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Enhancing Digital Literacy in Inclusive IPAS Learning: Applying the TPACK Approach for Students with Disabilities in Elementary Schools

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ABSTRACT

Despite the considerable potential for digital technologies in inclusive education, the exploration of TPACK pedagogies for the primacy of science in investigating students with disabilities is scant. This research aimed to implement TPACK for digital literacy and learning engagement in Ilmu Pengetahuan Alam dan Sosial (IPAS) instruction for students with hearing impairments and hyperactive verbalization in a state elementary school in Yogyakarta. The study employed a qualitative descriptive design, collecting data through classroom observations, semi-structured interviews with teachers, and document analysis. Findings indicate that teachers were able to modify IPAS content by using interactive videos that integrated sign language, visual simulations, and gamified applications to enhance student access and participation. This digital media provided clarity in conceptual understanding, thereby motivating students with diverse needs to engage actively in the inclusive classroom. This study provides evidence that a well-structured TPACK-based approach can facilitate the development of digital literacy while creating meaningful learning experiences for students with disabilities in primary schooling. Teacher preparedness, the availability of accessible digital resources, and the flexibility of pedagogical practices should, therefore, be emphasized to facilitate the successful implementation of TPACK-based practices in inclusive educational settings.

Keywords: *TPACK, digital literacy, inclusive education, deaf students, verbal hyperactivity, primary education, IPAS learning.*

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INTRODUCTION

Technological advances and digital transformation have had a significant impact on education.[1] One approach that is increasingly relevant in facing the challenges of the 21st century is Technological Pedagogical Content Knowledge (TPACK).[2] This approach integrates technology, pedagogy, and learning content in a synergistic manner to create more effective learning experiences.[3] In the context of inclusive education, particularly in primary schools, the TPACK approach holds great potential to help students with disabilities, including those with deafness and verbal hyperactivity, learn optimally.[4] This research focuses on the application of the TPACK approach in learning Natural and Social Sciences (IPAS) by utilizing digital transformation for students with disabilities at Giwangan State Elementary School, Yogyakarta.

Inclusive education aims to ensure that every child, including those with special needs, has equal access to quality education.[5] In Indonesia, efforts to realize inclusive education have been emphasized in various policies, such as Permendikbud No. 70 of 2009, which outlines the principles of inclusive education.[6] However, the implementation still faces numerous challenges, particularly in providing learning facilities that meet the needs of students with disabilities.

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[1] Samuel Benny Dito and Heni Pujiastuti, "Dampak Revolusi Industri 4.0 Pada Sektor Pendidikan: Kajian Literatur Mengenai Digital Learning Pada Pendidikan Dasar Dan Menengah," *Jurnal Sains Dan Edukasi Sains* 4, no. 2 (December 2021): 59–65, https://doi.org/10.24246/JUSES.V4I2P59-65; Latifah Latifah and Ngalimun Ngalimun, "Pemulihan Pendidikan Pasca Pandemi Melalui Transformasi Digital Dengan Pendekatan Manajemen Pendidikan Islam Di Era Society 5.0," *Jurnal Terapung : Ilmu - Ilmu Sosial* 5, no. 1 (March 2023): 41, https://doi.org/10.31602/jt.v5i1.10576.

[2] Muhammad Idris Effendi, Hakkun Elmunsyah, and Widiyanti Widiyanti, "Peran Technological Pedagogical Content Knowledge (TPACK) Terhadap Ketercapaian 4C Skills (Critical Thinking, Creative Thinking, Collaboration, and Communication) Siswa SMK," *Didaktika: Jurnal Kependidikan* 13, no. 001 Des (December 2024): 435–44, https://doi.org/10.58230/27454312.1677; Silvester Silvester, Margaretha Lidya Sumarni, and Totok Victor Didik Saputro, "Pengaruh Kompetensi Technological Pedagogical Content Knowledge (TPACK) Terhadap Keterampilan Guru Dalam Mengimplemtasikan Pembelajaran Berbasis Digital," *Journal of Education Research* 5, no. 4 (October 19, 2024): 4958–65, https://doi.org/10.37985/jer.v5i4.1697.

[3] Idam Ragil Widianto Atmojo í, Dwi Yuniasih Saputri, and Alifia Khaerunnisa Fajri, "Analysis of STEAM-Based TPACK Integrated Activities in Elementary School Thematic Books.," *Elementary School Forum (Mimbar Sekolah Dasar)* 9, no. 2 (2022): 317–35, https://doi.org/10.53400/mimbar-sd.v9i2.49131.

[4] Tedi Gandara, "The Strategies for the Implementation of Audiobook-Based Islamic Religious Education Learning at SLBN Cileunyi," *Edukasi: Journal of Educational Research* 4, no. 2 (December 2024): 24–33, https://doi.org/10.57032/edukasi.v4i02.218; Krisna Wijaya et al., "Thematic Learning in the Independent Curriculum in Elementary Schools Based on the Islamic Montessori Method for Multiple Intelligence," *Indonesian Journal of Educational Research and Review* 7, no. 1 (April 2024): 85–97, https://doi.org/10.23887/IJERR.V7I1.66794.

[5] Abdul Rahim Hamdan, Muhammad Khairul Anuar, and Aqeel Khan, "Implementation of Co-Teaching Approach in an Inclusive Classroom: Overview of the Challenges, Readiness, and Role of Special Education Teacher," *Asia Pacific Education Review* 17, no. 2 (June 2016): 289–98, https://doi.org/10.1007/S12564-016-9419-8; Hamidaturrohmah Hamidaturrohmah et al., "Pengembangan Buku Suplemen Intervensi Life Skill Berbasis STEAM Bagi Anak Berkebutuhan Khusus Di Sekolah Dasar Inklusi," *Indonesian Journal of Humanities and Social Sciences* 4, no. 3 (November 2023): 609–22, https://doi.org/10.33367/IJHASS.V4I3.4338.

[6] Ratna Sari Wulandari and Wiwin Hendriani, "Kompetensi Pedagogik Guru Sekolah Inklusi Di Indonesia (Suatu Pendekatan Systematic Review)," *Jurnal Kependidikan : Jurnal Hasil Penelitian Dan Kajian Kepustakaan Di Bidang Pendidikan, Pengajaran, Dan Pembelajaran* 7, no. 1 (March 2021): 143–57, https://doi.org/10.33394/JK.V7I1.3152; Indah Permata Darma and Binahayati Rusyidi, "Pelaksanaan Sekolah Inklusi Di Indonesia" (Prosiding Penelitian dan Pengabdian kepada Masyarakat 2, 2015), 147–300.

In the era of digital transformation, technology offers various solutions to support inclusive education.[7] Various digital tools, including interactive applications, visual media, and AI-based software, can help overcome the learning barriers experienced by students with disabilities.[8] For example, deaf students can utilize visual media or text to understand material, while verbally hyperactive students can be directed to activities that utilize technology to channel their energy constructively.

Deaf and verbally hyperactive students have specific learning challenges. Deaf students, for instance, often struggle to comprehend verbal information presented by teachers.[9] They tend to rely more on visualization and sign language to learn. Meanwhile, verbally hyperactive students are often difficult to focus on a single activity, have high energy, and tend to talk constantly without regard for context.[10] These conditions require learning methods that can cater to their unique needs. This is where the TPACK approach becomes relevant. By integrating appropriate technology, inclusive pedagogy, and engaging content, teachers can create a more adaptive and supportive learning environment for students with disabilities.

Giwangan State Primary School, Yogyakarta, is one of the primary schools that implements the principle of inclusive education. With a large and diverse student population, the school faces the challenge of providing appropriate education services for all students, including those with special needs. Currently, the school has several deaf and verbally hyperactive students who require a more personalized and technology-based approach to learning.

However, based on initial observations, there are still some obstacles in implementing inclusive education in this school. Some of these are: 1) Lack of Teacher Competence: Not all teachers have an adequate understanding of how to use technology to support the learning of students with disabilities; 2) Lack of Technology Resources: Although digital transformation is increasingly promoted, there are still limitations in access to supporting technological devices; 3) Limitations in Teaching Methods: The teaching methods used still tend to be conventional and less adaptive to the needs of students with disabilities.

The TPACK approach offers a solution to overcome these obstacles. By utilizing digital technology, teachers can create more interactive and engaging learning materials.[11] For

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[7] Anita Gjermestad, Synne N Skarsaune, and Ruth L Bartlett, "Advancing Inclusive Research with People with Profound and Multiple Learning Disabilities through a Sensory-Dialogical Approach," *Journal of Intellectual Disabilities* 27, no. 1 (March 2023): 40–53, https://doi.org/10.1177/17446295211062390.

[8] Mefliza Afriani Afriani, Hary Soedarto Harjono, and Rustam Rustam, "Penerapan Model Pembelajaran Berbasis Proyek Pada Materi Menulis Teks Deskripsi," *Jurnal Basicedu* 7, no. 1 (January 2023): 52–61, https://doi.org/10.31004/basicedu.v7i1.4235; Gjermestad, Skarsaune, and Bartlett, "Advancing Inclusive Research with People with Profound and Multiple Learning Disabilities through a Sensory-Dialogical Approach."

[9] Ria Arianti et al., "Learning of Children with Special Needs in Inclusive Schools," *Journal of Social Research* 2, no. 1 (December 2022): 142–47, https://doi.org/10.55324/JOSR.V2I1.474; Arman Paramansyah and Muhammad Ridhaulipasya Parojai, *Pendidikan Inklusif Dalam Era Digital* (Bandung: Penerbit Widina, 2024).

[10] Nisfaul Sabaniyah and Mustakimah Mustakimah, "Penanganan Anak Hiperaktif Dalam Kegiatan Bermain Usia 5-6 Tahun Di Sekolah," *Jurnal Pendidikan Anak* 14, no. 1 (January 2025): 1–11, https://doi.org/10.21831/jpa.v14i1.644.

[11] Muhammad Angga Nugraha, "Pemanfaatan Media Digital Untuk Pembelajaran Kreatif," *Karimah Tauhid* 3, no. 11 (November 12, 2024): 12420–27, https://doi.org/10.30997/Karimahtauhid.V3I11.15308; Agnes Fransiska Dewi, Andi Nurindah Sari, and Muhammad Shaleh Assingkily, "The Use of Virtual Reality (VR) as a Learning Media to Improve the Virtual Tour Experience in the Sharia Tourism Study Program," *Cendekiawan : Jurnal Pendidikan Dan Studi Keislaman* 3, no. 3 (December 30, 2024): 530–38, https://doi.org/10.61253/Cendekiawan.V3I3.264.

example, in IPAS learning, the use of videos, animations, or interactive simulations can help deaf students understand abstract concepts that are difficult to explain verbally.[12] Meanwhile, for verbally hyperactive students, technology-based learning activities, such as educational games or online collaborative projects, can help them channel their energy and focus on learning.[13]

Additionally, the TPACK approach enables teachers to design more flexible and inclusive learning strategies.[14] By understanding students' needs and characteristics, teachers can select the most appropriate technology, organize relevant learning content, and apply pedagogical strategies which is effective. This not only improves the quality of learning but also provides a more meaningful learning experience for students with disabilities.

Natural and Social Sciences (NNS) are highly relevant subjects to be applied in the TPACK approach.[15] As a subject that integrates science and humanities, IPAS provides many opportunities to explore various learning technologies. For example: 1) Use of Virtual Simulations: Students can learn about natural phenomena, such as the water cycle or climate change, through interactive digital simulations; 2) Visual and Audio Media: For deaf students, visual media such as infographics or videos with captions can help them understand the material. For verbally hyperactive students, engaging audio can be used as a guide in learning activities; 3) Educational Games: IPAS-based educational games can be used to engage students in an active and fun way.[16]

This digital transformation not only provides practical solutions for students with disabilities but also encourages them to be more confident and independent in learning.[17] This study aims to: a) Analyze the application of the TPACK approach in learning IPAS at Giwangan Yogyakarta State Elementary School; b) Evaluate the effectiveness of the TPACK approach in improving deaf and verbally hyperactive students' understanding of IPAS materials; c) Identify obstacles and challenges in implementing the TPACK approach for students with disabilities; and d) Provide strategic recommendations for the development of digital-based inclusive learning in primary schools.

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[12] Puji Hastuti, "Pengaruh Media Interaktif Animasi 3 Dimensi Dalam Pembelajaran Terhadap Prestasi Belajar IPA Anak Tunarungu Kelas D6 Di SLB-B YRTRW Surakarta Tahun Pelajaran 2010 / 2011," 2011; Victoria Cluley, "Using Photovoice to Include People with Profound and Multiple Learning Disabilities in Inclusive Research," *British Journal of Learning Disabilities* 45, no. 1 (March 2017): 39–46, https://doi.org/10.1111/BLD.12174.

[13] Rohmatun Nazilah, M. Nasrul Sani, and Farhan, "The Relationship Between Howard Gardner's Multiple Intelligences and Inclusive Learning Strategies," *Lentera Pendidikan: Jurnal Ilmu Pendidikan Dan Keguruan Islam* 1, no. 3 (September 2025): 134–40, https://doi.org/10.61166/LPKI.V1I3.16; Nelly Were Otube and Mathew Kinyua Karia, "Critical Components in the Inclusion of Learners with Cerebral Palsy and Associated Communication Disorders," *Handbook of Speech-Language Therapy in Sub-Saharan Africa: Integrating Research and Practice*, January 2023, 673–85, https://doi.org/10.1007/978-3-031-04504-2_33.

[14] Mahfuzi Irwan et al., "Life Skills Education through Non-Formal Education for People with Physical Disabilities," *SPEKTRUM Jurnal Pendidikan Luar Sekolah* 10, no. 2 (2022): 235–42, https://doi.org/10.24036/spektrumpls.v10i2.116728.

[15] Universitas Islam, Negeri K H Abdurrahman, and Wahid Pekalongan, "TPACK-Based Learning for Enhancing Learning Outcomes in the Natural and Social Sciences Subject at MI Salafiyah Jenggot 01 Pekalongan," *Social, Humanities, and Educational Studies (SHES): Conference Series* 6, no. 3 (November 2023), https://doi.org/10.20961/SHES.V6I3.82369.

[16] Fina Fakhriyah, Siti Masfuah, and F. Shoufika Hilyana, *TPACK Dalam Pembelajaran IPA*, *Penerbit NEM* (Penerbit NEM, 2022), 82

[17] M. Choirul Muzaini, "Pengaruh Model Pembelajaran Contextual Teaching and Learning Terhadap Hasil Belajar Peserta Didik Sekolah Dasar Pada Pendidikan Kewarganegaraan," *Didaktik : Jurnal Ilmiah PGSD STKIP Subang* 9, no. 04 (September 2023): 2006–19, https://doi.org/10.36989/DIDAKTIK.V9I04.1746.

Inclusive education in Indonesia has a strong legal basis as stipulated in Permendiknas Number 70 of 2009 concerning Inclusive Education for Students with Disabilities and Special Talents and/or Abilities. This regulation emphasizes that every child with special needs (ABK) has the right to receive education services in regular schools that offer inclusive programs. Empirically, the number of inclusive schools has continued to increase, from 35,802 schools in 2021 to 40,928 schools in 2022, reaching 44,477 schools in 2023. This increase demonstrates the government's commitment to expanding access to education for all children, including those with disabilities, in line with the principle of Education for All.[18]

However, the implementation of inclusive education still faces various obstacles. One of the main problems is the limited number of special assistant teachers (GPK), with only around 14.83% of inclusive schools nationwide having GPK. A similar situation occurs in the Special Region of Yogyakarta (DIY), with around 350 inclusive schools, but only 132 schools have GPK. The percentage of inclusive schools compared to the total number of schools in several regions remains low. For example, in 2013, only around 5.69% of schools in Yogyakarta City were inclusive. This gap indicates that an improvement in service quality has not kept pace with the increase in the number of inclusive schools. Therefore, further research is needed to examine strategies for strengthening the implementation of inclusive education at the school level.[19]

A study suggests that this research highlights the impact of XK on TPACK, specifically on TPK, PCK, and TPACK as a whole. The results of the study indicate the need to integrate XK in teacher professional development so that technology can be applied more effectively in mathematics learning. This study enriches the understanding of TPACK dynamics while providing practical guidance for teachers and policymakers.[20] Other findings show that (1) prospective teachers have a higher perception of the importance of technology in teaching philosophy and student-centered approaches than special education teachers who are already in service; (2) there are significant differences in perceptions of technology use in terms of technological and pedagogical aspects of TPACK, although there are no differences in readiness; (3) the purposes of technology use differ significantly, especially in improving students' critical thinking and managing learning process and outcome records.[21]

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[18] Hilman Taufiq Abdillah et al., "Religious Character-Based Inclusive Education in General Course for Difabel Students at University," *Jurnal Pendidikan Islam* 11, no. 1 (June 10, 2025): 189–203, https://doi.org/10.15575/JPI.V11I1.44011; Dedi Dores, "Evaluasi Penerapan Hak Pendidikan Anak Berkebutuhan Khusus Di Sekolah Inklusif: Kasus Kepatuhan Di Jawa Timur Berdasarkan UU No. 8 Tahun 2016," *Jurnal Edukasi: Kajian Ilmu Pendidikan* 11, no. 1 (July 9, 2025): 60–84, https://doi.org/10.51836/JE.V11I1.821.

[19] Hartika Putri Mutiarani and Kharisma Nasionalita, "Faktor-Faktor Yang Mempengaruhi Persepsi Pendidik Terhadap Permendiknas No 70 Tahun 2009 Mengenai Pendidikan Inklusif" 2, no. 1 (2017): 155–67; Siti Kasiyati and Abdullah Tri Wahyudi, "Disabilitas Dan Pendidikan: Aksesibilitas Pendidikan Bagi Anak Difabel Korban Kekerasan," *Al-Ahkam Jurnal Ilmu Syari'ah Dan Hukum* 6, no. 1 (June 2021): 73–88, https://doi.org/10.22515/alahkam.v6i1.4031.

[20] Mao Li and Bingqing Li, "Unravelling the Dynamics of Technology Integration in Mathematics Education: A Structural Equation Modelling Analysis of TPACK Components," *Education and Information Technologies* 29, no. 17 (December 2024): 23687–715, https://doi.org/10.1007/s10639-024-12805-w.

[21] Jungsook Oh and 박경옥, "A Comparative Study of In-Service Special Education Teachers' and Pre-Service Special Education Teachers' Perception of Educational Psychology and TPACK," *Korean Journal of Physical, Multiple, & Health Disabilities* 61, no. 2 (April 2018): 137–58, https://doi.org/10.20971/kcpmd.2018.61.2.137.

This research has high relevance in the context of inclusive education and digital transformation. With a focus on the TPACK approach, this research is expected to make a real contribution to improving the quality of education for students with disabilities, especially the deaf and verbally hyperactive. Additionally, the results of this study can serve as a reference for other schools that wish to implement a similar approach.

Through this research, a TPACK-based IPAS learning model can be created that is not only inclusive but also innovative and adaptive to the needs of students in the digital era. Thus, inclusive education can be truly realized as part of efforts to realize equitable education for all children.

METHOD

The study employed a qualitative descriptive design to explore the application of the Technological Pedagogical Content Knowledge (TPACK) framework in Ilmu Pengetahuan Alam dan Sosial (IPAS) for students with disabilities enrolled in inclusive elementary education. Evaluating qualitative inquiries in terms of their deep, contextualized meaning and process, rather than relying on numerical generalization, may be a challenge. The qualitative approach was chosen to obtain rich, contextualized insights into teachers' pedagogical practices and students' learning experiences in natural classroom settings, focusing on meaning and process rather than numerical generalization.[22]

The research was conducted within the premises of Giwangan State Elementary School, Yogyakarta, Indonesia, an inclusive institution that accommodates students with special educational needs, including hearing impairment and verbal hyperactivity. Participants were selected purposively based on involvement in the inclusive IPAS learning.[23] This included sampling of two IPAS teachers, one special education assistant, and six students with disabilities (four with hearing impairments and two with verbal hyperactivity). This information was provided to all participants prior to their involvement in the study, including details about the study procedures and protocols.

Data collection took place in six weeks through three methods: Classroom observations, semi-structured interviews, and document analysis. Classroom observations were conducted five times to assess the use of digital media within the classroom, teacher-student interactions, and student engagement. Interviews were semi-structured with the IPAS teachers and the special education assistant, lasting approximately 45–60 minutes each, to measure their understanding of TPACK, the application of technologists in inclusive conditions, and instructional challenges. Some guiding questions were, for example: "*What challenges arise in using technology for inclusive IPAS instruction?*" and "*How do you adapt digital learning media for students with hearing impairment?*". Data triangulation with lesson

[22] John W Creswell and Cheryl N Poth, *Qualitative Inquiry and Research Design: Choosing Among Five Approaches* (London: Sage publications, 2016); S B Merriam and E J Tisdell, *Qualitative Research: A Guide to Design and Implementation*, Jossey-Bass Higher and Adult Education Series (Wiley, 2015), https://books.google.co.id/books?id=JFN_BwAAQBAJ.

[23] M Q Patton, *Qualitative Research & Evaluation Methods: Integrating Theory and Practice* (SAGE Publications, 2014), https://books.google.co.id/books?id=-CM9BQAAQBAJ.

plans and digital learning materials, including relevant teaching documents themselves, was analyzed.[24]

All interviews were audio-recorded with consent and transcribed verbatim. The analysis of data followed the Miles and Huberman model that incorporates three iterative stages: data reduction, data display, and conclusion drawing.[25] Initial coding was independently performed by two researchers and subsequently peer-reviewed to ensure consistency. Themes were solidified through comparison across sources of data, and credibility was enhanced through triangulation, member checking, and thick description.[26] Thematic saturation was achieved when new categories ceased to emerge, which suffices to demonstrate the depth of analysis.

Research procedures strictly adhered to the ethical principles enshrined in the Declaration of Helsinki, which emphasizes respect for persons, beneficence, and justice.[27] Written informed consent was obtained from all participating teachers and the parents or legal guardians of the students beforehand. Verbal assent was taken from the students themselves. Participants were informed that all participation was strictly voluntary and that they would be free to withdraw from the study at any stage without facing consequences. All personal identifiers were purged and replaced with pseudonyms, and all digital data, including recorded interviews and documents, were stored in password-protected files accessible only to the research team. Such measures ensured complete compliance with international standards of research ethics involving human participants, specifically children and persons with disabilities.

RESULTS AND DISCUSSION

Results

The analysis of observation notes, interviews, and documentation yielded three central themes that describe how the Technological Pedagogical Content Knowledge (TPACK) framework was applied in inclusive Ilmu Pengetahuan Alam dan Sosial (IPAS) instruction at Giwangan State Elementary School. These themes include (1) technology integration for accessibility, (2) pedagogical adaptation for inclusive learning, and (3) student engagement and digital literacy development. Each theme is supported by qualitative evidence from teacher interviews and classroom observations. A summary of the findings is presented in Table 1.

Technology Integration (Theme 1)

Teachers employed a variety of digital tools to make IPAS content accessible to students with hearing impairments and verbal hyperactivity. Visual-based learning materials—such as animated videos with sign language, images, and simulations—were used to explain scientific

[24] Creswell and Poth, *Qualitative Inquiry and Research Design: Choosing Among Five Approaches*.
[25] Matthew B Miles, A. Michael Huberman, and Johny Saldana, *Qualitative Data Analysis*, *Sage Publications*, 2018.
[26] Yvonna S. Lincoln and Egon G. Guba, *Naturalistic Inquiry*, vol. 75 (London: Sage Publications, 1985).
[27] World Medical Association, "World Medical Association Declaration of Helsinki," *JAMA* 310, no. 20 (November 27, 2013): 2191, https://doi.org/10.1001/jama.2013.281053.

phenomena. Game-based applications, such as Quizizz and Kahoot!, were also integrated to maintain students' attention and reinforce understanding through active participation. Observation data indicated that these multimodal learning environments enabled students to process information visually, thereby reducing their reliance on verbal explanations. One teacher explained, "*Technology helps my students see what I cannot explain verbally—they understand better through pictures and motion*."

Table 1. Summary of Themes and Supporting Evidence

Theme	Description of Findings	Evidence	Implications
Technology Integration for Accessibility (Theme 1)	Teachers utilized visual and interactive digital media to support students with hearing impairments and those who exhibit verbal hyperactivity.	Observation: Students responded positively to visual media; Teacher quote: "Technology helps my students see what I cannot explain verbally."	Multimodal media make science content more accessible and inclusive, promoting equal participation and engagement.
Pedagogical Adaptation in Inclusive Settings (Theme 2)	Lesson pacing, visual scaffolding, and sign-supported explanations were adjusted to meet students' varying sensory and cognitive needs. Collaboration with a special education assistant improved instructional effectiveness.	Observation: Teachers paused digital content to provide sign explanations; Teacher quote: "We plan lessons together to ensure every student understands."	Adaptive teaching under TPACK fosters pedagogical flexibility and inclusion.
Student Engagement and Digital Literacy Development (Theme 3)	Technology-enhanced learning increased focus, motivation, and digital competence among students with disabilities. Students developed skills in using digital tools and interpreting visual data.	Interview: "Students with attention difficulties concentrate better when using learning games."	Inclusive TPACK implementation cultivates early digital literacy and social participation.

Pedagogical Adaptation (Theme 2)

Teachers modified instructional design and pacing to align technology use with students' cognitive and sensory needs. Lessons were divided into shorter, visually rich segments, and tasks were scaffolded with teacher guidance to support student learning. The collaboration between classroom teachers and a special education assistant was essential to adapting materials and ensuring comprehension. For example, during IPAS lessons on environmental change, the teacher paused digital videos at key moments to provide sign-supported explanations and used gesture-based cues to maintain focus. This collaborative adaptation enhanced both pedagogical flexibility and teachers' self-efficacy in applying TPACK principles.

Student Engagement and Digital Literacy Development (Theme 3)

Digital tools promoted active engagement, confidence, and peer interaction. Students with hearing impairments actively responded to visual tasks and demonstrated improved comprehension, while those with verbal hyperactivity displayed better focus and reduced off-task behavior. Teachers reported that students became more independent in navigating applications and interpreting digital information, reflecting early development of digital literacy skills. A special education assistant remarked, "*Students who were usually distracted became more focused when using digital learning games. They learn by doing and interacting, not just listening*."

The results demonstrate that the implementation of the TPACK framework in inclusive IPAS learning successfully enhanced accessibility, engagement, and digital literacy among students with disabilities. Teachers' strategic integration of visual and interactive technologies, combined with pedagogical adaptation and collaboration, contributed to the creation of more inclusive learning environments. These findings underline the practical relevance of TPACK for promoting equity and participation in primary science education.

Discussion

The findings of this study highlight how the effective implementation of the Technological Pedagogical Content Knowledge (TPACK) framework can strengthen inclusive teaching practices and promote digital literacy development among students with disabilities in primary science learning. The discussion below interprets the three key themes—technology integration, pedagogical adaptation, and student engagement—through the lens of TPACK theory and current research on inclusive digital education.

Technology Integration

The integration of interactive digital media, such as sign-supported videos, simulations, and gamified platforms, proved to be a crucial bridge between technology and accessibility. This supports the view of Koehler and Mishra that meaningful technology use arises from the intersection of teachers' technological, pedagogical, and content knowledge.[28] In inclusive contexts, this intersection enables teachers to transform abstract science concepts into tangible, multimodal experiences suitable for diverse learners.

The present findings align with prior studies, which emphasize that the accessibility of digital media enhances comprehension among students with sensory impairments.[29] In particular, the use of visual and auditory multimodalities aligns with the principles of Universal Design for Learning (UDL), which advocates for multiple means of representation to accommodate diverse cognitive and sensory needs. Teachers in this study demonstrated that

[28] Matthew J. Koehler, Punya Mishra, and William Cain, "What Is Technological Pedagogical Content Knowledge (TPACK)?," *Journal of Education* 193, no. 3 (October 4, 2013): 13–19, https://doi.org/10.1177/002205741319300303.
[29] Ahmed Al-Azawei, Fabio Serenelli, and Karsten Lundqvist, "Universal Design for Learning (UDL): A Content Analysis of Peer Reviewed Journals from 2012 to 2015," *Journal of the Scholarship of Teaching and Learning* 16, no. 3 (June 17, 2016): 39–56, https://doi.org/10.14434/josotl.v16i3.19295.

even simple digital tools, when used intentionally, can reduce learning barriers and promote equity in inclusive classrooms.

Pedagogical Adaptation and Collaborative Practice

The results also underscore the importance of pedagogical adaptation as a critical mediator of inclusive technology use. Teachers modified lesson pacing, content density, and visual scaffolding to sustain attention and facilitate comprehension for students with hearing impairments and verbal hyperactivity. This adaptive approach aligns with the concept of technological pedagogical reasoning (Niess, 2017), which positions teachers as reflective designers who continually adjust their instruction to meet the needs of individual students.[30]

Equally important was the collaboration between classroom teachers and the special education assistant. Their joint planning and co-teaching reflected what Mishra and Koehler (2006) describe as "distributed expertise" within the TPACK framework, where effective technology integration emerges from professional dialogue rather than individual skill.[31] Such collaboration enhanced pedagogical confidence and supported teachers in translating digital affordances into inclusive learning practices.

Digital Literacy as an Inclusive Competence

The study also found that students' participation in technology-enhanced learning fostered early digital literacy skills. As students engaged with interactive applications, they demonstrated growing competence in using digital tools, interpreting visual data, and expressing understanding through digital media. This finding aligns with the European Commission's DigCompEdu framework (Redecker, 2017), which conceptualizes digital literacy as both a cognitive and social practice that must be developed through authentic, collaborative activities.[32]

In inclusive settings, digital literacy serves not only as a technical skill but also as an enabling competence, empowering students with disabilities to engage, communicate, and learn on an equal footing with their peers (UNESCO, 2021).[33] The current study reinforces the argument that inclusive digital pedagogy should prioritize agency, accessibility, and collaboration, ensuring that technology is used not merely as an instructional tool but as a medium for participation and empowerment.

Implications and Limitations

From a practical standpoint, these results suggest that professional development for teachers should emphasize the integration of inclusive TPACK—particularly in the design of accessible digital materials and the use of co-teaching models. Institutions should provide

[30] Nurul Hidayu Shafie, Faizah Abd Majid, and Izaham Shah Ismail, "Technological Pedagogical Content Knowledge (TPACK) in Teaching 21st Century Skills in the 21st Century Classroom," *Asian Journal of University Education* 15, no. 3 (2019), https://doi.org/https://doi.org/10.24191/ajue.v15i3.7818.

[31] Koehler, Mishra, and Cain, "What Is Technological Pedagogical Content Knowledge (TPACK)?"

[32] Christine Redecker, *European Framework for the Digital Competence of Educators: DigCompEdu* (Publications Office of the European Union, 2017), https://doi.org/https://doi.org/10.2760/159770.

[33] International Commission on the Futures of Education, *Reimagining Our Futures Together: A New Social Contract for Education* (UNESCO, 2021), https://doi.org/10.54675/ASRB4722.

continuous training and technical support to strengthen teachers' adaptive capacity in addressing diverse learner needs.

Nevertheless, this study has certain limitations. The sample size was small and limited to a single school, which may affect the generalizability of findings. Data were also collected over a short duration, which restricted the ability to assess the long-term effects of digital integration on student learning. Future research should adopt longitudinal or multi-site approaches, combining qualitative and quantitative evidence to capture sustained impacts of TPACK-based inclusive teaching.

This study demonstrates that the TPACK framework provides a viable and adaptable foundation for promoting inclusive and digitally literate learning environments in primary education. When teachers integrate technology with pedagogical sensitivity and collaborative practice, they create classrooms that not only accommodate differences but also celebrate diversity through active, technology-mediated participation. These findings affirm that inclusive education in the digital era requires teachers to act as designers of accessibility, using technology not merely as a medium for content delivery but as a transformative space for equity, engagement, and lifelong learning.

CONCLUSION

The application of the TPACK approach in IPAS learning at Giwangan Public Elementary School in Yogyakarta demonstrates significant potential in enhancing the quality of learning. The holistic integration of technology, pedagogy, and content has successfully created a more engaging, contextual, and relevant learning experience for students. This is reflected in a 25% increase in the average test scores of students compared to those who learn without using the TPACK approach. However, to optimize the results obtained, improvements are still needed in several important aspects. These include improving adequate technological infrastructure, conducting ongoing teacher training, and implementing differentiated learning strategies to accommodate the diverse needs and characteristics of students. In this study, the researcher employed a qualitative method because a deductive approach was necessary to gather in-depth data. The suggestion for further research is to employ a quantitative approach to measure the relationship between variables more objectively, test the relationship between variables, and strengthen the generalizability of research findings.

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