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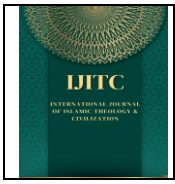

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SYSTEMATIC LITERATURE REVIEW ON BRAILLE LITERACY IN SPECIAL EDUCATION: CHALLENGES AND BRAILLE EDUCATION STRATEGIES

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ABSTRACT

This systematic literature review aims to evaluate the challenges and strategies in braille literacy for visually impaired students in special education. Major issues include inadequate technological support and insufficiently trained educators, highlighting a gap in integrating braille literacy into mainstream curricula and leveraging advanced technologies. The review's objective is to evaluate current practices and propose effective strategies to enhance braille education. Using the PRISMA framework, eight relevant studies were systematically reviewed. Findings reveal that continuous professional development for teachers and the integration of assistive technologies significantly improve braille literacy outcomes. Innovative tools show potential for making braille education more accessible globally. The review underscores the need for increased investment in technology, professional development, and the inclusion of braille literacy in mainstream education to promote inclusivity. This review contributes by identifying effective strategies to overcome barriers and suggesting measures to enhance braille literacy. Future research should focus on developing affordable, durable assistive devices and exploring new instructional methods to support visually impaired students worldwide. Aligning with Sustainable Development Goal (SDG) 4, this review emphasizes the importance of ensuring inclusive and equitable quality education and promoting lifelong learning opportunities for all, particularly for students with visual impairments.

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INTRODUCTION

In recent years, the importance of literacy as a fundamental skill has been increasingly recognized in special education, particularly for children with visual impairments. Braille literacy plays a crucial role in ensuring equitable access to information and fostering independence among visually impaired students (Croake et al., 2024). However, despite its significance, there exists a growing concern about the declining rates of braille literacy among these students, which has been attributed to various systemic and pedagogical challenges.

The current issue surrounding braille literacy is multifaceted, encompassing not only the limited availability of qualified educators trained in braille instruction but also the lack of resources and support systems tailored for students with visual impairments (Kana & Hagos, 2024). Additionally, the proliferation of digital technologies, while beneficial in many respects, poses a unique challenge by shifting focus away from traditional braille education (Hoskin, Coyne, et al., 2024). These factors have culminated in an urgent need to reassess existing strategies and develop innovative approaches to enhance braille literacy among visually impaired children.

LITERATURE REVIEW

The literature on braille literacy reveals several critical challenges. According to Emerson et al. (2009) and Kana and Hagos (2024) a significant barrier is the scarcity of teachers proficient in braille, which impedes consistent and effective instruction. Research by Norakyairee Mohd Raus (2019) highlights that many educators lack the necessary training and confidence to teach braille, often resulting in inadequate support for students. Moreover, Swenson (1988) emphasize that the integration of braille instruction into the broader curriculum remains insufficient, limiting students' opportunities to practice and apply their skills in meaningful contexts.

Conversely, studies also point to promising strategies that have been employed to address these challenges. For instance, Hoskin et al. (2024) demonstrate the effectiveness of incorporating assistive technologies alongside traditional braille instruction, which can enhance engagement and facilitate individualized learning. Additionally, Kao and Mzimela (2019) advocate for professional development programs that equip teachers with specialized skills and knowledge, thereby improving the quality of braille education. Furthermore, collaborative approaches involving parents, educators, and community resources have been shown to create a more supportive learning environment, as noted by (Muhammad Nizam Abdul Majid et al., 2022). These studies highlight the importance of integrating assistive technologies, professional development for educators, and collaborative approaches to enhance the effectiveness and supportiveness of braille education.

The primary objective of this systematic literature review is to explore the challenges faced in braille literacy education within the special education framework and to identify effective strategies that have been implemented to address these challenges. This review aims to synthesize current research findings, highlight gaps in the literature, and propose evidence-based recommendations for educators and policymakers to improve braille literacy outcomes.

Aligned with the SDG 4 of ensuring inclusive and equitable quality education and promoting lifelong learning opportunities for all, the primary objective of this systematic literature review is to explore the challenges faced in braille literacy education within the special education framework and to identify effective strategies that have been implemented to address these challenges (United Nations, 2018). This review aims to synthesize current research findings, highlight gaps in the literature, and

propose evidence-based recommendations for educators and policymakers to improve braille literacy outcomes.

The expected contribution of this article is twofold. Firstly, it aims to provide a detailed overview of the current state of braille literacy education, shedding light on the challenges that impede its effective implementation. Secondly, by presenting best practices and innovative strategies from existing literature, this review aspires to serve as a valuable resource for educators, administrators, and advocates dedicated to enhancing literacy opportunities for visually impaired students. Ultimately, this article seeks to support efforts in creating a more inclusive and effective educational environment for all learners.

METHODOLOGY

Systematic reviews involve a rigorous and comprehensive pre-planned search strategy designed to minimize bias by identifying, assessing, and synthesizing relevant research on the topic (MacFarlane et al., 2022). We performed a thorough examination of previously evaluated articles, including a meticulous description of the study's attributes and noteworthy findings. In addition, we evaluated the quality of the research and discussed possible reasons for the results. This chapter utilized systematic search strategies to ensure a comprehensive investigation. The systematic searching techniques involved three sub-processes: identification, screening, and eligibility assessment.

Identification

The systematic review technique consists of three essential phases that were utilized to select several relevant publications for this inquiry. During the initial phase, it is essential to discover keywords and search for pertinent terms using resources such as an online thesaurus, keywords recommended by Scopus, keywords given by experts, and previous research (Shaffril et al., 2021). Once all pertinent terms were chosen, search strings were generated for the Scopus and Web of Science databases, as shown in Figure 1. During the initial stage of the systematic review process, the current study project effectively obtained 87 papers from both databases. The papers and documents proceeded to the second stage, known as screening.

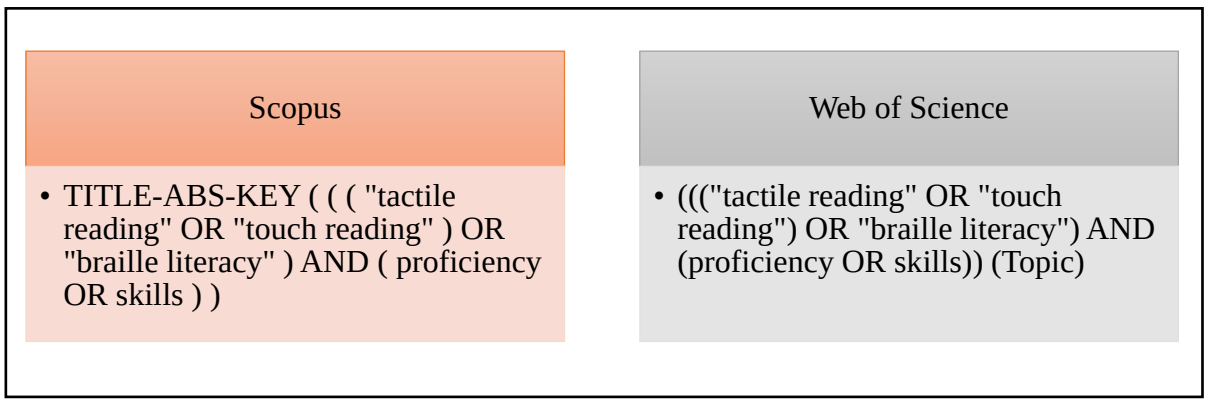

Figure 1: Full search string used in selected database (Scopus and Web of Science).

Screening

Superfluous documents should be disregarded at the initial phase of evaluation. During the initial stage, the researchers rejected 55 papers after using various criteria for inclusion and exclusion. In the subsequent stage, no articles were evaluated. The primary source of valuable knowledge is literature or research articles, making it the first criterion. In addition, the present study excludes publications that fall under the categories of book series, books, chapters, reviews, meta-analyses, meta-synthesis, systematic reviews, or conference proceedings. Moreover, the review was limited to studies conducted exclusively in the English language. It is essential to remember that the plan was established for a decade-long duration (2010–2024). The total number of publications is 41, as determined by the established criteria. Table 1 shows the selection criterion is searching.

Table 1. The selection criterion is searching.

Criterion	Inclusion	Exclusion
Language	English	Non-English
Timeline / Years	2010 – 2024	Before 2010
Document type	Journal (Article)	Book series, books, chapters, reviews, meta-analyses, meta-synthesis, systematic reviews, or conference proceedings
Publication stage	Final	Article in Press

Eligibility

There are now 32 articles that have completed the necessary requirements and are now in the eligibility phase, which is the third step of the process. The titles and essential content of each article were thoroughly scrutinized at this stage to ensure that they met the inclusion criteria and aligned with the objectives of the current study. Consequently, three reports were excluded: one because it was due to the out of field (n=3), another because its abstract did not provide any supporting evidence (n=8) and title not significantly (n=2). Finally, leaving 8 articles available for evaluation.

Quality Appraisal

All systematic reviews incorporate a process of critique or appraisal of the research evidence. The purpose of this appraisal is to assess the methodological quality of a study and to determine the extent to which a study has addressed the possibility of bias in its design, conduct and analysis. All papers selected for inclusion in the systematic review (that is – those that meet the inclusion criteria described in the protocol) need to be subjected to rigorous appraisal by two critical appraisers. The results of this appraisal can then be used to inform synthesis and interpretation of the results of the study by Hong et al. (2018). All authors extracted data specifically related to braille literacy about challenges and braille education strategies from articles that fulfilled the Mixed-Method Appraisal Tools (MMAT) (Appendix 1). MMAT enables researchers to appraise a systematic mixed studies review and covers the appraisal of five kinds of studies: qualitative research, randomised controlled trials, non-randomised studies, quantitative descriptive studies, and mixed methods studies (Hong et

al. 2018). For each selected study, two screening processes were conducted before proceeding to the quality assessment. The selected articles were assessed based on their quality using five main criteria established in the research design. Only those articles that scored above 80% based on the established criteria and their relevance to the topic were considered suitable for inclusion in the analysis (Table 2).

Table 2. Critical appraisal tool.

Study	JBI Critical Appraisal Tool
Argyropoulos et al. (2019)	5/5 (100%)
Bola et al. (2016)	5/5 (100%)
Farrand et al. (2022)	5/5 (100%)
Herzberg et al. (2017)	5/5 (100%)
Herzberg et al. (2023)	5/5 (100%)
McCarthy et al. (2016)	5/5 (100%)
Hoskin et al. (2024)	5/5 (100%)
Kamei-Hannan (2023)	4/5 (80%)

Data Abstraction and Analysis

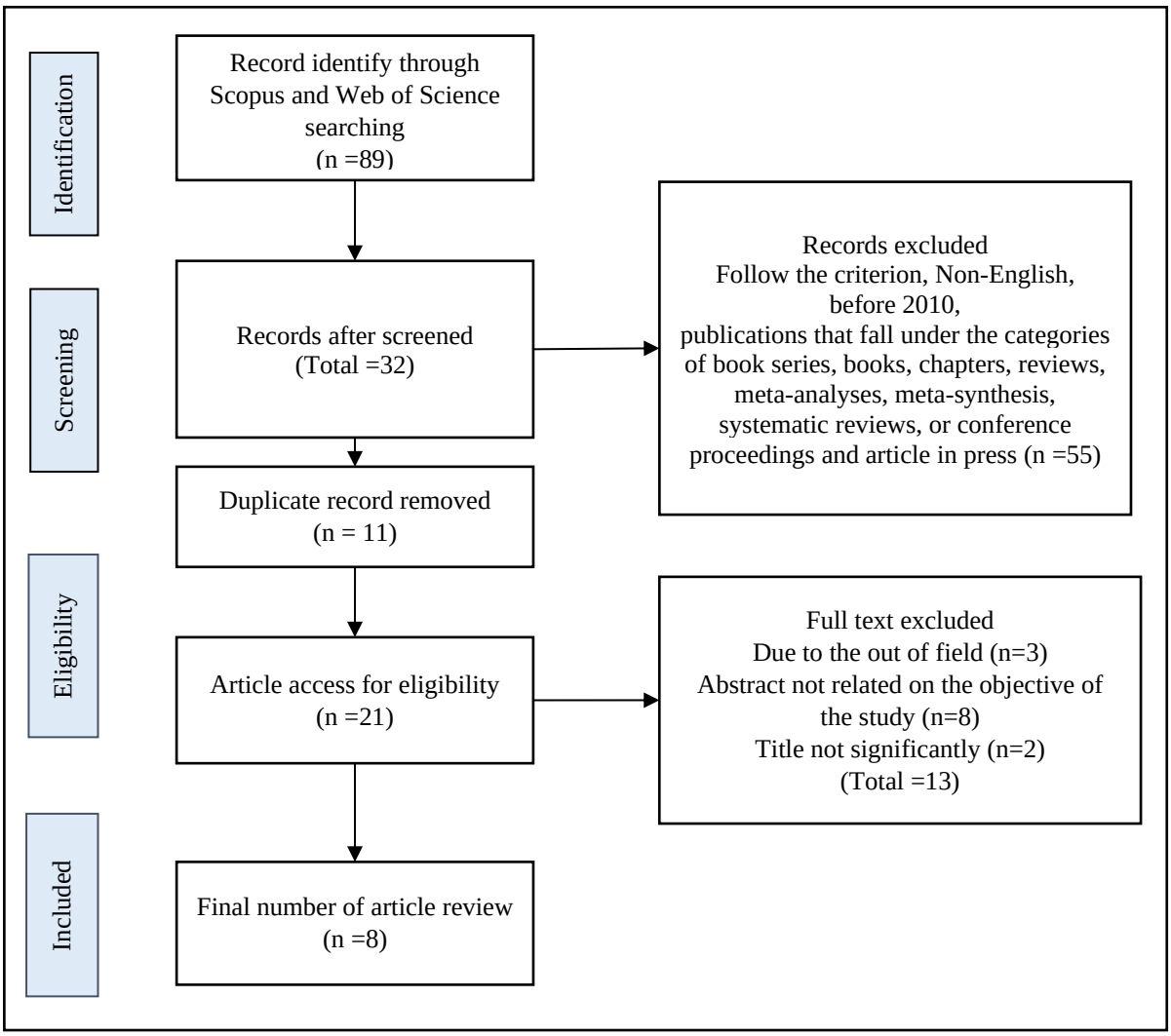

Figure 2. Flowchart of included articles retrieval process.

The PRISMA flow diagram outlines the systematic review process, starting with the identification of 89 records through database searches (Scopus and Web of Science). After initial screening, 32 records remained, with 55 excluded for criteria non-compliance. Following the removal of 11 duplicates, 21 records underwent full-text assessment, resulting in the exclusion of 13 articles due to being out of field (3), abstract irrelevance (8), or title insignificance (2). Ultimately, 8 articles were included in the systematic review, ensuring a focused and high-quality selection of studies (see Figure 2).

Data extraction in this study used the manual tabulation method. Identification of research characteristics includes items: research identity, methodology, participant, themes and findings (Table 3).

Table 3. Summary of included 8 research articles reviewed.

Study	Methodology	Participants	Themes & sub-themes	Findings
Argyropoulos et al. (2019)	Survey	75 students	Challenges in braille literacy -Technological support -Teaching training	Braille and large print were preferred mediums, but listening was the preferred performance medium.
Bola et al. (2016)	Action Research	29 sighted adults (braille teachers and educators)	Challenges in braille literacy -Instructional strategies	Sighted adults can learn braille reading with proper training.
Farrand et al. (2022)	Survey	19 university instructors of literary braille	Challenges in braille literacy -Teaching training -Instructional strategies	University programs primarily focus on UEB instruction, but there is a shift to online learning and a decrease in instructor experience.
Herzberg et al. (2017)	Survey	84 teachers	Challenges in braille literacy -Teaching training	Braille is introduced at various ages based on student needs. Motivation is crucial for successful braille use.
Herzberg et al. (2023)	Test and survey	17 teachers	Braille education strategies -Professional development for teachers with literacy instruction	Teachers' knowledge and skills improved, but challenges remain in applying Nemeth Code.
McCarthy et al. (2016)	single-subject, teacher interviews, and surveys	10 students 7 teachers	Braille education strategies -Integration of advanced technologies	Braille Tutor showed promise in supplementing braille instruction, potentially leading to faster learning and better outcomes.
Hoskin et al. (2024)	Case Study	25 students	Braille education strategies -Innovative tools	BrailleBunny prototype is promising but needs improvement in affordability, durability, and reliability.
Kamei-Hannan (2023)	Survey	44 teachers 48 Students	Braille education strategies - Innovative tools	The app showed positive results for braille literacy, but teacher support is necessary.

*****UEB- Unified English Braille

RESULT

Based on the 8 articles that have been selected, two themes can be identified related to braille literacy and education for visually impaired individuals. Here are the themes with relevant excerpts from selected articles:

Theme 1: Challenges in Braille Literacy

Braille literacy for students with visual impairments faces several significant challenges. Argyropoulos et al. (2019) identified that despite preferences for braille and large print, aural reading emerged as the most effective medium for comprehension among students. This finding underscores the need for enhanced braille learning experiences that can match the efficiency of aural reading. Additionally, the study pointed out major barriers, such as inadequate technological support and insufficiently trained teachers. This highlights a critical gap in the education system that needs addressing to improve braille literacy outcomes.

Another critical challenge is the proficiency of sighted individuals in braille literacy. Bola et al. (2016) demonstrated that sighted adults could achieve proficiency in braille through focused training, which implies that braille literacy is not solely dependent on visual deprivation. However, the study also highlighted that low tactile acuity did not significantly affect braille reading speed, suggesting that other factors, such as motivation and the right teaching methods, play a crucial role in learning braille. This finding challenges the assumption that only individuals with visual impairments can effectively learn braille.

Furthermore, Farrand et al. (2022) explored the instructional strategies in university preparation programs for professionals working with students with visual impairments. They found that while some strategies remained unchanged over the past two decades, there have been notable updates in instructional materials and a shift towards online learning. The study also noted a decline in the level of experience among instructors and highlighted the importance of proficiency exams. These findings suggest that despite advancements, there are ongoing challenges in preparing educators adequately, which in turn affects the quality of braille instruction students receive.

Herzberg et al. (2017) further emphasize that teachers' experiences with literacy instruction for dual-media students who use print and braille reveal that the average age for introducing braille is 7.8 years, and only about 25% of these students are at or above grade level with their braille literacy skills, indicating a need for tailored approaches and comprehensive curricula. This highlights the importance of specialized instructional strategies to improve braille literacy outcomes for dual-media students.

The challenges in braille literacy are multifaceted, involving issues related to technology, teacher training, and instructional methods. Despite some progress, there remain significant barriers that hinder effective braille education. Addressing these challenges requires a concerted effort to improve technological support, enhance teacher training programs, and adopt innovative instructional strategies that cater to the diverse needs of students with visual impairments. Figure 3 shows theme 1 and sub-themes.

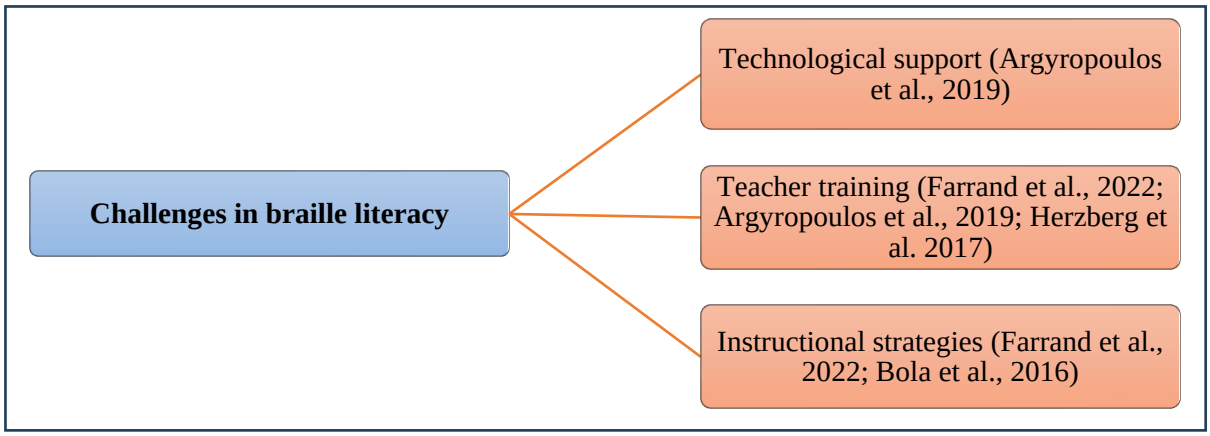

Figure 3. Theme 1 and sub-themes.

Theme 2: Braille Education Strategies

To address the challenges in braille literacy, various strategies have been proposed and implemented. Herzberg et al. (2023) emphasized the importance of professional development for teachers of students with visual impairments, particularly in learning the Nemeth Code within UEB contexts. The study showed that participants who underwent synchronous professional development sessions demonstrated significant improvements in their skills. This highlights the need for continuous professional development to ensure that teachers can provide high-quality braille instruction and support students effectively.

Technological advancements have also been leveraged to enhance braille education. For instance, McCarthy et al. (2016) evaluated the effectiveness of an artificial intelligence-based Braille Tutor designed to supplement traditional braille instruction. Their study found that students using the Braille Tutor reached accuracy faster and learned more contractions compared to those who did not use the tool. This suggests that integrating advanced technology with traditional teaching methods can significantly enhance braille literacy education, providing students with more frequent and consistent reinforcement.

Moreover, innovative tools such as BrailleBunny have been developed to support braille learning. Hoskin et al. (2024) detailed the co-design and testing of this device, which aimed to address braille illiteracy, particularly in developing countries like the Philippines. Despite needing improvements in financial accessibility, durability, and reliability, user feedback was positive, indicating that such devices can provide valuable support in learning standard-size braille. This highlights the potential of assistive technologies in making braille education more accessible and effective globally.

Kamei-Hannan (2023) reflected on the design, development, and implementation of a braille mobile app, “Reading and Writing Adventure Time”, aimed at supporting braille literacy for first through twelfth-grade readers. The project utilized usable and participatory design methods, involving teachers and students in the process. During implementation, the app received high ratings from teachers on key indicators relevant to braille literacy, with professional development and technical support being critical for its success. This study emphasizes the importance of continuous support for educators to effectively utilize educational technology.

Effective braille education strategies are crucial for overcoming the challenges in braille literacy. Professional development for teachers, the integration of advanced technologies, and the use of innovative tools can significantly improve the quality of braille instruction. These strategies not only

enhance learning outcomes for students with visual impairments but also ensure that braille literacy is accessible to a broader population, promoting inclusivity and educational equity. Figure 4 shows theme 2 and sub-themes.

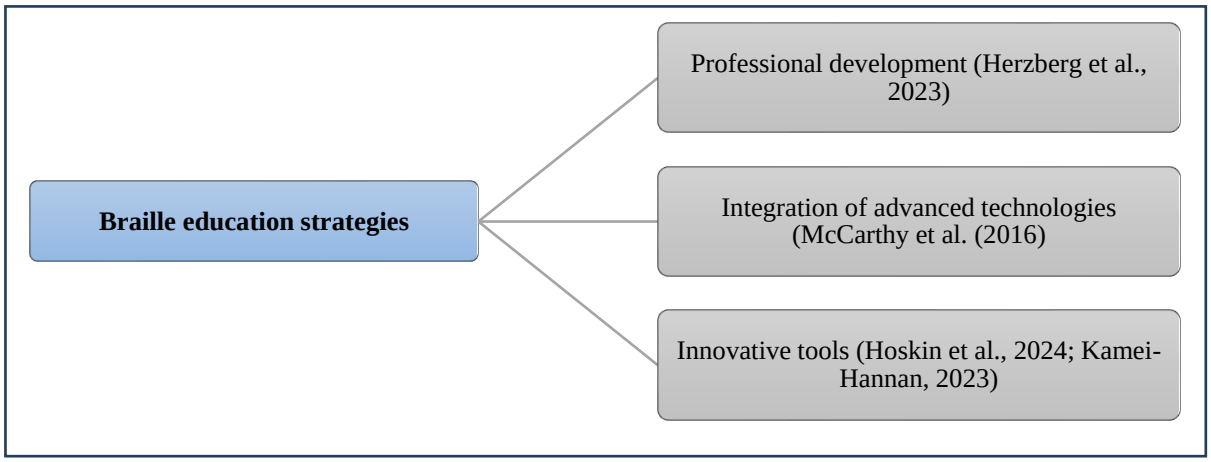

Figure 4. Theme 2 and sub-themes.

DISCUSSION

The findings from the systematic literature review on braille literacy in special education reveal a complex landscape of challenges and promising strategies that collectively shape the educational experiences of visually impaired students. This discussion synthesizes the key insights from the reviewed studies, offering a nuanced understanding of the current state of braille literacy and the potential pathways for improvement.

Challenges in Braille Literacy

The challenges in braille literacy are deeply rooted in systemic issues, primarily revolving around the availability of resources and the preparedness of educators. Argyropoulos et al. (2019) identified a significant gap in technological support, which hinders the effective teaching and learning of braille. The preference for aural reading over braille among students suggests that current braille instruction methods may not be as engaging or efficient, underscoring the need for innovative approaches that can make braille learning more appealing and effective.

Inadequate technological support remains a pressing concern. Many educational settings lack the necessary assistive technologies, such as braille embossers, refreshable braille displays, and specialized software. These tools are essential for providing a comprehensive learning experience that can enhance students' engagement and proficiency in braille. Without these technologies, students may find braille learning cumbersome and less effective compared to other methods like aural reading. Thus, there is a critical need to invest in and integrate these technologies into the educational infrastructure to support braille literacy.

Furthermore, the study by Farrand et al. (2022) sheds light on the declining proficiency of university instructors in braille literacy, a trend exacerbated by the shift towards online learning. This decline in expertise among educators is alarming, as it directly impacts the quality of instruction that visually impaired students receive. The emphasis on proficiency exams and continuous professional

development is crucial to bridging this gap and ensuring that teachers are well-equipped to deliver high-quality braille education.
Moreover, the challenge extends beyond technological support to the training and preparedness of educators. Farrand et al. (2022) highlighted a decline in the level of experience among university instructors teaching braille. This decline, coupled with a shift towards online learning, raises concerns about the quality and consistency of braille instruction. Proficiency exams and continuous professional development are essential to equip educators with the skills and knowledge required to effectively teach braille. Ensuring that teachers are well-prepared is crucial for improving braille literacy outcomes and providing students with the support they need.

Bola et al. (2016) challenge the conventional notion that braille literacy is exclusively a skill for the visually impaired. Their findings that sighted adults can achieve proficiency in braille through focused training highlight the potential for braille to be more widely adopted as a universal literacy tool. This insight opens up new avenues for inclusive education, where braille literacy can be integrated into mainstream curricula, promoting greater awareness and understanding of visual impairments among all students.

The findings from Bola et al. (2016) challenge the traditional perception that braille literacy is exclusive to those who are visually impaired. Their study demonstrated that sighted adults could achieve proficiency in braille through focused and intensive training. This suggests that with proper training and resources, braille literacy can be accessible to a broader population. This insight has significant implications for inclusive education. By integrating braille literacy into mainstream curricula, educational institutions can foster greater awareness and understanding of visual impairments among all students, promoting inclusivity and empathy.

Moreover, Herzberg et al. (2017) analyzed the experiences of teachers providing literacy instruction to dual-media students who use both print and braille. They found that introducing braille to students typically occurred at an average age of 7.8 years, driven by factors such as the student's diagnosis, print reading speed, and stamina. The study highlighted that student motivation and confidence are critical in acquiring braille literacy. Approximately half of the students were at or above grade level in print literacy, while only about 25% achieved similar levels in braille literacy. This underscores the need for continuous professional development to ensure that teachers are equipped to motivate and guide students through the challenges of learning braille, especially in dual-media contexts.

This discussion integrates findings this theme from multiple studies to provide a comprehensive overview of the challenges and potential strategies in braille literacy education, highlighting the importance of technological support, professional development, and inclusive educational practices.

Braille Education Strategies

To counter the identified challenges, several effective strategies have been highlighted in the literature. Herzberg et al. (2023) emphasized the importance of professional development for teachers of students with visual impairments, particularly in mastering the Nemeth Code within UEB contexts. The study showed that participants who underwent synchronous professional development sessions demonstrated significant improvements in their skills. This highlights the need for continuous professional development to ensure that teachers can provide high-quality braille instruction and support students effectively.

Herzberg et al. (2023) emphasized the importance of professional development for teachers. Their study highlighted the positive outcomes of synchronous professional development sessions, where

teachers demonstrated significant improvements in their skills in using the Nemeth Code within UEB contexts. This finding underscores the need for continuous professional development to keep educators updated with the latest methodologies and tools in braille instruction. Investing in the professional growth of teachers is crucial for maintaining high standards of education and ensuring that students receive timely and accurately prepared learning materials.

Technological advancements have also been leveraged to enhance braille education. For instance, McCarthy et al. (2016) evaluated the effectiveness of an artificial intelligence-based Braille Tutor designed to supplement traditional braille instruction. Their study found that students using the Braille Tutor reached accuracy faster and learned more contractions compared to those who did not use the tool. This suggests that integrating advanced technology with traditional teaching methods can significantly enhance braille literacy education, providing students with more frequent and consistent reinforcement.

The integration of technology in braille education is another promising strategy. McCarthy et al. (2016) evaluated the effectiveness of an artificial intelligence-based Braille Tutor designed to supplement traditional braille instruction. Their study found that students using the Braille Tutor reached accuracy faster and learned more contractions compared to those who did not use the tool. This finding suggests that advanced technological tools can significantly enhance braille literacy education by providing students with more frequent and consistent reinforcement. Integrating AI-based tools with traditional teaching methods can create a more engaging and effective learning environment for visually impaired students.

Moreover, innovative tools such as BrailleBunny have been developed to support braille learning. Hoskin et al. (2024) detailed the co-design and testing of this device, which aimed to address braille illiteracy, particularly in developing countries like the Philippines. Despite needing improvements in financial accessibility, durability, and reliability, user feedback was positive, indicating that such devices can provide valuable support in learning standard-size braille. This highlights the potential of assistive technologies in making braille education more accessible and effective globally.

Furthermore, innovative tools such as BrailleBunny, as discussed by Hoskin et al. (2024), represent a leap forward in making braille education more accessible and effective. The co-design and testing of this device aimed to address braille illiteracy, particularly in developing countries like the Philippines. Although the prototype requires improvements in financial accessibility, durability, and reliability, user feedback was positive, indicating that such devices can play a crucial role in supporting braille learning. This highlights the potential of assistive technologies in providing valuable support and making braille education more accessible globally.

Effective braille education strategies are crucial for overcoming the challenges in braille literacy. Professional development for teachers, the integration of advanced technologies, and the use of innovative tools can significantly improve the quality of braille instruction. These strategies not only enhance learning outcomes for students with visual impairments but also ensure that braille literacy is accessible to a broader population, promoting inclusivity and educational equity.

Kamei-Hannan C. (2023) provides insightful reflections on the design, development, and implementation of a braille mobile app aimed at supporting braille literacy skills for first-through twelfth-grade students. The project highlighted the importance of usable and participatory design, emphasizing the necessity of involving teachers and students throughout the process to ensure the app met their needs. High ratings from participants during implementation underscore the app's effectiveness, particularly in the areas of reading and writing braille. The study also stressed the

significance of professional development and technical support, revealing that substantial assistance was necessary during the initial phases of technology integration.

The synthesis of these findings reveals that while significant challenges exist in braille literacy education, there are also substantial opportunities for improvement through targeted strategies. Enhancing technological support, investing in continuous professional development for educators, and integrating innovative tools are critical steps towards overcoming the barriers in braille literacy. By addressing these challenges and leveraging effective strategies, we can ensure that visually impaired students receive the quality education they deserve, fostering their independence and academic success. The potential for braille to be adopted as a universal literacy tool further underscores the importance of inclusive educational practices that benefit all learners. Figure 5 shows theme and sub-themes for braille literacy.

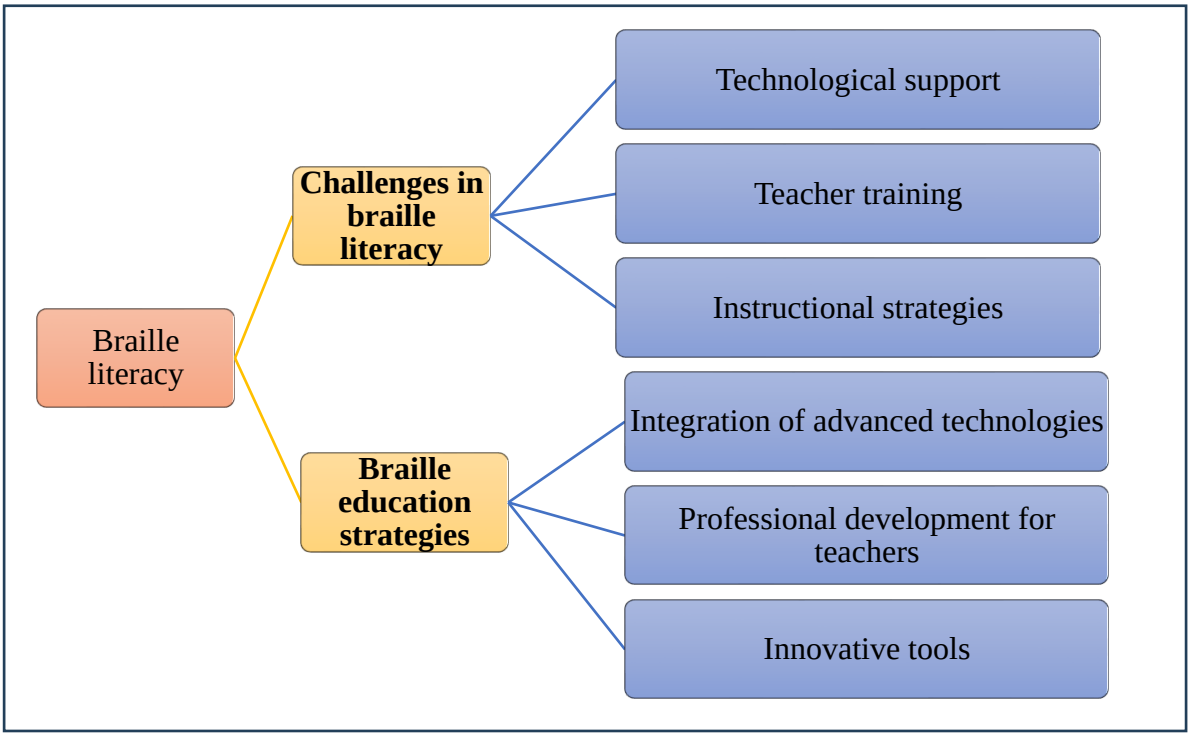

Figure 5. Theme and sub-themes for braille literacy.

CONCLUSIONS

This synthesis of findings supports SDG 4, which aims to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all. The research examined the effectiveness of various methods and technologies in enhancing braille literacy among visually impaired students. The studies involved various approaches such as the development of assistive technologies, mobile applications, and professional development programs for teachers. The findings demonstrate that these interventions can significantly improve the knowledge and skills of both students and teachers in braille literacy.

The results indicate that inclusive teaching approaches and the use of advanced technology can enhance braille literacy. The methodologies employed, such as pre- and post-tests, case studies, and participatory design methods, provide deep insights into the effectiveness of the implemented interventions. Theoretically, the research highlights the importance of motivation, confidence, and

early introduction of braille in achieving literacy. It underscores the need for educators to be well-versed in both traditional and modern instructional strategies to effectively support dual-media learners.

Practically, the research highlights the importance of continuous training for teachers and the need for additional resources and professional development. Schools and educational institutions should integrate advanced technological tools, like AI-based Braille Tutors and mobile apps, to supplement traditional teaching methods. The use of assistive technologies like BrailleBunny and mobile applications has shown great potential in improving the efficiency of braille teaching and learning. The positive reception of tools like BrailleBunny suggests that innovative devices can play a crucial role in supporting braille learning, particularly in developing regions where resources are limited.

Improving braille literacy among visually impaired students has significant social implications. It can enhance educational opportunities, employability, financial independence, and self-esteem. The developed technologies can also be adapted for use in developing countries, benefiting students worldwide. Environmentally, the shift towards digital tools and resources can reduce the reliance on physical braille materials, contributing to sustainability efforts by minimizing paper usage.

Despite these promising findings, the research has certain limitations, including the need for improvements in financial accessibility, durability, and reliability of the developed assistive tools. The studies primarily focus on specific technologies and geographic regions, limiting the generalizability of the results. Future research should explore a wider range of technological tools and include diverse educational settings to validate the findings further. Additionally, longitudinal studies are needed to assess the long-term impact of these interventions on braille literacy and academic success.

Future research should also investigate the cost-effectiveness of implementing advanced technological tools in different educational contexts. Studies could explore how to make innovative braille learning tools more financially accessible and durable, particularly in developing countries. Furthermore, research should examine the potential of integrating virtual and augmented reality technologies into braille education to create even more engaging and immersive learning experiences.

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APPENDIX 1

Table the criteria used to determine the rigour of the methodology and analysis used in the selected articles

Research Design	Assessment criteria
Qualitative	QA1—Is the qualitative approach appropriate to answer the research question? QA2—Are the qualitative data collection methods adequate to address the research question? QA3- Are the findings adequately derived from the data? QA4- Is the interpretation of results sufficiently substantiated by data? QA5—Is there coherence between qualitative data sources, collection, analysis and interpretation?
Quantitative (descriptive)	QA1—Is the sampling strategy relevant to address the research question? QA2- Is the sample representative of the target population? QA3- Are the measurements appropriate? QA4- Is the risk of nonresponse bias low? QA5- Is the statistical analysis appropriate to answer the research question?
Quantitative (non-randomised)	QA1- Are the participants representative of the target population? QA2- Are measurements appropriate regarding both the outcome and intervention (or exposure)? QA3- Are there complete outcome data? QA4- Are the confounders accounted for in the design and analysis? QA5- During the study period, is the intervention administered (or exposure occurred) as intended?
Mixed methods	QA1- Is there an adequate rationale for using a mixed methods design to address the research question?

	QA2- Are the different components of the study effectively integrated to answer the research question? QA3- Are the outputs of the integration of qualitative and quantitative components adequately interpreted? QA4- Are divergences and inconsistencies between quantitative and qualitative results adequately addressed? QA5- Do the different components of the study adhere to the quality criteria of each tradition of the methods involved?

Source: (Hong et al., 2018)