocks that integrate tactile, auditory, and visual cues can improve language acquisition outcomes through hands-on operation. After synthesising findings from multiple similar studies, we found that these multisensory systems can provide a compensatory pathway for learners with sensory processing disorders, and this model is consistently positively correlated with improved comprehension and reduced cognitive load.

By reviewing relevant academic literature, the authors of this paper find that inclusive educational technologies, originally only deployed in early childhood education to support learners with physical disabilities, are gradually being expanded to the contexts of higher education and vocational training. The adaptive tool developed by Mohanty & Dubosh 2025) enables medical interns with hearing impairments and mobility impairments to complete physical examinations, ensuring their equal access to clinical skills learning. Similarly, (Lo &

International Journal of
Education, Psychology and Counseling
IJEPC
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Volume 11 Issue 64 (September 2026) PP. 170-185

Wang, 2024) study of pre-service educators preparing to teach students with visual impairments shows that podcast-based teaching tools can improve these educators' knowledge levels, self-efficacy, and teaching confidence; Furthermore, (Kawame et al., 2025) found in medical education settings that visualisation-enhanced lung sound representation tools can boost medical students' diagnostic interpretation and clinical reasoning skills. These accessibility tools are driving equitable competency development in complex disciplines, supporting both learning outcomes and career readiness.

A large body of existing literature consistently confirms that immersive interaction technologies can effectively improve learning accessibility and engagement across diverse learner populations. Among these technologies, three types of mixed reality, tablet-based systems, and digital simulation environments can precisely bridge the gap between abstract knowledge and experiential understanding. (Kahveci et al., 2023) found that tablet-mediated structured visual interventions for abstract concepts improved mathematics learning outcomes for autistic children; (Sucharitakul et al., 2023) proposed that multisensory educational kits improved the traditional dance learning performance of learners with visual impairments in contexts with insufficient physical guidance; (Zeng et al., 2025) also noted that advanced 3D visualisation tools supporting neuroanatomy learning enhanced learners' spatial comprehension and learning motivation. These technologies can provide access pathways to learning content that traditional teaching approaches cannot deliver, and their interactive features, including support for self-directed exploration, repeated operation, and on-demand adjustment, are particularly well-suited for groups with differentiated instructional needs.

Core themes repeatedly referenced in existing literature show that iterative design, user feedback, and adaptive optimisation are the core guidelines for developing accessibility-oriented educational tools. Existing research generally points out that while multi-sensory accessible educational tools can significantly improve learning outcomes, they still face common challenges including insufficient usability, sensory balance dysfunction, and limited adaptability to diverse learners. Four cross-domain studies, led respectively by(Ibarra-Cabrera et al., 2025; Kahveci et al., 2023; Kawame et al., 2025; Mohanty & Dubosh, 2025), all corroborate these issues. This paper argues that the accessibility attributes of educational technology are by no means a static outcome, but a continuously evolving dynamic process. It is essential to adhere to user-centred design centred on learners with disabilities, to guarantee the long-term effectiveness and inclusivity of the tools.

A synthesis of existing reviews shows that multisensory assistive tools for accessible, inclusive education deliver core benefits. Multiple studies, including (Ibarra-Cabrera et al., 2025; Manasa et al., 2020; Mohanty & Dubosh, 2025), have confirmed their value. Immersive technologies integrated with mixed reality, tablets, and physical interaction interfaces can strengthen experiential learning, benefiting both general learners and special needs groups with sensory, cognitive, or physical disabilities. That said, their real-world effectiveness depends critically on usability, adaptive design, and continuous iteration based on learner feedback. These technologies nonetheless represent a major advancement for inclusive pedagogies.

Conclusion

This study presents a systematic literature review of tangible teaching aids (TTA). Relevant studies were identified through searches of SCOPUS and ERIC, with a focus on approaches that support students' visualisation abilities through physical objects, digital technologies, and

International Journal of Education, Psychology and Counseling
IJEPC
EISSN : 0128-164X
Volume 11 Issue 64 (September 2026) PP. 170-185
multisensory learning activities. The review aims to evaluate the effectiveness of TTAs across different educational contexts and academic disciplines. It addresses three main research questions: How do TTAs support the development of visualisation abilities? What educational mechanisms explain their effectiveness? What implications do these findings have for future teaching practices and research?

This study demonstrates that tangible teaching aids can convert abstract, complex, and difficult disciplinary concepts into visible and interactive learning experiences. Their use consistently strengthens students' visual thinking abilities. Tangible teaching aids can be applied across various disciplines, including science and engineering, the social sciences and the arts. They may be implemented through physical models, practical kits, and sand table tools. By presenting complex content in concrete forms, these aids reduce learner's cognitive demands and help them overcome difficulties associated with abstract concepts more effectively than teacher-based instruction.

This review synthesis existing studies and shows the physical learning environments are increasingly being integrated with five main types of digital tools: augmented reality, mixed reality, virtual simulations, interactive applications, and visualisation platforms. These technologies complement tangible teaching aids by providing interactive representations of microscopic, spatial, and dynamic phenomena, that are otherwise difficult to observe. As a result, they can strengthen learners' conceptual understanding, engagement, and analytical thinking. However, technology alone does not ensure effective learning. Positive outcomes also depend on instructional scaffolding, guided exploration, feedback, and repeated interaction. Therefore, the most effective approach is a multimodal learning environment that combines digital technologies with these essential instructional supports.

The main findings of this study are that multisensory and accessibility-focused teaching aids can enhance visualisation skills across diverse group learners. Educational tools that combine visual, tactical, and auditory elements consistently benefit learners with sensory, cognitive, and physical abilities, while also supporting mainstream students. The studies reviewed further indicate that inclusive education technology has moved away from adapting tools after implementation towards incorporating universal accessibility from the design stage. This shift reflects a growing recognition that addressing diverse learning needs can strengthen learners' visualisation abilities.

This review brings together fragmented evidence from different disciplines within the field of visualisation education. It identifies a common limitation in the existing literature, as many studies focus on one technology, a particular subject area, or a specific group of learners. The broad conceptual framework developed in this review explains how physical, digital and multisensory educational tools work together to strengthen learners' visualisation skills. It challenges the assumption that improvements in visualisation ability result solely from the use of technology. Instead, such development depends on learning processes that involve interaction, sensory participation, spatial representation, and experiential exploration. The framework also provides a comprehensive structure for analysing the formation of mental models and the development of visuospatial reasoning. The review further offers practical recommendations for several stakeholders' groups. Educators should include physical learning experiences when teaching abstract spatial concepts. Educational institutions should invest in learning environments that combine physical and digital technologies. Accessibility should be incorporated from the earliest stages of instructional design. Technology developers should also prioritise usability and learner need rather than focusing only on technological advancement.

This review has four main limitations. First, it includes only studies indexed in selected data bases, which may have excluded relevant publications available through other academic sources. Second, the review prioritised English-language studies, so important findings published in other languages may have been overlooked. Third, the included studies varied considerably in their research designs, participant profiles, educational contexts, and assessment methods, which limited direct comparison across studies. Fourth, the review did not include unpublished grey literature, and this may have resulted in the exclusion of effective but unreported research. Based on these limitations, five area are recommended for future research. Further studies should examine the long-term effects of tangible teaching aids on the development of visualisation ability. Researchers should also investigate whether their effectiveness differs across educational levels and academic disciplines. Future work should evaluate learning outcomes produced by combining physical, digital and multisensory approaches. Standardised instruments for measuring visualisation ability should also be developed to enable more rigorous comparisons across studies. In addition, researches should assess the adaptability of these teaching aids in under-resourced educational contexts. The evidence synthesised in this review indicates that tangible teaching aids provide an effective approach to improve students' visualisation abilities. Three main mechanisms support this development: physical interactions, multisensory engagement, and immersive exploration. Together, these mechanisms, strengthen conceptual understanding and visuospatial reasoning. The findings also support a shift from passive knowledge transmission towards active knowledge construction. They further demonstrate the value of systematic reviews and suggest that the future integration of physical, digital, and inclusive educational tools will play an important role in visualisation-based learning.

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International Journal of Education, Psychology and Counseling
IJEPC
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