The Intertwining of Inclusive and Digital Learning

A Scoping Review on Digital Learning in Inclusive Science Education

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Abstract:

This paper explores emerging trends in digitally supported inclusive science education, with a particular focus on inquiry-based learning. Drawing on UNESCO's (2001, 2017, 2020) definition of inclusive education and the Framework for Inclusive Science Education (Brauns & Abels, 2020), we reviewed the current state of knowledge on digital learning in inclusive science contexts. Our aim was to lay the groundwork for future research on fostering inclusive inquiry-based learning through digital materials. Whereas subsequent publications will address our research project more broadly, this paper presents the findings of an initial scoping review. We systematically analyzed the literature from the past decade to map and synthesize evidence on the use of digital learning tools in inclusive science education at the primary school level. Three key trends emerged: (a) research on digitally supported inclusive science education has predominantly focused on gifted students, rather than on those with special educational needs; (b) certain teacher training programs aimed at integrating digital media into inclusive science education have shown promising results; and (c) teachers face significant challenges, particularly in their ability to engage all students with digital materials in inquiry-based science teaching. We discuss these findings in detail to provide starting points for future research on the role of digital tools in inclusive science education.

1   Introduction

In the past decade, two key topics have gained significant prominence in educational research: inclusion and digitality. Although these areas are both critically important, they also present substantial challenges within education systems all over the globe that are striving to meet the diverse needs of learners. The concept of inclusive education has been interpreted in various ways across international discussions, with definitions shaped by cultural and educational differences (Ainscow, 2021; Makoelle, 2014; Shyman, 2015; Spandagou, 2021). Nel et al. (2011) highlighted the country-specific nature of inclusion, noting that sociocultural and educational contexts play significant roles in its implementation. Despite these variations, efforts have been made to develop a more universal definition of inclusive education (Makoelle, 2014). UNESCO's (2001) definition, aligned with the 1960 *Convention against Discrimination in Education and Sustainable Development Goal 4* (SDG 4) of the 2030 Agenda (UNESCO, 2017), centers on two key principles. First, every learner is equally valued, and none should be excluded based on factors such as gender, religion, language, nationality, ethnicity, social background, economic status, or ability (Ballard, 1997; NCERI, 1995). Second, inclusive education aims to identify and remove barriers—whether curricular, pedagogical, or related to teaching practices—and ensure equitable access to high-quality education for all learners.

The core principle of inclusive pedagogy—removing barriers—presents both opportunities and challenges. It holds the potential to transform schools into change agents (Howladar, 2018), fostering participation and well-being through quality education for all. However, empirical research has also highlighted significant barriers, such as inadequate teacher training, the perception of diversity as a challenge, physical barriers, underutilized resources, and a lack of effective organizational and pedagogical strategies (Arnaiz Sánchez et al., 2019).

A key issue in discussions about inclusive practices is the application of inclusive pedagogies across various school subjects. In science education, the *Framework for Inclusive Science Education* (Brauns & Abels, 2020) was developed to explore the relationship between inclusive pedagogy and science teaching. Based on a systematic literature review, the framework identified 16 categories, including *'Creating inclusive science learning environments,' 'Developing students' science conceptions inclusively,'* and *'Creating inclusive scientific documentation'* (Brauns & Abels, 2020, p. 22). However, these categories remain largely theoretical, failing to directly address how the specific characteristics of science education can be translated into inclusive practices (Wellington & Ireson, 2017). To bridge this gap, the framework introduced subsequent levels that focus on practical implementation, such as *'Enabling inquiry-based learning materially guided'* (Brauns & Abels, 2020, p. 22). In total, the framework includes 12 action-oriented subcategories defined by verbs such as *'supporting,' 'enabling,'* and *'creating'*. These subcategories provide concrete guidance for implementing inclusive science education through digital tools, action-based strategies, linguistic adjustments, and material support (e.g., Wellington & Ireson, 2017).

The second prominent focus of the past decade has been on digital learning, particularly in science education (Momani et al., 2023). In the context of inquiry-based learning, the *Eight Learning Events Model* by LeClercq and Poumay (2005) was one of the first theoretical frameworks to be used as a professional development tool, helping teachers integrate digital materials into their teaching (Nuninger et al., 2023). This model advocates for the standardization of core teaching and learning situations (Verpoorten et al., 2007), highlighting the phases of exploration, creation, experimentation, debate, and meta-reflection as essential for incorporating digital tools into inquiry-based learning (LeClercq & Poumay, 2005). Since then, various pedagogical frameworks for integrating digital media into science education have emerged (e.g., Bosse et al., 2019; Böttinger &

Schulz, 2021; Pannullo et al., 2025; Schaumburg, 2021). However, the topic of inclusion remains largely peripheral in all of these models. Whereas some frameworks mention inclusive practices—such as the importance of clear instructions and constructive feedback (LeClercq & Poumay, 2005)—they do not fully address the implications of these practices for inclusive teaching (Abels & Stinken-Rösner, 2022). With this review, we aimed to fill this gap by examining how the intersection of inclusive education and digital learning in science education has been explored in the literature and by identifying opportunities for further development in this area.

2 Research Question and Methodological Approach

Drawing upon the discourses outlined above, we examined empirical research at the intersection of digital learning, inclusion, and science education. Our primary aim was to identify emerging trends by systematically categorizing the existing research in these areas. Specifically, we explored the landscape of digital learning within inclusive science education to set the stage for future studies. To achieve this end, we conducted a scoping review of literature published from 2014 to mid-2024, thereby mapping and synthesizing the available evidence at the intersection of digital learning, inclusion, and science education. While the overarching research project, *Promotion of Inclusive Science Education Through the Use of Digital Materials* (PISE-DM), will be discussed in a subsequent article, we present the findings from the initial scoping review in the current paper[1].

By following Nightingale's (2009) and Snyder's (2019) literature review guidelines, our process adhered to the following five steps: (a) defining the objective, (b) developing a search strategy, (c) selecting studies on the basis of inclusion/exclusion criteria, (d) extracting data, and (e) summarizing findings and identifying gaps. To map the state of research on digital learning in inclusive science education, our inclusion/exclusion criteria, outlined in Table 1, ensured that only studies addressing both digital learning and inclusive science education would be included. Studies that focused solely on digital learning or inclusion in education, without a science education context, were excluded. Our criteria further specified that publications must be

Table 1: Inclusion criteria for our literature review

Inclusion criteria	Details
Type of study	• qualitative and/or quantitative empirical studies or • documentation of digital inclusive practices
Focus of the study	• digital learning • educational inclusion • context of science education
Type of participants	• practitioners working with students 4 to 16 years of age and/or • students 4 to 16 years of age from every background, gender, culture, nationality, religion, and geographical location
Type of intervention	• any kind (e.g., peer tutoring, one-on-one intervention, classroom-based intervention, short- and long-term intervention)
Publication type	• double-blind peer review • published from 2014 to mid-2024
Other	• studies must focus on both educational inclusion and digital learning in science education • studies focusing on either educational inclusion or digital learning are excluded

[1] For related work from the predecessor project TAPSE, see Andersen, 2020.

peer reviewed and published within the last ten years, ensuring both quality and relevance. The search focused on studies involving students between the ages of 4 and 16, as well as practitioners working with this age group. Given the varying structures of primary school systems across different countries (e.g., ages 6–10 in Germany, 4–12 in Luxembourg, 6–16 in Denmark), we considered a broad age range to capture relevant studies in primary science education.

Building on these inclusion criteria, we conducted a search using Google Scholar, Scopus, and Science Direct. In the first stage of the scoping review, we identified 91 papers focusing on the intersection of inclusive and digital learning. After applying the inclusion criteria (Table 1) and excluding studies unrelated to primary science education, we reduced the number of relevant articles to 28, which were retained for further analysis. Data were extracted from the selected papers and systematized using content analysis, as outlined by Bengtsson (2016). We developed a coding scheme around key themes such as digital tools, inclusive practices, participant demographics, and outcomes. Each study was reviewed, and relevant data were extracted accordingly. The data were then coded thematically to identify patterns and trends. To ensure reliability, three researchers independently reviewed the coded data, resolving discrepancies through discussion. Finally, the findings were synthesized to map trends in digital learning for inclusive science education and to identify gaps in the literature.

3 Findings: Emerging Trends in Digital Learning for Inclusive Science Education

The empirical research on inclusive education, digital learning, and science education is extensive and internationally widespread when considered separately (e.g., Ainscow, 2021; Howladar, 2018; Makoelle, 2014; Pedaste et al., 2015; Shyman, 2015; Sotiriou et al., 2020). Nonetheless, our scoping review revealed a significant gap in studies specifically addressing the intersection of these three domains: digitality, inclusion, and science education. Although some studies focused on two of these areas (e.g., Comarú et al., 2021), when all three were considered, digital learning was often treated peripherally or as not central to the research questions or data collection. For example, although several studies have explored the intersection of inclusion and science education (e.g., Apanasionok et al., 2020; Librea-Carden et al., 2021; Sebti & Elder, 2024), the role of digital learning—such as testing a digital tool—was not a primary focus of the research in those studies.

The following presentation of our results highlights studies that addressed all three areas, though they often emphasized only two. Despite this limitation, our review identified three recurring themes that emerged as key trends in research on digital learning in inclusive science education.

1. Focus on gifted students over students with special educational needs

One key trend in research on digital learning in inclusive science education is the emphasis on gifted students rather than on those with special educational needs (SEN). Several studies highlighted the benefits of digital learning materials for gifted students (Cerna et al., 2021; Ebenbeck, 2023), who often struggle in traditional educational settings, experiencing boredom that can negatively affect both their well-being and academic performance (Gottschalk & Weise, 2023; Rutigliano & Quarshie, 2021). Digital tools, such as interactive projects and digital books, engage gifted students by facilitating real-world connections and offering thought-provoking challenges (Gottschalk & Weise, 2023). Ebenbeck (2023) also underscores the effectiveness of Computerized Adaptive Testing (CAT), which adjusts the level of difficulty of questions in real time to match students' abilities.

These digital tools have the potential to boost motivation and engagement, thereby allowing students more flexibility in pursuing individual interests (Rutigliano & Quarshie, 2021). Specifically, augmented reality and personalized online assessments have been shown to foster critical thinking and independent problem solving (Brussino, 2020; Chen et al., 2013). However, although research has explored digital learning tools for gifted students (e.g., Brussino, 2020; Rutigliano & Quarshie, 2021), there is a notable dearth of studies that have focused on the application of these tools to science education for students with SEN, as well as those from ethnic minority groups or indigenous communities and those who are asylum seekers or refugees. Particularly for asylum-seeking students, empirical studies remain scarce (Allen et al., 2021; Alper & Goggin, 2017; Dreamson et al., 2018; Idol, 2006; Sorbring et al., 2017), with a notable lack of research on how inclusion impacts their educational experiences and how digital learning can support their participation in science education.

2. Promising teacher training programs for digital media in inclusive science education

Another trend identified in our review involves the growing recognition of the importance of teacher training for the effective integration of digital media into inclusive science education. There is broad consensus that science teachers need professional knowledge regarding both inclusion and digitalization (Kerres, 2018; Stinken-Rösner & Abels, 2021; Weidenhiller et al., 2022, 2024). However, teacher training programs aimed at integrating digital materials into inclusive science education vary widely in content and methodology. Among these, the one-day in-service training by Weidenhiller et al. (2024) stands out for its effectiveness, as demonstrated by the pre- and post-survey results of 141 participating science teachers. This training addressed teachers' attitudes and self-efficacy regarding inclusion and digitalization. During the one-day session, teachers planned and implemented a digitally supported science experiment,

receiving in-depth training on how to address the diverse needs of their students. The entire process —from planning to implementation and evaluation— was digitally supported (Weidenhiller et al., 2022), with teachers considering students' needs and potential barriers at each stage.

What distinguished this training from other professional development programs was its emphasis on empowering teachers to use digital media to design experiments and align each phase with the inquiry process. This approach encouraged teachers to adapt experiments to the unique diversity of their classrooms, tailoring strategies to meet students' individual needs. Pre- and post-survey results indicated significant improvements in teachers' attitudes towards digital media and self-efficacy across the TPACK domains (Weidenhiller et al., 2024). Notably, improvements were observed in the following three domains: pedagogical knowledge (PK), which focuses on students' individual needs; content knowledge (CK); and technological knowledge (TK), which includes the effective use of digital tools (Mishra & Koehler, 2006). Weidenhiller et al. (2024) emphasize that enhancing teachers' attitudes towards digital materials and boosting their self-efficacy are strong predictors of success in inclusive classrooms (Sharma & Jacobs, 2016).

This training program also stands out by focusing on the development of digitally supported experiments that address diverse student needs, in line with previous studies (Kerres, 2018; Stinken-Rösner & Abels, 2021) that have highlighted the importance of combining digital media design with inclusive teaching methods. Despite the promising results from such programs (for other studies with similar outcomes, see, e.g., Liu, 2013; Luo et al., 2023), our review revealed a significant gap in research on teacher training specifically designed to professionalize teachers in engaging all students in digitally supported inquiry-based science education.

3. Challenges in using digital media for inquiry-based learning in inclusive science education

A third key trend identified in the literature is the recognition of barriers to using digital media in inclusive science education, particularly within inquiry-based learning. The complexity of the inquiry process was often found to present challenges, such as difficulties regarding materials and instructions (Stinken-Rösner & Abels, 2021) or methodological obstacles such as formulating hypotheses or reflecting on measurement inaccuracies (Baur, 2018). Research has highlighted several strategies for addressing these challenges and creating differentiated, student-centered learning experiences. One effective approach involves the strategic use of digital materials designed to enhance accessibility and reduce barriers through multimedia design (Kerres, 2018).

A central component of inclusive inquiry-based learning with digital tools is the ability to adjust complexity, abstraction, and observation levels to meet the diverse needs of students, as demonstrated by Bruckermann et al. (2017). Other studies have explored how digital devices can support communication for students with physical impairments (Lidström & Hemmingsson, 2014) and have identified barriers to accessing digital tools, including physical, cognitive, and skill-related limitations (Sorbring et al., 2017). Additionally, studies indicate that certain digital tools remain inaccessible to students with SEN, particularly when essential features, such as text-to-speech software or subtitles, are not available (Alper & Goggin, 2017). These findings underscore the importance of ensuring that digital tools are designed inclusively to cater to a wide range of learning needs in science education.

4 Discussing Research Gaps and Future Research Directions

Significant progress has already been made in inclusive science education, digital learning, and teacher training. However, our scoping review highlights a critical need for more focused research at the intersection of these three domains. Specifically, further studies are needed on the use of digital tools for students with SEN and on comprehensive teacher training programs that integrate inclusive education and digital learning. Overcoming barriers to digital inclusion in science education will require continued innovation, collaboration, and a deeper understanding of how to design accessible, differentiated learning environments for all students. Our findings revealed significant gaps in research on how the inclusion of all learners in digitally supported science education can be effectively facilitated. Although inclusion in science teaching and the digitalization of science education have been extensively studied individually (e.g., Ballard, 1997; Bruckermann et al., 2017; Comarú et al., 2021; Paul, 2018), few empirical studies have explored the intersection of these areas. This gap is particularly evident in primary science education, where the integration of inclusive practices and digital tools remains largely unexplored.

One reason for this gap may stem from the historical development of digital learning technologies in education. Digital learning was introduced later in primary schools than in secondary schools (cf. Kerres, 2018), resulting in a delayed start for both research and implementation. Additionally, challenges such as limited technological resources and insufficient teacher training have further hindered the integration of digital tools into primary science education. Moreover, the scarcity of studies on digital learning in inclusive science education may reflect broader trends in science education research. In the past decade, much of the focus has been on hands-on learning, which is perceived as more engaging for students and more effective for fostering a deeper understanding of scientific concepts (cf. Andersen, 2020). By contrast, digital learning has often been regarded as supplementary to hands-on learning in science education (cf. Lin et al., 2017; Pannullo et al., 2025). This emphasis on experiential learning

may have led researchers to overlook the potential of digital tools to enhance inclusion, particularly for students with SEN. Furthermore, the rapid pace of digital technology development may have outstripped teachers' ability to fully integrate these tools into inclusive teaching practices.

The evolving nature of inclusion itself is another important consideration. Whereas inclusion in education has traditionally focused on physical accessibility (Ballard, 1997), there is now a growing recognition of the importance of cognitive, emotional, and social inclusion (Ainscow, 2021; Brussino, 2020; Spandagou, 2021). When used effectively, digital tools have the potential to support all of these aspects by offering personalized learning experiences that cater to diverse learning styles and abilities. However, research has yet to fully explore how digital resources can be designed to unlock their full potential for inclusion in science education. The intersection of digitalization and inclusion presents a unique opportunity for interdisciplinary research. Combining insights from educational technology, disability studies, and pedagogy could lead to a more nuanced understanding of how digital tools can support diverse learners in science classrooms. Future studies could investigate the specific types of digital interventions that are most effective for different student populations, the role of professional development in integrating digital tools, and how digital learning can be scaled to ensure equitable access for all students.

Emerging trends from existing studies at the intersection of digitalization, inclusion, and science education reveal significant disparities in the focus of such research. Notably, there is more empirical research on certain student groups (e.g., gifted students) than others, such as asylum seekers and refugees. Given the growing number of refugees and asylum seekers worldwide (UNESCO, 2020) and the unique challenges these students face—such as discrimination, language barriers, and cultural differences (Cerna et al., 2021)—it is surprising that there is limited research on how to better include them by using digital learning materials. This gap is especially notable given the positive impact of digital learning on motivation and academic outcomes (cf. Lin et al., 2017) and underscores the need for research on how digital tools can be adapted to support the unique needs of refugees and asylum seekers to ensure their meaningful participation and success in science education.

Whereas some empirical research has explored how digital learning materials can promote the inclusion of students with SEN (cf. Alper & Goggin, 2017; Gottschalk & Weise, 2023), our review highlights the need for more studies on how these materials can help SEN students engage in inquiry-based learning in science. Future research should explore how digital tools can help SEN students understand natural phenomena, develop problem-solving skills, form hypotheses, and test theories. Investigating how digital materials can support students with specific needs (e.g., ADHD, autism, Tourette's syndrome) in inquiry-based science learning is also essential. Tools such as text-to-speech software, translation tools, and visual representations have already shown promise in supporting SEN students (cf. Gottschalk & Weise, 2023), making it crucial to explore how these tools can enhance SEN students' engagement in science education. More specifically, research should focus on how such tools can help SEN students design investigations, form explanations, and make real-world connections through exploration.

Finally, teacher training programs that focus on the use of digital media in inclusive science lessons warrant further attention. According to the in-service teacher training study by Weidenhiller et al. (2024), a promising approach involves having teachers plan and conduct digitally supported experiments while receiving training on how to address the diverse needs of their students. This approach not only enhances teachers' technological skills but also equips them to create an inclusive learning environment, enabling all students to benefit from digital media in science education.

5 Conclusion

The integration of digital tools into inclusive science education presents both opportunities and challenges. Our scoping review underscores the need for further research into how these tools can best support diverse learners, including those with SEN, refugees, asylum seekers, and ethnic minorities. Although the existing evidence shows positive outcomes, further work is required to design tools that effectively facilitate inquiry-based learning and problem-solving for all students. Interdisciplinary research across educational technology, disability studies, and pedagogy is essential for advancing our understanding of how digital tools can foster inclusion in science education. Additionally, strengthening professional development programs for teachers is crucial for equipping them with the skills that are necessary to integrate these tools into diverse classrooms. By addressing research gaps and improving teacher training, we can unlock the full potential of digital tools to create an inclusive, empowering learning environment in science education for all students.

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