CURRENT ACADEMIC STUDIES IN EDUCATION AND TECHNOLOGY

EDITORS
Dr. Mehmet Özkaya
Dr. Selahattin Alan

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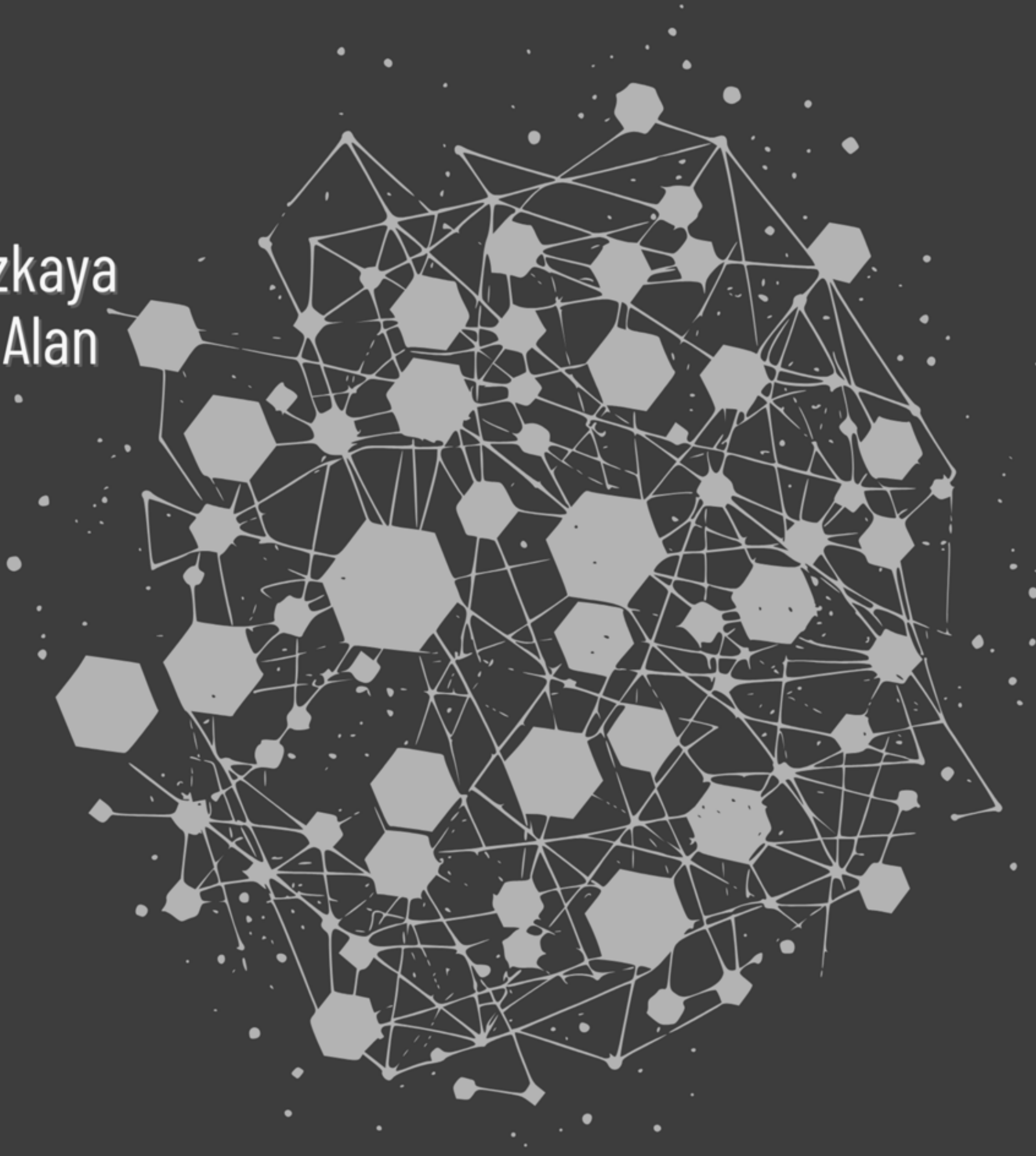

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Review Process

Any paper submitted for the book chapter is reviewed by at least two international reviewers with expertise in the relevant subject area. Based on the reviewers' comments, papers are accepted, rejected, or accepted with revision. If the comments are not addressed well in the improved paper, then the paper is sent back to the authors to make further revisions. The accepted papers are formatted by the conference for publication in the proceedings.

About the Book

The rapid expansion of digital technologies continues to reshape educational theory, practice, and research across diverse contexts. *Current Academic Studies in Education and Technology* brings together peer-reviewed scholarly chapters that examine contemporary issues at the intersection of technology and education, with a particular focus on STEM and STEAM education, technology-enhanced learning, sustainability, digital transformation, and interdisciplinary perspectives. This edited book includes contributions from international authors based in Finland, Italy, Indonesia, Morocco, Türkiye, and United States of America.

Current Academic Studies in Education and Technology consists of eight chapters, each addressing a distinct yet interconnected dimension of technology and education. The chapters explore themes such as collective support structures in STEM education, sustainability-oriented STEAM practices, individual differences in technology-enhanced learning, digital transformation in education and finance, non-STEM approaches to technology education, and global research trends in youth participation. Together, these contributions provide theoretical and empirical insights into current challenges and emerging directions in the field.

Citation

Özkaya, M., & Alan, S. (Eds.). (2025). *Current Academic Studies in Education and Technology*. ISRES Publishing.

Foreword

The accelerating pace of technological change continues to redefine how education is conceptualized, designed, and experienced across the globe. From technology-enhanced learning environments to interdisciplinary STEM and STEAM practices, contemporary educational systems are increasingly shaped by digital transformation, data-driven approaches, and evolving societal expectations. Within this dynamic landscape, scholarly inquiry plays a critical role in interpreting change, questioning assumptions, and guiding sustainable and equitable educational practices. *Current Academic Studies in Education and Technology* brings together a carefully selected collection of peer-reviewed chapters that reflect the diversity, complexity, and interconnectedness of current research at the intersection of technology and education. The contributions in this book address a wide range of themes, including collective and informal support structures in STEM education, sustainability-oriented educational practices, individual differences in technology-enhanced learning, non-STEM approaches to technology education, digital transformation across sectors, and global research trends related to youth participation and engagement. What unites these chapters is not a single methodology or disciplinary lens, but a shared commitment to examining how technological developments influence learning processes, instructional design, institutional structures, and broader social contexts. The authors approach technology not merely as a tool, but as a dynamic component of educational ecosystems—one that interacts with pedagogy, culture, policy, and human agency. This book is intended for researchers, educators, graduate students, and policymakers seeking informed and critical perspectives on contemporary issues in technology and education. By combining theoretical discussions, empirical findings, and systematic analyses, the book aims to contribute to ongoing international dialogue and to support reflective practice in both research and educational settings. We extend our sincere appreciation to the contributing authors and reviewers whose scholarly rigor and collaboration have made this book possible. It is our hope that *Current Academic Studies in Education and Technology* will serve as a valuable academic resource and inspire further research and innovation in the field.

December 2025

Dr. Mehmet Özkaya

Dr. Selahattin Alan

Dedication

This book is dedicated by its editors to all children, in recognition of the fact that scholarly work in technology and education - including research on emerging artificial intelligence - shapes how learning is understood, designed, and examined across diverse contexts.

December 2025
Editors

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Chapter I

Silent Solidarity in STEM Education: Collective Support Networks in Constrained, Technology-Rich Elementary School Systems

Candace M. Smith

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To Cite This Chapter

Smith, C. M. (2025). Silent solidarity in stem education: collective support networks in constrained, technology-rich elementary school systems. In M. Ozkaya, & S. Alan (Eds.), *Current Academic Studies in Education and Technology* (pp. 1-14). ISRES Publishing

Chapter Highlights

This chapter examines how elementary teachers navigate the expanding expectations of STEM education while working within systems marked by limited resources, shifting technologies, and competing instructional pressures. Drawing on systems thinking and teacher experiences, it highlights the quiet but powerful forms of collective support that enable educators to sustain innovation in technology-enhanced learning environments. The Chapter Highlights below outline the central themes, findings, and implications that frame this work.

- **STEM Instruction Within Constrained Systems** – Elementary teachers navigate increasing expectations to implement robotics, coding, AI tools, digital platforms, and engineering design within environments shaped by accountability pressures, shifting technological demands, and limited resources.
- **Silent Solidarity as a Support Mechanism** – Teachers develop quiet, informal networks that provide emotional reassurance, digital troubleshooting, shared resources, and encouragement, all of which are key elements that sustain STEM innovation despite systemic constraints.
- **The Role of Systems Thinking in STEM Reform** – STEM adoption is influenced by interconnected factors, including school culture, infrastructure, leadership,

collaboration time, professional trust, and teachers' shared beliefs, which reinforces the need to understand STEM implementation as a systems-level process.

- **Formal and Informal Structures Supporting STEM** – Professional learning communities, leadership teams, and committees provide structural backing for STEM work, while teacher-initiated networks fill gaps through spontaneous collaboration, mentoring, and sharing of digital instructional tools.
- **Impact on STEM Instructional Practice** – Collective support enables teachers to experiment with unfamiliar technologies, integrate interdisciplinary STEM concepts, troubleshoot digital issues, and advocate for equitable device access, ultimately enhancing instructional quality.
- **Barriers to Technology-Enhanced STEM Learning** – Standardized testing, limited planning time, inequitable device distribution, insufficient technical support, and inconsistent STEM-specific professional development act as systemic barriers to effective STEM implementation.
- **Implications for Leaders and Future Directions** – Sustainable STEM reform requires coordinated systems thinking, psychological safety for experimentation, recognition of informal teacher leadership, investment in digital equity, and protected time for interdisciplinary collaboration.

Introduction

Elementary teachers are at the center of the national push to expand science, technology, engineering, and mathematics (STEM) education and to integrate digital tools into everyday instructional practice. Schools are increasingly expecting teachers to incorporate robotics, coding, simulation tools, digital assessment platforms, artificial intelligence (AI) applications, and engineering design tasks, while simultaneously responding to heightened accountability systems and rapidly changing learning environments (Apple et al., 2023). The pandemic intensified these pressures, as teachers navigated unfamiliar technologies, shifting instructional formats, and new expectations around digital learning. Kim and Asbury (2020) note that "the speed at which schools and teachers were required to enact major operational and emotional changes led to a strong emphasis on uncertainty" (p. 1071). Today, that same uncertainty continues to shape how teachers implement STEM instruction within constrained systems (Giroux, 1986; Giroux, 1997; Ravitch, 2010).

Despite these challenges, teachers consistently demonstrate resilience, adaptability, and creativity. While much is known about the importance of professional collaboration in supporting these qualities (Kim & Asbury, 2020), far less is understood about how teachers create informal, organic support networks that help them manage the demands of STEM integration and technology-enhanced teaching. This mixed-methods study addresses that gap by examining how elementary teachers develop and maintain collective support networks, what participants repeatedly described as silent solidarity, within restrictive educational environments (Giroux & McLaren, 1989).

Silent solidarity refers to the quiet, often unseen ways teachers support one another, such as sharing digital resources, troubleshooting devices, reinforcing colleagues who advocate for student-centered decisions, and offering emotional support in the face of complex STEM initiatives. Through the lens of systems thinking (Garipagaoglu, 2023; Senge et al., 2023), these networks reveal how teachers create adaptive, relational infrastructures that sustain STEM innovation even when formal structures fall short. In an era defined by digital transformation and increasing STEM expectations, understanding these networks is crucial for creating sustainable and equitable instructional environments.

Theoretical Framework: Systems Thinking and STEM Innovation

The systems thinking framework provides a powerful lens for interpreting STEM implementation in elementary schools. Garipagaoglu (2023) describes education as "one BIG elephant," a complex and interconnected system that cannot be understood by examining its parts in isolation (p. 126). This metaphor is particularly relevant to STEM education, which requires teachers to integrate interdisciplinary content, digital technologies, engineering design, and inquiry-driven approaches within the broader constraints of school systems (Apple et al., 202; Lotter, et al, 2021). Senge et al. (2023) emphasize that systems thinking helps educators understand "interdependence and change" (p. 8), enabling them to respond effectively to the forces shaping instructional practice. In the context of STEM, this means recognizing that technology adoption is not merely a technical matter. It is shaped by:

- school culture,
- access to devices and infrastructure,
- teacher relationships,
- leadership practices,
- professional trust,

- time for collaboration, and
- shared beliefs about innovation and student learning (Giroux & McLaren, 1989; Ravitch, 2010).

A science, technology, engineering, and mathematics construct transformation cannot occur unless the surrounding ecosystem supports risk-taking, experimentation, and interdisciplinary planning (Lotter et al., 2021). Apple et al. (2023) similarly argue that systemic conditions, such as policy mandates, organizational structures, and uneven resource distribution, strongly influence educators' capacity to enact innovative instructional practices. Silent solidarity thus becomes a systems-level phenomenon: a way teachers collectively respond to pressures and gaps within the system by forming relational structures that enable them to implement STEM practices (Giroux, 1997). Together, these interconnected conditions illustrate that STEM implementation is never the result of a single factor but rather the cumulative effect of multiple systemic influences acting in concert. To clarify how these forces operate within elementary school environments, Table 1 outlines the key systemic factors that shape teachers' capacity to integrate STEM and technology-enhanced instruction (Apple et al., 2023).

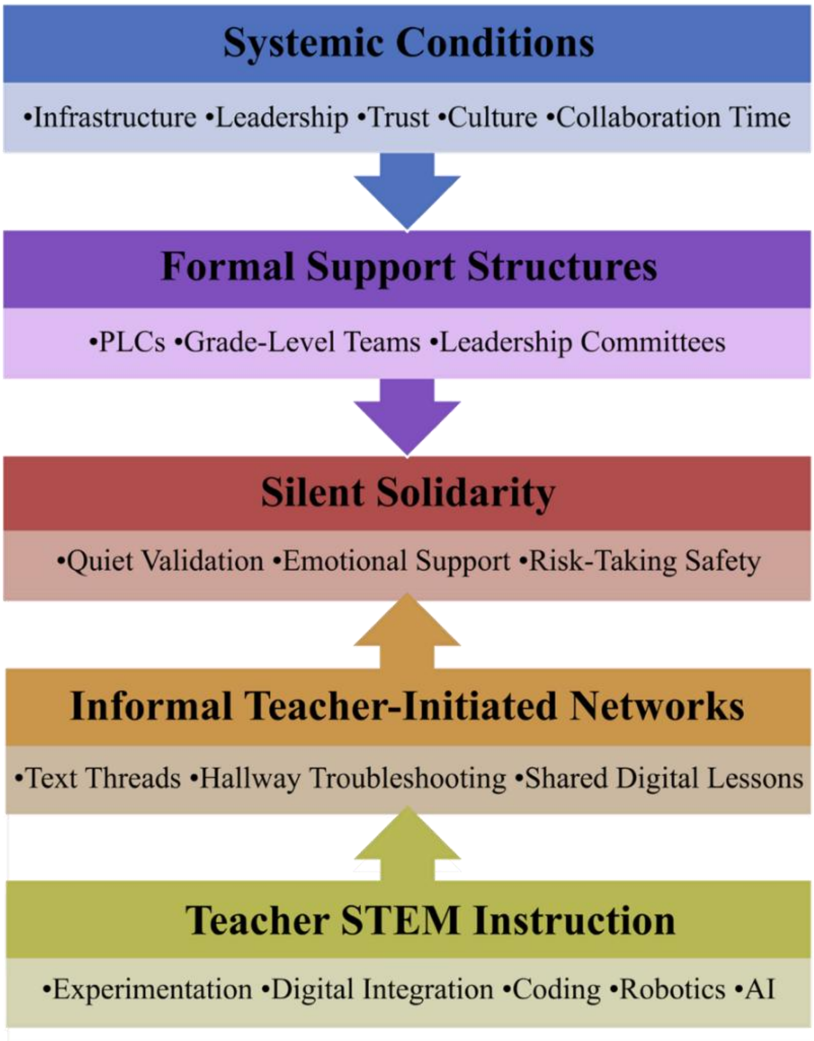
Table 1. Systemic Factors Influencing STEM Implementation in Elementary Schools

Systemic Factor	Description	Relevance to STEM Implementation
Infrastructure and Device Access	Availability of devices, bandwidth reliability, and technical support resources.	Determines feasibility of using robotics kits, coding platforms, simulations, AI tools, and digital assessments.
Leadership Practices	Administrative expectations, clarity of communication, and responsiveness to teacher needs.	Shapes teachers' confidence in experimenting with new technologies.
Professional Trust	Trust among colleagues and leadership.	Supports psychological safety required for innovation.
Collaboration Time	Scheduled opportunities for co-planning and problem solving.	Enables interdisciplinary STEM planning and troubleshooting.
School Culture	Norms surrounding risk-taking, innovation, and collaboration.	Influences willingness to adopt emerging STEM tools.
Teacher Beliefs About Innovation	Educators' internalized views on STEM and digital learning.	Shapes lesson design and persistence with STEM challenges.

Systems Model

The following systems model illustrates how silent solidarity functions as an adaptive, relational support structure within technology-rich elementary STEM environments. Figure 1 illustrates the interaction between systemic conditions (infrastructure, leadership, professional trust, and school culture), formal structures (PLCs, teams, and committees), informal networks (sharing, troubleshooting, and mentoring), and the central phenomenon of silent solidarity. Arrows demonstrate how these components collectively influence STEM instructional practices and teacher capacity for innovation.

Figure 1. Systems Model



Literature Review

Collective Teacher Efficacy and Collaboration

Collective teacher efficacy is widely recognized as a key driver of school improvement and teacher resilience. Preston and Donohoo (2021) argue that leaders who create structures for meaningful collaboration empower teachers to challenge ineffective initiatives and engage in deep professional inquiry. However, they also note that teachers often maintain "a culture of nice" that discourages open confrontation about instructional practices (p. 29). This dynamic can limit innovation, particularly in STEM, where teachers must confront new pedagogies, unfamiliar technologies, and interdisciplinary approaches.

Hargreaves and Fullan (2012) reinforce the idea that teacher collaboration is essential to high-quality instruction, describing *professional capital* as a collective endeavor involving shared expertise, continuous improvement, and deep professional knowledge. Implementing STEM requires these conditions, as teachers must integrate concepts across disciplines and navigate complex technologies.

Technology Integration and Digital Instruction

Technology-enhanced learning has become a defining element of modern STEM education. Digital learning platforms, coding and robotics tools, virtual simulations, AI-powered adaptive programs, digital science notebooks, augmented reality applications, and collaborative data dashboards are increasingly embedded in elementary classrooms. However, many teachers lack sufficient professional development to use these tools effectively or to align them with standards.

Research consistently shows that teachers rely heavily on colleagues (not formal training) to learn, troubleshoot, and refine digital instructional practices. Informal collaboration emerges as a primary mechanism for resolving technical problems, sharing instructional resources, and integrating digital tools effectively into STEM lessons.

STEM Integration as Interdisciplinary Practice

True STEM education requires interdisciplinary thinking, where science, mathematics, engineering, and technology are connected through real-world problem solving. This type of instruction demands collaboration, collective creativity, and shared planning. Teachers must coordinate lessons, co-develop engineering design challenges, and align digital resources across subjects. Informal networks of support enable these connections to flourish.

Systemic Constraints and Barriers

Teachers continue to navigate structural constraints, including:

- standardized testing pressures,
- limited planning time,
- inequitable device distribution,
- insufficient technical support,
- lack of STEM-specific PD,
- scripted curricula, and
- rigid pacing calendars.

Rose (2009) critiques how overemphasis on standardized tests can "limit the development of competence" by narrowing instruction toward test preparation rather than inquiry-based STEM learning (p. 103). These systemic pressures make silent solidarity essential: it becomes the mechanism through which teachers support one another to preserve student-centered, technology-rich STEM learning.

Methodology

This study employed a mixed-methods research design to investigate how elementary teachers perceive collective support for understanding the context of STEM and digital instructional demands. Twenty-six K-5 teachers from suburban Chicago districts completed an online survey, and three participants participated in follow-up interviews. Survey items included Likert-scale questions on collaboration and open-ended prompts addressing experiences with digital tools, resource sharing, and professional support. Interviews provided deeper insight into collective support behaviors, technology-related challenges, and STEM instructional practices. Qualitative data were coded using ATLAS.ti Web Educational. The analytic process involved data familiarization, thematic coding, cross-referencing of survey and interview findings, and triangulation of results with the literature. Ethical considerations included obtaining informed consent, maintaining confidentiality, and de-identifying participant data. The research approach aligned with systems thinking by centering on the relationships, informal structures, and collaborative processes that shape teacher experience.

Findings

Silent Solidarity: Quiet Support for STEM Innovation

Silent solidarity emerged as a dominant theme in teachers' descriptions of how they navigate technology-enhanced STEM instruction. One participant explained:

"They're behind me, even if they don't say it out loud."

Teachers described feeling supported by colleagues who quietly validated their decisions, especially when experimenting with new digital tools or advocating for STEM-related changes. This quiet backing allowed teachers to take instructional risks without feeling isolated.

Silent solidarity manifested through:

- quiet emotional support when technology failed,
- unspoken agreements about sharing digital resources,
- colleagues privately expressing alignment with STEM-related concerns raised in meetings,
- experienced teachers encouraging newer colleagues to attempt engineering lessons or coding tasks.

For many teachers, silent solidarity functioned as a shield against fear of retaliation, particularly for untenured educators concerned about appearing incompetent with technology.

Formal Structures Supporting STEM Collaboration

Teachers identified several formal organizational structures that supported technology and STEM integration:

- Professional learning communities focusing on digital strategies,
- Grade-level teams co-planning engineering design activities,
- Union committees advocating for equitable device access,
- School leadership teams coordinating STEM initiatives,
- Curriculum committees evaluating digital tools.

However, teachers emphasized that formal structures often addressed surface-level needs and did not consistently provide the depth of support needed for rapid STEM implementation.

Informal, Teacher-Initiated Networks

Informal networks were described as the most effective mechanism for sustaining digital and STEM innovation. Teachers shared:

- digital simulations and coding lessons,
- troubleshooting strategies for devices and platforms,
- engineering design tasks that worked well in their classrooms,
- emotional support after failed STEM lessons,
- mentorship related to specialized STEM tools (e.g., robotics kits, AI programs).

These networks arose organically and operated through text threads, hallway conversations, after-school sessions, and spontaneous problem-solving moments. Teachers repeatedly described how experienced colleagues provided guidance for integrating technology into science and math lessons. These informal interactions worked in tandem with more structured supports to create a layered system of collaboration around STEM and technology integration. Table 2 summarizes the formal and informal support structures teachers identified and illustrates how each contributed to sustaining innovation in their classrooms.

Table 2. Formal and Informal Teacher Support Structures for STEM and Technology Integration

Type of Support	Description	Examples from Study	Impact on STEM Instruction
Formal Structures	Organizational systems designed to support instruction.	PLCs focused on digital tools; committees on device equity.	Provides structure and baseline consistency.
Grade-Level Teams	Scheduled meetings with shared instructional goals.	Co-planning engineering challenges; aligning digital notebooks.	Supports interdisciplinary coherence.
Informal Networks	Spontaneous, teacher-driven collaboration.	Hallway troubleshooting; shared simulations; mentoring.	Encourages experimentation and sustained innovation.
Silent Solidarity	Quiet relational support.	Private validation; emotional reassurance.	Enhances psychological safety for STEM risk-taking.

Collective Advocacy for Digital Equity and STEM Access

Teachers utilized collective support to advocate for the equitable distribution of devices, updated STEM materials, and enhanced infrastructure. Silent solidarity strengthened this advocacy by ensuring that vocal teachers knew they had others behind them. One teacher described feeling empowered to speak out because colleagues privately affirmed her concerns about resource inequities. Even with these collective efforts, teachers continued to encounter persistent barriers that limited the depth and consistency of STEM integration in their classrooms. These challenges revealed the structural constraints that collective support alone could not fully overcome. Table 3 outlines the primary obstacles identified by participants and illustrates how these systemic barriers shaped their daily instructional decisions.

Table 3. Barriers to Technology-Enhanced STEM Instruction Identified by Teachers

Barrier	Description	Representative Experience	Implications for Practice
Standardized Testing Pressures	High-stakes testing reduces inquiry-based STEM time.	STEM lessons pushed out during testing periods.	Narrows instructional opportunities for engineering tasks.
Limited Planning Time	Insufficient time for interdisciplinary STEM work.	Teachers report learning tools on personal time.	Slows adoption and reduces implementation quality.
Inequitable Device Distribution	Uneven access to functioning devices.	Some classes lacked devices for coding or simulations.	Creates inconsistent learning experiences.
Insufficient Technical Support	Limited staff or slow response to tech issues.	Unresolved device failures disrupt lessons.	Discourages continued digital tool use.
Lack of STEM-Specific PD	Training often too general or infrequent.	Teachers felt unprepared for coding/engineering platforms.	Increases anxiety and limits fidelity.
Scripted Curricula & Rigid Pacing	Mandated pacing limits STEM exploration.	Little room for engineering design tasks.	Restricts interdisciplinary problem-solving.

Discussion

Silent solidarity plays a critical role in enabling teachers to adopt and sustain STEM instructional practices. Technology integration requires experimentation, persistence, and resilience, qualities that are difficult to maintain without psychological safety and professional trust. In constrained systems, where fear of evaluation or misunderstanding is pervasive, teachers rely on subtle but powerful forms of mutual support.

Systems thinking highlights how these networks operate as adaptive structures within the larger educational system. When formal supports fall short, teachers create their own relational infrastructures to navigate complexity. These networks improve digital implementation by:

- diffusing expertise across teams,
- reducing individual risk-taking pressure,
- enhancing teacher confidence with unfamiliar technologies,
- building capacity for interdisciplinary STEM instruction,
- amplifying teacher voice in decision-making.

Silent solidarity is not passive; it is an active, strategic, professional response to systemic constraints.

Implications for STEM Schools and Digital Transformation

The findings suggest several implications for school leaders and policymakers:

1. **Prioritize protected time for STEM collaboration.**
   STEM integration requires interdisciplinary planning and shared digital learning.
2. **Leverage informal teacher leadership.**
   Schools should recognize teachers who naturally mentor others in technology use.
3. **Invest in digital equity and infrastructure.**
   Collective support cannot compensate for insufficient devices or unreliable systems.
4. **Cultivate psychological safety.**
   Teachers must feel safe taking instructional risks essential for digital and STEM innovation.
5. **Adopt a systems thinking approach.**
   STEM reform requires coordinated structures, consistent PD, and supportive leadership—not isolated expectations.

Conclusion

Silent solidarity, teachers' quiet, behind-the-scenes support, plays a foundational role in sustaining STEM and technology-enhanced learning in elementary schools. In systems characterized by uncertainty, rapid change, and resource inequities, these networks empower teachers to take calculated risks, share expertise, troubleshoot challenges, and advocate for their students. STEM transformation depends not only on devices or digital tools but on the collective strength, resilience, and relational capacity of teachers.

As schools expand STEM initiatives and further integrate digital tools into instruction, educational leaders must create conditions that value teacher collaboration, support risk-taking, and honor the systems-level contributions teachers make through silent solidarity. Understanding and nurturing these networks is critical for creating sustainable, equitable, and innovative STEM learning environments.

References

Apple, M. W., Au, W., & Gandin, L. A. (2023). The Routledge handbook of critical education. Routledge.

Garipagaoglu, B. C. (2023). Systems thinking in education: A paradigm for effective teaching and learning. In S. Dulay (Ed.), Empowering educational leaders: How to thrive in a volatile, uncertain, complex and ambiguous world (pp. 115-130). Peter Lang.

Giroux, H. A. (1986). Radical pedagogy and the politics of student voice. Interchange, 17(1), 48-69. https://doi.org/10.1007/bf01811018

Giroux, H. A. (1997). Pedagogy and the politics of hope: Theory, culture, and schooling: A critical reader. Westview Press.

Giroux, H. A., & McLaren, P. (1989). Introduction: Schooling, cultural politics, and the struggle for democracy. In H. A. Giroux & P. McLaren (Eds.), Critical pedagogy, the state, and cultural struggle (pp. xi-xxxv). State University of New York Press.

Hargreaves, A., & Fullan, M. (2012). Professional capital: Transforming teaching in every school. Teachers College Press.

Kim, L. E., & Asbury, K. (2020). 'Like a rug had been pulled from under you': The impact of COVID-19 on teachers in England during the first six weeks of the UK lockdown. British Journal of Educational Psychology, 90(4), 1062-1083. https://doi.org/10.1111/bjep.12352

Lotter, C. R., Thompson, S., Dickenson, T. S., & Rea, M. (2023). Impact of teacher leadership training on elementary teachers' instructional practices and student engagement. Teaching and Teacher Education, 12(1).

Preston, B. C., & Donohoo, J. (2021). It's not collective efficacy if it's easy. Educational Leadership, 79(3), 27-31.

Ravitch, D. (2010). The death and life of the great American school system: How testing and choice are undermining education. Basic Books.

Rose, M. (2009). Why school? Reclaiming education for all of us. The New Press.

Senge, P., Cambron-McCabe, N., Lucas, T., Smith, B., & Dutton, J. (2023). Schools that learn: A fifth discipline fieldbook for educators, parents, and everyone who cares about education (Updated ed.). Crown Business.

About the Author

Candace M. Smith, Ed.D., is an Assistant Professor in the College of Education and Human Development at Governors State University in the United States and a former elementary teacher, assistant principal, and principal with more than twenty years of experience in PK–5 education. Her professional work spans urban and suburban school contexts, including Chicago Public Schools and leadership in North Lawndale, grounding her scholarship and teaching in the lived realities of elementary educators. Dr. Smith teaches coursework in STEAM education and researches STEAM pedagogy, with particular attention to how interdisciplinary, technology-rich learning environments shape instructional decision-making and teacher collaboration. Her scholarship centers on teacher empowerment, professional trust, collective support networks, and leadership structures that influence instructional autonomy in constrained educational systems. Through mixed-methods research, she examines how educators navigate post-pandemic demands, professional development, and systemic accountability while sustaining forms of "silent solidarity" that support both instructional practice and professional identity. In addition to her academic work, Dr. Smith serves as an educational consultant, partnering with schools to design leadership pathways and professional learning structures that honor teacher expertise and voice.

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Chapter II

Aquaponics, Rainwater Harvesting, and Urban Farming as a STEAM Construct for Early Childhood Through Higher Education

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To Cite This Chapter

Dignam, C. (2025). Aquaponics, rainwater harvesting, and urban farming as a steam construct for early childhood through higher education. In M. Ozkaya, & S. Alan (Eds.), *Current Academic Studies in Education and Technology* (pp. 15-37). ISRES Publishing

Chapter Highlights

This chapter explores aquaponics, rainwater harvesting, and urban farming as interconnected STEAM frameworks that strengthen water literacy, ecological understanding, and sustainability education from early childhood through higher education. The chapter blends research, developmental progressions, and implementation strategies that support hands-on, systems-based learning across diverse educational settings.

- **Introduces aquaponics, rainwater harvesting, and urban farming** as living instructional systems that integrate science, engineering, mathematics, and the arts.
- **Outlines a spiral STEAM curriculum** demonstrating how water- and food-based concepts progress from early childhood through higher education.
- **Highlights documented learning outcomes,** including gains in ecological literacy, data skills, engineering design, and problem-solving.
- **Identifies practical implementation challenges and solutions** such as system maintenance, cost, teacher preparation, and space constraints.

Introduction

Global water security has become one of the defining challenges of the twenty-first century. Expanding populations, urbanization, land-use change, and increasingly unpredictable climate regimes intensify pressures on freshwater resources in ways that affect food systems, ecological integrity, and community well-being. Sustainable water sourcing highlights persistent gaps in safe drinking water, wastewater management, and water-use efficiency, particularly in regions already facing hydrological stress and variable rainfall patterns (Raimondi et al., 2023; UN-Water, 2021). Access to water impacts societies on every continent and shapes the lived experiences of students, families, and communities, making it directly relevant across the early childhood to higher education spectrum.

Educational environments that integrate science, engineering, creativity, and civic responsibility provide powerful spaces for cultivating nuanced understandings of water, food, and sustainability. Aquaponics, rainwater harvesting (RWH), and urban farming function as living systems that invite learners to investigate biological interactions, chemical processes, technological design, mathematical reasoning, and artistic representation simultaneously. These systems also position students to consider water not only as a physical resource but also as a cultural, ethical, and communal element essential to life. Indigenous perspectives, articulated in various national and tribal contexts, frame water as sacred and relational, emphasizing stewardship obligations that transcend disciplinary boundaries (Larned, 2018). Such perspectives align closely with contemporary conceptions of STEAM education that integrate science and the arts to deepen both intellectual and humanistic engagement.

Aquaponics, RWH, and urban farming, therefore, represent more than instructional add-ons. They operate as interconnected STEAM constructs that can advance ecological literacy, problem-solving, systems thinking, design, and communication. Each approach offers a tangible, inquiry-rich medium for studying water quality, nutrient cycles, climate patterns, and sustainable food systems. Moreover, each offers students opportunities to work collaboratively, document observations, build models, and create representations that communicate environmental insights to broader audiences. Research across environmental education consistently demonstrates that such hands-on and community-centered learning experiences strengthen knowledge, dispositions, and conservation-oriented behaviors, particularly when designed with clear learning outcomes (Ardoin et al., 2020).

The purpose of this chapter is to conceptualize aquaponics, RWH, and urban farming as a coherent STEAM framework that extends from early childhood through higher education. The chapter draws on a diverse collection of peer-reviewed studies, technical reports, and educational resources to illustrate how these systems can serve as developmental pathways for building water literacy, ecological understanding, engineering competence, and civic awareness. The sections that follow outline the knowledge base upon which this framework rests and offer a structured progression for teachers, school leaders, university faculty, and community organizations seeking to integrate water- and food-based learning environments into their curricula and programs.

The interconnected nature of water, food systems, and sustainability is evident in aquaponics, RWH, and urban farming. Each system contributes unique disciplinary insights while reinforcing shared STEAM dimensions such as ecological literacy, engineering design, mathematics, creativity, and civic responsibility. Figure 1 illustrates the integrated framework that anchors these systems within a unified water–food–climate construct.

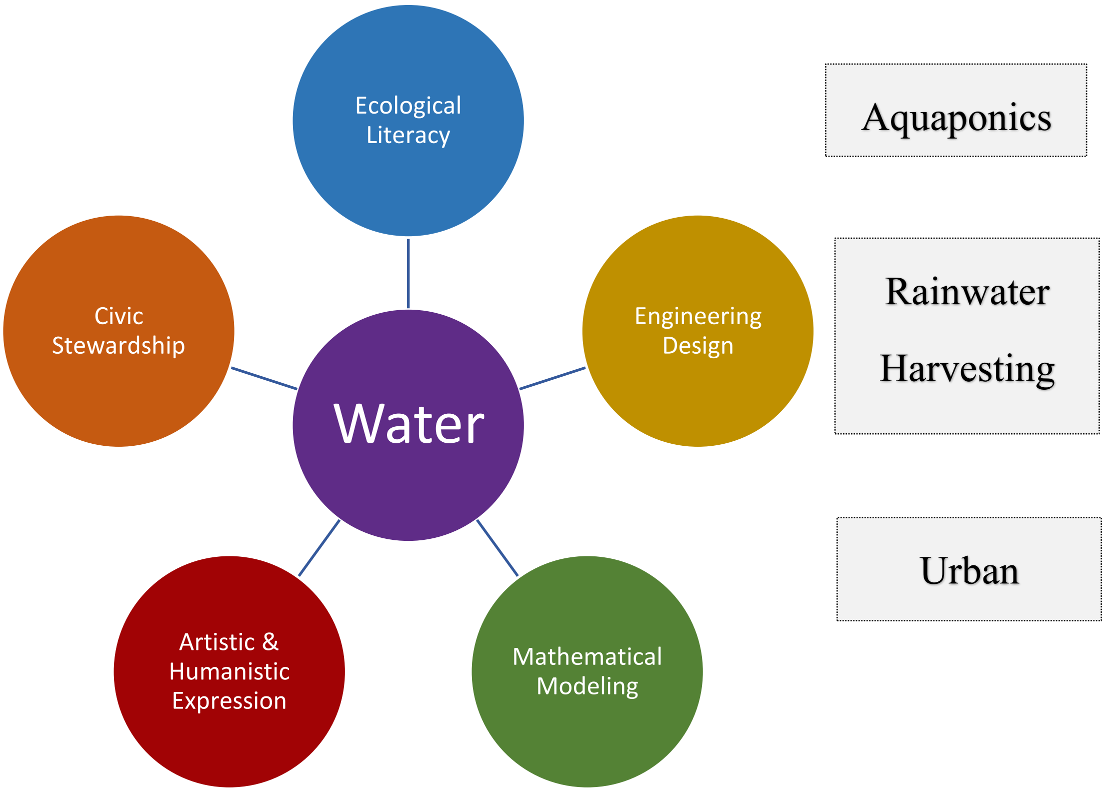

Figure 1. Water-Informed STEAM Learning

Water, Sustainability, and STEAM Education

Educational systems are increasingly called upon to respond to ecological disruption, climatic variability, and complex socio-environmental challenges. Water functions as a central thread in these global dynamics, linking food production, energy consumption, public health, and community resilience. Students who learn to analyze water systems develop competencies that extend beyond disciplinary content and into interdisciplinary reasoning, interpretation of variability, and evaluation of sustainability strategies. Environmental education research demonstrates that programs grounded in real ecosystems or resource-related issues often strengthen learners' knowledge acquisition, environmental attitudes, and stewardship behaviors. However, many programs fall short in developing measurable conservation outcomes or sustained behavioral changes (Ardoin et al., 2020). These limitations highlight the need for educational designs that incorporate ecological complexity, practical skill development, and reflective practice.

Water-centered STEAM approaches offer a multidimensional pathway for addressing such needs. Scientific learning outcomes can be cultivated through investigations of hydrology, chemistry, microbiology, and ecosystem interactions. Students observe evaporation, transpiration, infiltration, nutrient cycling, and water quality indicators as integrated processes rather than isolated facts. Engineering practices emerge through system construction, device optimization, problem diagnosis, and iterative testing. Mathematical reasoning becomes visible through calculations of volume, flow rates, yield projections, and temporal changes in environmental variables. Artistic and expressive modalities invite learners to communicate patterns, illustrate processes, design infographics, and create representations that broaden public understanding of sustainability issues.

Cultural and civic perspectives enrich these disciplinary experiences. Perspectives from Indigenous communities, as represented in national and tribal publications, reinforce understandings of water as a relational entity tied to identity, memory, and collective responsibility (Larned, 2018). Such cultural framings align with emerging conceptions of environmental and sustainability education that emphasize ethics, justice, and community engagement. Students encounter water not only as a scientific phenomenon but also as a subject of governance and stewardship.

Systems thinking forms the conceptual backbone of STEAM education in water-related contexts. Learners examine feedback relationships among water availability, climate change, agricultural practices, urban development, and ecological impacts. They investigate how environmental stressors shape plant growth, water scarcity, and resource competition, drawing on global analyses of how agricultural commodities, such as coffee, influence water supply and scarcity across continents (Sporchia, 2023). Such examples illustrate the real-world consequences of consumption, trade, and climate variability, helping students understand that local actions are connected to broader global systems. Students also interpret research documenting how rainfall variability, temperature extremes, and changing climate patterns influence agricultural viability in Central and South America (Marengo et al., 2014). These broader perspectives prepare learners to understand the vulnerabilities and adaptive capacities of water-dependent systems.

The integration of water, sustainability, and STEAM education, therefore, provides a comprehensive foundation for the constructive learning environments analyzed in this chapter. Aquaponics, RWH, and urban farming each offer opportunities to investigate biophysical processes, study engineered solutions, evaluate conservation practices, and explore cultural narratives. The next section examines aquaponics as a living laboratory that operationalizes such integrated learning in ways accessible to students across multiple grade levels.

Aquaponics as a Living STEAM Laboratory

Aquaponics provides a dynamic platform for interdisciplinary learning, as it integrates biological, chemical, and mechanical subsystems into a single, functioning ecosystem. Students observe how fish, plants, water, bacteria, and engineered components interact in real time. Such systems illustrate nutrient cycling, water quality dynamics, and ecological feedback loops in ways that are directly visible, measurable, and modifiable. Aquaponics also provides flexible entry points across grade levels, ranging from small classroom grow towers to large-scale systems used for undergraduate research and community outreach.

Aquaponics Systems in Education

Aquaponics functions through the continuous recirculation of water between fish tanks and plant-growing units. Fish waste provides ammonia, which is transformed by nitrifying bacteria into nitrites and nitrates that nourish plants. The plants, in turn, filter and clean the water before it returns to the fish, creating a closed-loop system that demonstrates biological interdependence and sustainable design. Educational research demonstrates that systems of this kind can effectively anchor science, technology, engineering, agriculture, and environmental studies, as their operation necessitates attention to water chemistry, organism health, nutrient cycling, and environmental monitoring (Bice et al., 2020). Teachers who adopt aquaponics frequently report that such systems help students connect abstract scientific concepts to observable phenomena. Students analyze fluctuations in pH, ammonia, nitrite, nitrate, and dissolved oxygen, linking these measures to fish behavior and plant health (Hart et al., 2013). They also gain practice in data collection, troubleshooting, and iterative improvement. Aquaponics systems serve as living models for discussing sustainability, resource efficiency, and the environmental implications of food production. Aquaponics systems, therefore, support the integration of scientific inquiry with engineering design, mathematical analysis, and ecological ethics.

Evidence of Learning Outcomes

A growing body of research demonstrates that aquaponics is an effective context for cultivating science learning and systems thinking. A large-scale, project-based aquaponics initiative implemented across rural high schools enhanced students' understanding of ecosystem interactions, carrying capacity, and the nitrogen cycle. Students who participated in the aquaponics-based curriculum demonstrated significantly higher ecological knowledge compared with control groups, and the hands-on design and maintenance tasks strengthened their responsibility, collaboration, and observational skills (Thompson et al., 2023).

Findings from a study conducted with grade 10 biology students further illustrate the value of aquaponics in enhancing student achievement. Students engaged in aquaponics-based activities that targeted "Ecosystems Ecology and Contemporary Environmental Issues" demonstrated meaningful gains in both conceptual understanding and scientific process skills. Teachers involved in the study perceived aquaponics as motivating for learners and supportive of conceptual integration, but they also noted that they needed additional clarity on how to articulate connections among the STEM domains (Baykır et al., 2022). These findings highlight the importance of adopting STEAM-structured learning objectives that intentionally integrate creativity and communication with scientific and technical content.

Aquaponics also supports health and nutrition education. A study examining the use of classroom grow systems as teaching models in middle school health education found that aquaponics systems helped students better understand food production, nutrient sources, and the relationship between environmental systems and personal health. Small-footprint classroom systems offered practical entry points for teaching sustainable agriculture and food literacy in schools that lacked outdoor garden space (Bice et al., 2020). Collectively, these studies demonstrate that aquaponics enhances content mastery, inquiry skills, problem-solving, and student engagement. The evidence strongly suggests that aquaponics functions best when students have sustained opportunities to monitor system variables, troubleshoot imbalances, and reflect on how biological and engineered components operate in concert.

Implementation Challenges and Solutions

Despite its benefits, several challenges influence the successful implementation of aquaponics in educational environments. Teachers often cite the initial cost of equipment, ongoing maintenance demands, and the need for technical troubleshooting as primary constraints. Systems must be monitored for clogging, pump failure, pH imbalance, or nutrient deficiencies, which can overwhelm educators new to the technology (Hart et al., 2013). Alignment with academic standards can also pose questions for teachers seeking to integrate aquaponics meaningfully within science, mathematics, engineering, or agricultural curricula.

Research on implementation identifies several strategies that alleviate these challenges. Providing accessible teacher professional development that covers system operation, curriculum integration, and troubleshooting improves teacher confidence and willingness to engage with aquaponics (Bice et al., 2020). Designing systems that are modular, scaled to classroom size, and accompanied by curricular guides reduces the cognitive load on teachers while allowing students to participate in maintenance and monitoring tasks. Partnerships with local farms, universities, and environmental organizations can offer supplemental expertise and reinforce the authenticity of aquaponics as a learning tool. Equally important is the integration of assessment tools that document not only content understanding but also system management skills, data practices, and problem-solving strategies.

STEAM Design Opportunities

Aquaponics richly supports STEAM learning because its operation requires scientific reasoning, engineering design, quantitative analysis, and creative representation. Students engage in engineering tasks when constructing or refining system components such as media beds, water flow pathways, and filtration units. They apply mathematical reasoning by modeling water flow rates, analyzing growth curves, tracking nutrient levels, and evaluating trends in water quality indicators (Thompson et al., 2023). Students also create graphs, design data dashboards, and construct visual explanations that communicate key insights about their systems' performance.

Artistic and humanistic perspectives enhance these technical experiences. Students create diagrams, infographics, videos, and narrative reflections that explain the significance of sustainable food systems. They design interpretive displays that illustrate nutrient cycling, water conservation, and plant–fish relationships for school visitors or community partners.

Aquaponics, therefore, provides an integrative platform through which learners can analyze scientific data, engineer solutions, and communicate meaning with clarity and purpose.

Rainwater Harvesting as a Context for Engineering Design and Civic Stewardship

Rainwater harvesting (RWH) represents a practical and adaptable approach to water management that can be incorporated into educational settings across grade levels. The practice involves capturing, storing, and reusing precipitation for household, agricultural, and ecological purposes. As water scarcity intensifies across many regions, RWH systems demonstrate how communities can supplement freshwater supplies, reduce stormwater runoff, and increase resilience to climatic variability. The technology's simplicity, scalability, and relevance to daily life make it an ideal context for STEAM learning, providing rich opportunities for students to explore hydrology, engineering design, mathematical modeling, environmental ethics, and public communication.

Global and Local Significance of Rainwater Harvesting

Rainwater harvesting has long been practiced in arid and semi-arid regions and is now gaining recognition as a critical component of sustainable water management in both rural and urban settings. Technical reviews emphasize that RWH systems reduce pressure on municipal water supplies, mitigate flooding, and offer site-specific solutions that improve water security in the face of erratic rainfall patterns (Raimondi et al., 2023). Research indicates that RWH contributes to climate adaptation strategies by increasing community-level water independence and decreasing vulnerability to drought cycles, which are expected to intensify under changing climate conditions. Studies analyzing precipitation trends, agricultural risks, and climate projections across Central and South America emphasize the importance of rainfall variability, prolonged dry periods, and increasing temperature extremes for water-reliant communities and crops (Marengo et al., 2014). These trends highlight the importance of equipping learners with the knowledge and skills necessary to comprehend and address regional water challenges. Educational initiatives that introduce students to water collection and reuse can contribute to broader conservation efforts and help foster a generation of learners who understand the technological and social complexities of water stewardship.

Early Childhood and K–12 Educational Applications

Rainwater harvesting aligns naturally with hands-on, inquiry-based learning in K–12 education. The *Rainwater Harvesting Youth Education Manual*, which supports programs such as 4-H and Junior Master Gardener, provides a wide range of accessible activities that illustrate water movement, storage, and use (Kniffen & Gerlich, 2014). Early lessons in the manual introduce learners to raindrop formation, splash direction, and soil infiltration. Students conduct simple experiments that reveal how different soil substrates absorb and retain water, or how vegetation affects runoff. Such activities help students visualize the relationships among rainfall, soil composition, erosion, and plant health.

As learners progress, the manual introduces watershed concepts, rainfall simulators, and simple rain barrel systems. Students calculate catchment areas, estimate storage capacity, and model the amount of water that can be collected during a typical storm. Lessons encourage learners to analyze the impact of land use, slope, and vegetation on water quality and supply (Kniffen & Gerlich, 2014). These activities build foundational hydrologic literacy and empower students to evaluate how their immediate environments influence water availability.

Connections to STEAM education are strengthened through engineering design tasks embedded in RWH learning. Students design gutters, funnels, and storage systems that maximize collection efficiency. They test prototype devices, revise designs based on evidence, and compare performance across materials and environmental conditions. These tasks cultivate design thinking, metacognition, and collaborative problem solving. Mathematical reasoning is also evident as students compute surface area, estimate water volume, and track system performance over time.

Arts-based extensions enhance understanding by inviting students to create maps of their school watershed, design posters that promote water conservation, or produce digital narratives that document local water issues. Such creative tasks support interdisciplinary learning and connect scientific inquiry with communication, storytelling, and advocacy.

Higher Education and Community Projects

Rainwater harvesting holds significant educational potential in higher education, especially in engineering, environmental science, architecture, and urban planning programs. State-of-the-art reviews of RWH technologies describe advanced filtration systems, treatment methods, and design considerations that can inform undergraduate and graduate coursework (Raimondi et al., 2023). Students analyze case studies evaluating roof catchment systems, first-flush devices, sedimentation tanks, and disinfection strategies to assess their effectiveness. These analyses deepen student understanding of water quality standards, public health considerations, and system reliability.

Many colleges and universities have integrated RWH into campus sustainability initiatives, offering opportunities for authentic, site-based learning. Students can participate in designing campus collection systems, assessing potential storage volumes based on local climate data, or monitoring system function over time. Such projects connect academic learning with institutional sustainability goals, helping students understand how water engineering decisions impact larger ecological and social systems.

Community partnerships extend these learning opportunities beyond the campus. Students collaborate with neighborhood organizations, city agencies, or local farms to design rainwater collection systems that address community-identified needs. These partnerships allow students to apply engineering and scientific concepts to real-world contexts while learning about access, governance, and environmental justice. Integrating RWH into community-based projects also encourages students to consider cultural and economic factors that shape water use practices, thereby aligning technical decision-making with ethical and civic dimensions.

Urban Farming and Food Systems as STEAM Practice

Urban farming has emerged as a vital strategy for addressing water scarcity, food insecurity, and ecological degradation in both developed and developing regions. As cities expand and climate variability disrupts traditional agricultural systems, urban farming offers flexible, small-scale, and resource-efficient approaches to food production. These practices also provide rich opportunities for STEAM learning, connecting students to soil science, botany, water management, engineering, environmental justice, and artistic expression. When integrated with aquaponics and RWH, urban farming functions as an essential third pillar of a comprehensive STEAM construct focused on sustainability, resilience, and community well-being.

Urban Farming Within the Water–Food–Climate Relationship

Urban agriculture operates at the intersection of water availability, climate conditions, and community food needs. Research examining climate impacts across Central and South America suggests that shifting precipitation patterns, intensifying drought cycles, and rising temperatures have a significant influence on agricultural productivity (Marengo et al., 2014). These conditions often compromise crop viability and reduce access to reliable food sources, particularly in areas that depend on rainfall for irrigation. As global freshwater supplies decline, and as population growth continues to heighten demand, urban agriculture becomes a necessary supplement to conventional food systems.

Urban farming also aligns with broader analyses of global water stress. Reports addressing water scarcity emphasize the need for integrated strategies that minimize freshwater extraction, improve water quality, and enhance the sustainability of food production (Raimondi et al., 2023; UN-Water, 2021). Urban farms that incorporate RWH, greywater reuse, or drip irrigation systems demonstrate how local action can reduce demand on municipal water infrastructures. Moreover, studies examining the environmental footprint of global agricultural commodities reveal the extent to which consumption patterns in one region can drive water scarcity in another. For example, analyses of global coffee production highlight the stresses placed on water basins in producing nations, illustrating the complex linkages between consumption, trade, and environmental strain (Sporchia, 2023). Integrating such insights into urban farming education helps students recognize the interconnectedness of water, climate, agricultural practices, and global supply chains.

Educational and Social Dimensions

Urban farming lends itself to educational innovation due to its accessibility and its relevance to everyday life. School gardens, rooftop planters, community plots, and small indoor growing systems provide flexible, hands-on learning environments that allow students to observe plant growth, soil dynamics, and environmental interactions. Students investigate concepts such as evaporation, transpiration, nutrient cycling, and pollination. They monitor soil moisture, track microclimates across a schoolyard, and experiment with the effects of shading, mulching, or soil composition on plant health.

Students also gain opportunities to interpret how water scarcity shapes communities. Lessons that incorporate rainfall data, runoff patterns, or irrigation strategies help students understand disparities in water access across urban neighborhoods. Residential blocks characterized by limited green space, aging infrastructure, or poor stormwater drainage may experience heightened vulnerability to flooding or drought. Urban farming projects provide opportunities for dialogue about environmental justice, public health, and community resilience.

The social dimensions of urban agriculture further enhance its educational value. Food production in community spaces fosters collaboration, intergenerational learning, and cultural exchange. Students cultivate vegetables connected to their cultural traditions, interview family or community members about food practices, or document the history of local vacant lots transformed into productive green spaces. These activities align with STEAM goals by merging scientific inquiry with artistic, linguistic, and narrative practices that illuminate the personal and communal significance of food and water.

STEAM Pathways

Urban farming supports all components of STEAM education and can be integrated into curricula with increasing sophistication across grade levels. Science learning is inherent to studying plant physiology, soil chemistry, decomposition, and ecological relationships. Students examine how sunlight, water, and nutrient availability influence plant development. Investigations of soil texture, pH, and organic content help students understand the factors that determine plant health and ecosystem functioning.

Engineering tasks arise naturally in the design of irrigation systems, raised beds, composting structures, and protective coverings. Students experiment with gravity-fed irrigation, drip systems connected to rain barrels, or low-cost water filtration devices designed to improve water reuse within garden systems. These activities cultivate problem-solving skills and support iterative design processes grounded in real-world constraints.

Mathematics becomes visible as students monitor growth rates, calculate planting densities, estimate yields, and track harvest weights across different seasons. Mathematical tasks offer opportunities for analyzing data, interpreting variability, and modeling resource use. Students also create visual displays that effectively communicate their findings, thereby enhancing their ability to represent scientific data clearly and persuasively.

The arts contribute by offering powerful channels for expression and public engagement. Students sketch garden layouts, photograph seasonal changes, create posters promoting water conservation, or produce digital stories documenting community partnerships. These creative expressions support interpretive communication and reinforce the cultural values associated with food, water, and ecological care.

When viewed collectively, urban farming provides a versatile and meaningful context for STEAM learning. Its integration with aquaponics and RWH creates a unified educational framework grounded in sustainability, systems thinking, and civic responsibility.

Taken together, aquaponics, rainwater harvesting, and urban farming function as complementary systems that support interdisciplinary learning grounded in sustainability. Although each system offers unique instructional advantages, they share overlapping scientific, engineering, mathematical, artistic, and civic dimensions. Table 1 presents a comparative view of these STEAM constructs, highlighting the strengths each system brings to educational practice.

Table 1. Comparative STEAM Constructs

System	Scientific Concepts	Engineering Design Applications	Mathematical Practices	Arts & Humanistic Connections	Civic/Community Elements
Aquaponics	Nutrient cycling, water chemistry, ecology	Filtration design; system construction; troubleshooting	Flow rates; chemical monitoring; growth modeling	Infographics, diagrams, interpretive displays	Food literacy; sustainability ethics
Rainwater Harvesting	Hydrology, infiltration, water quality	Catchment design; storage systems; treatment devices	Surface area calculations; volume estimates; rainfall modeling	Watershed mapping; conservation messaging	Water stewardship; public education
Urban Farming	Plant physiology, soil chemistry, microclimates	Irrigation design; raised beds; compost systems	Yield tracking; planting density; resource modeling	Garden design; photography; cultural food storytelling	Environmental justice; community resilience

A Spiral STEAM Curriculum from Early Childhood Through Higher Education

A developmental progression that spans early childhood through higher education strengthens the impact of aquaponics, RWH, and urban farming by ensuring that students revisit core ideas with increasing sophistication. A spiral STEAM curriculum draws on the principle that complex ecological and technological concepts become accessible when learners encounter them repeatedly through hands-on experiences, reflective practice, and structured inquiry. The three systems examined in this chapter provide a coherent set of learning pathways through which students can build a foundational understanding in the early grades, expand their investigative and analytical competencies in middle and high school, and engage in advanced applications and research in higher education.

Developmental Progression

Early Childhood

Young children benefit from direct sensory engagement with water, soil, plants, and natural materials. Simple activities, such as observing how water flows across different surfaces, planting seeds in small containers, or comparing how plants respond to sunlight, introduce fundamental concepts of cause and effect, observation, and environmental variability. Early childhood learners also benefit from storytelling, dramatization, and the visual arts, which highlight the importance of water in daily life and community well-being. These experiences nurture curiosity, empathy for living things, and an emerging sense of responsibility for the natural world.

Elementary School

Elementary students can participate in small-scale growing systems, classroom rain barrels, or simple hydroponic devices. They measure rainfall, track plant growth, examine soil, and record water-use practices. Such activities support the development of measurement skills, data recording, and descriptive writing. Students create drawings, maps, posters, and diagrams that represent the water cycle or illustrate how plants rely on water and nutrients to survive. Early STEAM experiences allow children to integrate scientific concepts with visual communication, narrative writing, and mathematical reasoning.

Middle School

Middle school learners are developmentally prepared to engage with increasingly structured investigations. Aquaponics, in particular, offers a practical platform for studying ecosystems, water chemistry, and sustainable agriculture. Research indicates that middle school students demonstrate improved understanding of food systems, nutrient flows, and environmental health when classroom growing systems are incorporated into instruction (Bice et al., 2020). Similarly, RWH activities from youth education manuals enable students to conduct experiments with soil infiltration, runoff, and watershed flows (Kniffen & Gerlich, 2014). Students calculate catchment area, estimate water storage volume, and construct small-scale prototypes that model water movement. These activities cultivate systems thinking by permitting learners to examine the interdependence of water, soil, climate, and living organisms.

High School

High school students can participate in full-scale project-based investigations that integrate aquaponics, RWH, and urban farming. Aquaponics environments aligned with NGSS standards have been shown to elevate ecological knowledge, data literacy, and systems understanding (Thompson et al., 2023). Students analyze water quality, model nutrient flows, troubleshoot imbalances, and collect longitudinal data on the health of fish and plants. They also design irrigation systems, test water filtration devices, and evaluate how rainfall patterns influence garden yields.

Urban farming activities enhance environmental literacy and enable students to investigate how climate, soil chemistry, and water availability impact food production. Lessons that incorporate global climate research enable students to understand how temperature and rainfall variability impact agricultural viability across different regions (Marengo et al., 2014). Students investigate environmental justice concerns by analyzing how access to water, distribution of green spaces, and availability of food vary across urban neighborhoods.

Higher Education

Aquaponics, RWH, and urban farming each offer robust opportunities for advanced research, engineering design, sustainability planning, and community-engaged scholarship in higher education. Students can examine treatment technologies, water quality standards, or system optimization strategies using technical literature on RWH and water treatment (Raimondi et al., 2023). Undergraduate and graduate learners design systems that respond to community needs, collaborate with municipal agencies, or analyze case studies related to water scarcity and climate resilience. Students studying environmental science, engineering, agriculture, or urban planning can investigate structural inequities, policy considerations, and long-term sustainability outcomes associated with local and global water systems. These experiences reinforce the development of professional competencies and position students as contributors to interdisciplinary sustainability challenges.

Educators often benefit from a clear overview of how water- and food-based systems evolve across developmental levels. The progression described above reflects a coherent sequence of experiences that deepen scientific, engineering, and civic competencies over time. Table 2 organizes these developmental stages into a concise STEAM progression from early childhood through higher education.

Table 2. Developmental STEAM Progression Early Childhood Through Higher Education

Grade Level	Core Focus	Sample Learning Activities	Learning Outcomes
Early Childhood	Sensory engagement with water and plants	Observing water flow; planting seeds; comparing sunlight effects; storytelling about water	Curiosity, observation, emerging ecological awareness
Elementary	Foundational water and plant science	Classroom rain barrels; tracking plant growth; soil exploration; simple hydroponics	Measurement, descriptive writing, basic data skills, visual communication
Middle School	Systems and environmental interactions	Aquaponics water testing; soil infiltration studies; small RWH prototypes; nutrient cycle exploration	Systems thinking, data literacy, experimental design
High School	Integrated engineering and ecological analysis	Full-scale aquaponics monitoring; rainfall modeling; irrigation design; environmental justice studies	Ecological reasoning, engineering design, longitudinal data collection
Higher Education	Applied research and community-focused design	RWH treatment evaluations; optimization studies; sustainability planning; community partnerships	Professional competencies, civic engagement, interdisciplinary research

Alignment With Learning Outcomes

A spiral STEAM curriculum supported by aquaponics, RWH, and urban farming advances multiple categories of learning outcomes across cognitive, skill-based, and dispositional domains.

Cognitive Outcomes

Students gain a deeper understanding of ecosystems, hydrology, nutrient cycling, climate impacts, and sustainable food systems. High school studies have demonstrated increases in ecological knowledge and understanding of interdependent systems following sustained aquaponics instruction (Thompson et al., 2023). Educational reviews also highlight that water-related instruction strengthens environmental knowledge and conceptual reasoning, especially when grounded in conservation-focused learning (Ardoin et al., 2020).

Skill-Based Outcomes

Skill development occurs through data collection, measurement, graphing, analysis, and evidence-based argumentation. Students construct models, use engineering design processes, troubleshoot system failures, and evaluate trade-offs. Research on aquaponics and environmental education consistently shows improvements in problem-solving, planning, and scientific inquiry when learners are engaged in sustained, hands-on investigations (Baykır et al., 2022).

Dispositional and Behavioral Outcomes

A growing body of literature emphasizes the importance of fostering stewardship, collaboration, and civic engagement in environmental education. Students who participate in experiential water- and food-related learning develop stronger environmental attitudes, an increased sense of responsibility, and heightened awareness of community needs (Ardoin et al., 2020). Experiences that require students to care for living systems, monitor resources, or communicate findings to authentic audiences reinforce ethical dispositions and promote lasting commitment to conservation practices.

Implementation and Assessment

Integrating aquaponics, RWH, and urban farming into educational practice requires thoughtful planning and attention to the material, pedagogical, and social dimensions that shape learning. These systems offer substantial benefits but also present implementation challenges that educators and institutions must anticipate. When these considerations are addressed through appropriate assessment practices, the three systems become powerful tools for STEAM instruction and environmental literacy across grade levels.

The research summarized in this section illustrates that the successful adoption of aquaponics, RWH, and urban farming depends on addressing a set of recurring practical and pedagogical challenges. Many of these obstacles can be mitigated through thoughtful planning, targeted professional development, and well-designed partnerships. Table 3 outlines the major implementation challenges and corresponding solutions documented across the literature.

Table 3. Implementation Challenges and Solutions

Challenge	Systems Affected	Recommended Solutions
System maintenance & troubleshooting	Aquaponics	PD on water chemistry; modular system design; student-led monitoring
Cost of equipment & materials	All three	Grants; phased installation; partnerships; low-cost designs
Teacher preparation & confidence	Aquaponics, RWH	Targeted PD; curriculum guides; mentorship networks
Space constraints	Aquaponics, Urban Farming	Vertical towers; indoor microfarms; compact barrels
Assessment & data collection	All three	Performance-based assessments; data dashboards; reflective tasks

Challenges and Solutions in Implementation

Research on aquaponics in educational environments identifies several recurring challenges: system maintenance, teacher preparation, material costs, and classroom space constraints. Studies examining the adoption of aquaponics systems report that teachers often express enthusiasm for the instructional potential of aquaponics but remain concerned about the complexity of system upkeep, water quality monitoring, and long-term sustainability (Baykır et al., 2022). Many educators describe a lack of formal training in aquaculture, horticulture, or nutrient cycling, which can limit their confidence in facilitating inquiry-driven instruction. Addressing these concerns requires structured professional development that provides technical knowledge, troubleshooting strategies, and opportunities to model lessons in safe, low-stakes environments.

Cost is another barrier identified in both aquaponics and RWH research. While many systems can be designed using low-cost or recycled materials, initial investment in pumps, tanks, tubing, sensors, barrels, or filtration devices may exceed what some schools can reasonably allocate. Reviews of school and community-based water initiatives emphasize solutions such as grant funding, community partnerships, phased system installation, and student-led design projects that reduce cost while increasing ownership (Kniffen & Gerlich, 2014). Spatial constraints also influence system adoption. Urban schools with limited outdoor space may struggle to install traditional garden beds or large aquaponics units. Indoor micro-farms, tabletop aquaponics systems, vertical growing towers, and compact rainwater collection devices offer practical alternatives that preserve instructional value. Such systems allow students to collect, measure, and interpret water-use data even in settings with limited physical space.

Assessment Frameworks

Assessment practices tied to aquaponics, RWH, and urban farming should capture student learning across scientific inquiry, engineering design, mathematical reasoning, and environmental attitudes. Performance-based assessments are particularly well-aligned with these systems because they emphasize observable behaviors, real data, and iterative decision-making.

Scientific Inquiry and Data Literacy

Students can be assessed on their ability to collect water quality data, conduct nutrient tests, measure plant growth rates, or model rainfall capture. Research demonstrates that engagement in aquaponics increases students' understanding of ecosystem dynamics and improves their ability to interpret scientific evidence (Thompson et al., 2023). Teachers may use rubrics that evaluate hypothesis formation, data accuracy, representation of variables, and interpretation of trends.

Engineering Design Competencies

Engineering assessments can focus on system optimization, prototype design, and evidence-based revisions. Students modify irrigation layouts, adjust system flow rates, or redesign filtration components to address observed problems. These tasks align with national engineering standards, allowing educators to assess iterative problem-solving, collaboration, and design justification.

Environmental Literacy and Dispositional Outcomes

Environmental education literature emphasizes the importance of assessing changes in attitudes, stewardship behaviors, and civic awareness (Ardoin et al., 2020). Students may complete reflective writing tasks, create public-facing conservation materials, or participate in community presentations that demonstrate their ability to synthesize scientific concepts with ethical and civic reasoning.

Conclusion

Aquaponics, RWH, and urban farming represent powerful instructional systems that position water, food, and sustainability at the center of STEAM education from early childhood through higher education. Collectively, these systems demonstrate how hands-on, place-based learning can cultivate ecological literacy, strengthen scientific and engineering competencies, and deepen students' understanding of the interdependent relationships among natural resources, human communities, and technological innovation. Research reveals that aquaponics enhances students' understanding of ecosystem dynamics, nutrient cycling, and environmental decision-making (Baykır et al., 2022; Thompson et al., 2023). Rainwater harvesting enhances hydrological reasoning and provides accessible ways to explore climate variability, water scarcity, and adaptive engineering design (Kniffen & Gerlich, 2014; Raimondi et al., 2023). Urban farming serves as the social and cultural bridge across these practices, highlighting issues of food access, community well-being, and environmental justice (Larned, 2018; Marengo et al., 2014).

A unifying thread across all three systems is the centrality of water. Studies addressing global water scarcity, climate change, and unequal access to potable water highlight the need for sustained policy, education, and community-level adaptation (Ardoin et al., 2020; Raimondi et al., 2023; UN-Water, 2021). Schools, colleges, and universities, therefore, hold a critical role in preparing future citizens to understand the complexities of freshwater systems, design solutions that reduce water-related vulnerabilities, and participate in collective efforts toward sustainability. A spiral STEAM curriculum provides a structure through which students can gradually build this expertise, revisiting core concepts with increasing depth as they advance through developmental stages.

Recommendations

Strengthen Access Through Scalable System Design

Institutions should adopt flexible system designs that allow educators to begin with small-scale classroom units before expanding to more complex installations. Low-cost tabletop aquaponics units, compact rain barrels, and container-based garden systems allow all schools—including those with limited space or funding—to participate meaningfully. Research identifies cost and system maintenance as primary deterrents for educators (Baykır et al., 2022; Hart et al., 2013). Incremental adoption, coupled with thoughtful procurement and community partnerships, increases sustainability and reduces financial burden.

Provide Robust Professional Development

Teacher confidence grows when professional development integrates ecological concepts, engineering basics, troubleshooting skills, and curriculum design. Workshops, certification programs, and collaborative teacher networks ensure that educators have the support needed to interpret water quality data, sustain system health, and facilitate inquiry-based learning. Professional development should also model interdisciplinary instruction by demonstrating how aquaponics, RWH, and urban farming intersect across science, mathematics, environmental ethics, and the arts.

Embed Community Partnerships Into Program Design

Community engagement strengthens learning outcomes and improves project sustainability. Partnerships with municipal water agencies, environmental nonprofits, agricultural extension services, Tribal Nations, and local farms provide authentic contexts for student learning. Students can contribute to neighborhood water audits, participate in community garden installations, or support conservation communication efforts. These collaborations connect STEAM investigation to real-world civic action and highlight the sociocultural dimensions of water and food systems.

Develop Integrated Assessment Frameworks

Assessment should capture not only scientific and engineering competencies but also environmental attitudes, collaborative practices, and civic dispositions. Performance-based assessments, reflective writing, data modeling, and community presentations offer comprehensive ways to evaluate student learning. Reviews of environmental education outcomes highlight the importance of measuring shifts in stewardship, understanding of socioecological systems, and readiness to participate in conservation practices (Ardoin et al., 2020).

Integrate Water, Food, and Climate Systems Across the Curriculum

Aquaponics, RWH, and urban farming should not function as isolated enrichment activities. The most effective programs embed these systems across multiple subject areas and grade levels. Mathematics instruction can incorporate system-based data analysis; language arts can integrate conservation-focused storytelling and digital communication; social studies courses can examine global water politics and food sovereignty. Such integration reinforces the interconnectedness of ecological systems and human responsibility.

References

Ardoin, N. M., Bowers, A. W., & Gaillard, E. (2020). *Environmental education outcomes for conservation: A systematic review*. *Biological Conservation, 241*, 108224. https://doi.org/10.1016/j.biocon.2019.108224

Baykır, A., Mirici, S., & Sönmez, D. (2022). *Aquaponics systems as an educational tool: Effects on students' achievement and teachers' views*. *International Journal of Curriculum and Instruction, 15*(1), 693–714.

Bice, M. R., Ball, J. W., Hollman, A., Meyer, D., & Ringenberg, J. (2020). A qualitative assessment of considerations on how teachers can use classroom growing systems as a teaching model in middle school classrooms. *The Health Educator, 52*(1), 4–14.

Hart, E. R., Webb, J. B., & Danylchuk, A. J. (2013). Implementation of aquaponics in education: An assessment of challenges and solutions. *Science Education International, 24*(4), 460–480

Kniffen, B., & Gerlich, R. (2014). *Rainwater harvesting activities for youth education*. Texas A&M AgriLife Extension Service. Retrieved from http://rainwaterharvesting.tamu.edu/

Larned, S. M. (2018). Water is Life: The Native American Tribal Role in Protecting Natural Resources. *Environmental and Earth Law Journal, 8*, 53-94

Marengo JA, Chou SC, Torres RR, Giarolla A, Alves LM, Lyra A. 2014. *Climate Change in Central and South America: Recent Trends, Future Projections, and Impacts on Regional Agriculture.* CCAFS Working Paper no. 73. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Copenhagen, Denmark. Available online at: www.ccafs.cgiar.org

Raimondi, A., Quinn, R., Abhijith, G. R., Becciu, G., & Ostfeld, A. (2023). Rainwater harvesting and treatment: State of the art and perspectives. *Water*, *15*(8), 1518. https://doi.org/ 10.3390/w15081518

Sporchia, F., Caro, D., Bruno, M., Patrizi, N., Marchettini, N., & Pulselli, F. M. (2023). Estimating the impact on water scarcity due to coffee production, trade, and consumption worldwide and a focus on EU. *Journal of Environmental Management*, *327*, 116881. https://doi.org/10.1016/j.jenvman.2022.116881

Thompson, K. R., Webster, C. D., Pomper, K. W., & Krall, R. M. (2023). Use of a project-based aquaponics curriculum in rural Kentucky school districts increases secondary students' understanding of ecosystems. *Interdisciplinary Journal of Environmental and Science Education, 19*(3), e2313. https://doi.org/10.29333/ijese/13687

UN-Water. (2021). *Summary progress update 2021: SDG 6 – Water and sanitation for all (Version July 2021)*. United Nations. https://www.unwater.org/publications/summary-progress-update-2021-sdg-6

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Chapter III

Assessing Individual Differences in Technology-Enhanced Learning: The Eye-Tracking Mental Load Assessment framework

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Abstract

Technology-enhanced learning (TEL) integrates digital tools such as multimedia and adaptive systems to optimize educational experiences. However, TEL effectiveness depends on how well these systems align with learners' cognitive capacities rather than on technology itself. This study introduces the Eye-Tracking Mental Load Assessment (ET-MLA) framework, designed to distinguish between perceptual and working memory load through fixation-related eye-tracking metrics. Building on cognitive load theory and the load theory of selective attention, ET-MLA combines fixation duration and fixation rate to identify variations in learners' mental states. The framework emphasizes the importance of individual eye-movement behavior profiles, acknowledging that fixation-related parameters are idiosyncratic and stable across tasks. By establishing individual baselines, ET-MLA enables adaptive TEL environments to adjust learning materials dynamically, thereby reducing extraneous cognitive load and improving instructional efficiency. This approach advances personalized and data-driven educational design, contributing to more effective, cognitively aligned digital learning environments.

Keywords: Eye-movement behavior, Individual differences, Attention, Adaptive displays, technology enhanced learning.

Introduction

Technology-enhanced learning (TEL) aims to enrich educational experiences by integrating information and communication technologies, including multimedia elements such as narrated explanations, interactive animations, simulations, and linked hypermedia environments, to promote better learning outcomes (Kalyuga & Liu, 2015).

Empirical research (Skuballa et al., 2018; Mayer & Moreno, 2003; Lazarides et al., 2019). has shown that the pedagogical effectiveness of technology-enhanced learning environments stems largely from their capacity to promote learner engagement and cognitive processing, rather than from the technology per se. Consequently, one of the central challenges for TEL systems is to develop designs that not only facilitate effective learning but also provide reliable means to assess and quantify improvements in educational performance and outcomes (Guri-Rosenblit & Gros, 2011; Ivanović et al., 2017). To minimize unnecessary cognitive strain, it is essential to examine the underlying cognitive mechanisms and processes involved, as research has produced mixed evidence regarding the overall effectiveness of TEL environments (Kalyuga & Liu, 2015).

There is a growing need to establish a comprehensive framework that accounts for individual learner characteristics—such as prior knowledge, working memory capacity, and domain-specific abilities—to better determine the intrinsic difficulty of educational content (Brünken et al., 2010). As task complexity varies, the distribution of cognitive resources becomes a critical factor in learning efficiency. When cognitive load remains within a learner's capacity, surplus resources can be devoted to filtering irrelevant information and supporting effective processing. Conversely, when these cognitive resources are overloaded, both relevant and irrelevant stimuli compete for attention, thereby impairing performance and learning outcomes (Liu et al., 2022). Consequently, different types of cognitive load—namely perceptual load and working memory load—play distinct roles in shaping how learners process and respond to information within technology-enhanced learning environments.

To address this research gap, the present study introduces the Eye-Tracking Mental Load Assessment (ET-MLA) framework. The framework aims to distinguish between two key types of mental load—perceptual load and working memory load—and to provide insights that can guide the design of more effective e-learning and blended learning environments.

Instructional design in TEL

Technology-enhanced learning systems may incorporate adaptive displays, particularly within adaptive or personalized learning contexts. However, not all TEL environments qualify as adaptive; only those that dynamically modify their content or interface in response to user data—such as gaze behavior, task performance, or cognitive load. An adaptive display is characterized by its ability to adjust in real time to meet individual learner needs (Keeble & Macredie, 2000; Chahine et al., 2023). Such systems gather real-time input from various sensors or performance-monitoring tools and subsequently adapt the visual or informational content to optimize the user experience (Chahine et al., 2023).

The Cognitive Load Theory (CLT) serves as a central framework for understanding and improving the instructional design of multimedia and online learning environments (Chandler & Sweller, 1991; Martin, 2012; Martin, 2014). According to CLT, the efficiency of learning is influenced by how cognitive resources are distributed among three types of load: intrinsic, extraneous, and germane. Intrinsic load reflects the inherent difficulty of the learning material, determined by the complexity of its components and the learner's existing knowledge base. Extraneous load originates from poorly designed instructional materials that impose unnecessary cognitive effort—such as redundant explanations, unclear structure, or irrelevant visual elements (Kalyuga & Liu, 2015). In contrast, germane load represents the mental effort directed toward schema construction and automation, supporting deeper understanding and long-term retention. This type of load is strongly influenced by learners' engagement and motivation (Martin, 2014; Kalyuga & Liu, 2015). Effective instructional design, therefore, aims to minimize extraneous load while balancing intrinsic and germane loads to ensure that learners operate within their optimal cognitive capacity, as both cognitive overload and underload can impair learning outcomes (Ayres & van Gog, 2009).

As highlighted by Choi and Lee (2022) and Kalyuga and Liu (2015), the level of extraneous cognitive load experienced by learners is strongly shaped by instructional design variables such as the presentation format, the clarity and interactivity of learning activities, and the degree of adaptive support offered within the learning environment. Leppink et al. (2013) found that revising instructional materials into a more accessible and coherent format led students to report, through self-assessment, lower levels of intrinsic and extraneous load and higher levels of germane load. Nonetheless, obtaining valid and reliable estimates of mental load remains a persistent methodological challenge, particularly when learners are not yet familiar with the content. Under such circumstances, students often struggle to identify whether learning difficulties stem from the intrinsic complexity of the material or from the way it is presented, complicating the differentiation between intrinsic and extraneous cognitive loads (Cierniak et al., 2009). Moreover, despite numerous attempts, researchers continue to face difficulties in disentangling the effects of distinct cognitive load types in educational contexts (Brünken et al., 2010; Martin, 2014). These limitations of subjective reporting highlight the need for objective measures - for example, eye-tracking - which can reveal underlying cognitive mechanisms and provide more precise, real-time insights into mental load dynamics during learning.

To address the limitations of subjective assessments of cognitive load, this study draws on the Load Theory of Selective Attention proposed by Lavie and Dalton (2014), which complements the Cognitive Load Theory (CLT) by explaining how attentional capacity is distributed between relevant and irrelevant information. The theory emphasizes the crucial role of working memory in managing priorities between targets and distractors during task performance. According to Lavie and Dalton (2014), when the perceptual load of task-relevant stimuli is sufficiently high, attentional resources are fully consumed by these stimuli, leaving no capacity for processing distractors. Under such conditions, early selection mechanisms operate efficiently, filtering out irrelevant information. In contrast, when perceptual load is low, residual perceptual capacity allows distractors to be processed, resulting in late selection and reduced attentional efficiency. However, when perceptual load becomes excessively high, it can overwhelm the learner's perceptual system, leaving insufficient capacity to process all relevant information. This imbalance can lead to disorganized attention and increased extraneous cognitive load, particularly when combined with high working memory demands. The interaction between perceptual and working memory loads therefore determines how effectively learners process relevant content while suppressing irrelevant information. In summary, maintaining an optimal balance between perceptual and working memory demands is crucial for effective learning. While moderate perceptual load enhances focus and supports efficient processing of relevant information, excessive perceptual load can overwhelm attentional capacity and increase extraneous cognitive effort. Similarly, high working memory load depletes available cognitive resources, reducing the ability to inhibit distractors and further amplifying extraneous load.

Methods of assessing mental load. Eye-tracking

Various methods are available for assessing mental load, including both subjective self-reports and objective measurements based on behavioral, physiological, or performance-related data. Subjective approaches typically rely on participants' ratings to estimate the perceived difficulty of learning materials. In contrast, objective techniques employ tools such as eye-tracking, dual-task paradigms, or neuroimaging methods like functional near-infrared spectroscopy (fNIRS) to capture mental effort through observable indicators (Martin, 2014). Although all of these approaches are valid, their effectiveness is highly context-dependent and influenced by the specific characteristics of the learning environment (Charles & Nixon, 2019; Tao et al., 2019). Among these, eye-tracking stands out for its capacity to reveal not only what users are focusing on but also how and when their cognitive processes unfold during task performance (Calvi et al., 2008). Therefore, this study employs eye-tracking as the primary method for assessing mental load, as it provides fine-grained, real-time insights into fluctuations in learners' cognitive demand.

Within the domain of eye-tracking research (Charles & Nixon, 2019; Tao et al., 2019; Liu et al., 2022), pupil size has emerged as one of the most robust physiological indicators of mental effort and processing load. Nevertheless, pupil size is influenced not only by mental load but also by other factors such as fatigue, emotional arousal, and general physiological states (Grandchamp et al., 2014; Martin, 2014). Consequently, although changes in pupil diameter reliably signal fluctuations in the intensity of mental effort, they do not specify the underlying source of the load or the processing stage at which it occurs.

Fixation-related eye movement parameters are widely recognized as sensitive indicators of mental load (Di Stasi et al., 2013; Recarte & Nunes, 2000). Metrics such as the average fixation duration and the cumulative duration of consecutive fixations within a specific area of interest have been shown to reflect an observer's ongoing perceptual and cognitive engagement (Castelhano & Henderson, 2008b; Henderson & Ferreira, 2004; Castelhano et al., 2009). Empirical research consistently demonstrates that prolonged fixation durations correspond to an increased need for detailed visual analysis, particularly when individuals encounter contextually incongruent or unexpected elements within a scene. Accordingly, fixation duration is considered a reliable marker of higher-order cognitive operations, reflecting the effort required to maintain contextual coherence and synthesize visual input into meaningful representations (Castelhano et al., 2009).

However, in previous studies, contradictory findings have been reported regarding fixation behavior—some showing increased fixation duration with rising mental load, while others observed the opposite pattern (Di Stasi et al., 2013; Recarte & Nunes, 2000; Foy & Chapman, 2018; De Rivecourt & Kuperus, 2008; Liu et al., 2022). These inconsistencies are likely due to the fact that different studies investigated distinct types of mental load, as suggested by Liu et al. (2022) and explained through the Load Theory of Selective Attention (Lavie & Dalton, 2014). When analyzed together, fixation duration and fixation rate can effectively distinguish between perceptual load and working memory load (Liu et al., 2022). A high perceptual load is typically characterized by shorter fixation durations and higher fixation frequencies, suggesting that learners must perform more fixations to comprehend visually dense materials. In contrast, a high working memory load is reflected by longer fixation durations and lower fixation frequencies, indicating greater cognitive effort to organize and retain information.

Framework description

Within the context of TEL platforms, real-time eye-tracking data provides valuable insights into learners' cognitive and emotional states, thereby enabling personalized and adaptive learning experiences through advanced user profiling (Ivanović et al., 2018). Among TEL systems that incorporate eye-tracking technology, one notable example is AdeLE (Gütl & García-Barrios, 2005), which integrates gaze data with content-tracking information to deliver adaptive instructional experiences tailored to individual learners' behaviors and needs. Another example is E5Learning (Calvi et al., 2008), which employs real-time eye-tracking metrics to assess cognitive workload, comprehension challenges, and fatigue, dynamically adjusting the content presentation accordingly. Specifically, E5Learning analyzes data across two consecutive time intervals: a decrease in blink rate, an increase in fixation count, or a rise in the arithmetic mean of pupil diameter is interpreted as an indication of high workload or non-understanding. To detect fatigue, the system computes the mean pupil diameter and blink frequency - if the pupil diameter values exhibit a monotonic increase, this trend is classified as a sign of tiredness (Calvi et al., 2008).

While several TEL systems, such as AdeLE and E5Learning, have demonstrated the potential of integrating eye-tracking technology to support adaptive learning, the theoretical understanding of how these systems influence learners' cognitive processes remains incomplete. Although comprehensive reviews have explored the general role of TEL in higher education (Kirkwood & Price, 2014; Ivanović et al., 2017), limited empirical evidence exists concerning its specific impact on perceptual load, particularly as revealed through eye-tracking measures. The Load Theory of Selective Attention (Lavie & Dalton, 2014) provides a useful framework for investigating the sustainability of learners' mental processes in technology-based environments and for designing instructional approaches that enhance efficiency by balancing perceptual and working memory load.

Research grounded in CLT has predominantly explored strategies to regulate intrinsic cognitive load, for example by assessing and adjusting instructional design according to learners' prior knowledge (Kalyuga et al., 2003) or by enhancing germane load through the refinement of instructional materials (Cierniak et al., 2009; Martin, 2014). However, understanding perceptual load as a complementary factor is equally important for explaining how learners process and retain information. Integrating insights on perceptual load derived from eye-tracking metrics provides an opportunity to further optimize TEL systems. By analyzing how learners visually interact with instructional content, TEL environments can dynamically adapt to individual cognitive capacities, identify sources of extraneous load, and guide educators in improving instructional effectiveness. This perspective is particularly relevant for the development of adaptive systems capable of assessing and regulating mental load at its source. Building on prior research (Bend & Öörni, 2025), the present study proposes the use of fixation-based eye-tracking metrics, specifically fixation duration and fixation rate, as indicators for assessing perceptual load. These measures provide actionable insights for designing adaptive TEL systems that cater to individual learners' needs, ultimately enhancing educational outcomes.

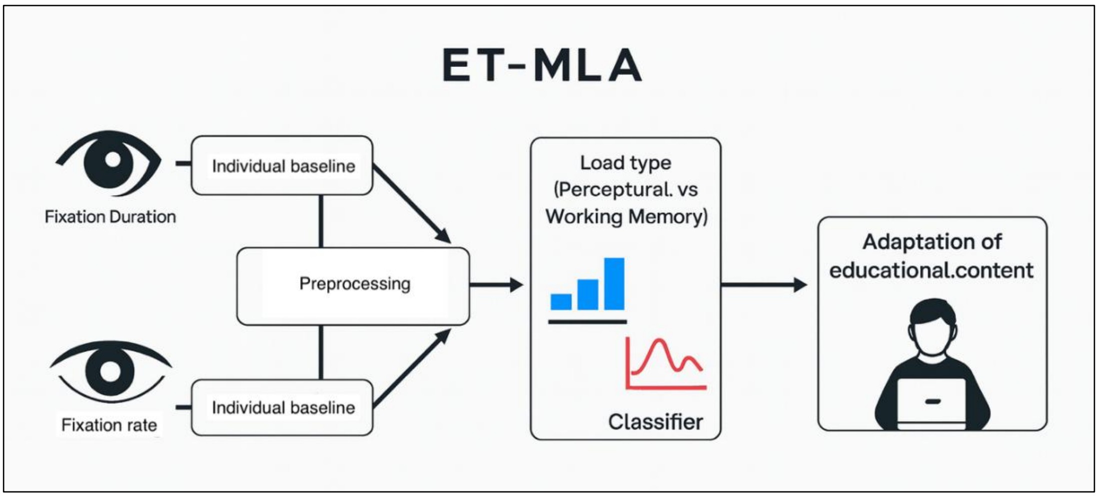

Figure 1. Eye-Tracking Mental Load Assessment Framework

The ET-MLA (Eye-Tracking Mental Load Assessment) framework is founded on three key principles: 1) the combination of fixation duration and fixation rate can be used to differentiate between perceptual and working memory load; 2) fixation-related parameters are idiosyncratic, requiring the establishment of individual Eye-Movement Behaviour Profiles (EmBPs); and 3) appropriate adaptation of learning content can reduce extraneous cognitive load and enhance learning outcomes (see Figure 1).

Grounded in the Load Theory of Selective Attention (Lavie & Dalton, 2014; Liu et al., 2022), the framework offers a practical approach for assessing and identifying sources of extraneous cognitive load in TEL environments. In the initial phase, baseline values for fixation duration and fixation rate are established through a simple calibration task. These individual baseline metrics are then referenced during the learning phase, where fixation-related parameters are continuously monitored and preprocessed. In the subsequent stage, a classifier interprets these data to determine whether the learner is experiencing high perceptual load or high working memory load. Specifically, shorter fixation durations combined with higher fixation frequencies indicate elevated perceptual load, while longer fixation durations coupled with lower fixation frequencies signify increased working memory load. Based on these assessments, the learning system dynamically adjusts instructional content to optimize cognitive efficiency and support adaptive learning.

Principle 1: The combination of fixation-related metrics.

Effort spent on processing irrelevant information or performing redundant actions contributes to extraneous cognitive load, diverting mental resources away from meaningful learning. When perceptual load becomes excessively high, learners' capacity to process relevant information is constrained, forcing them to expend additional extraneous effort to comprehend the material. Likewise, excessively high working memory load can exhaust cognitive resources, further intensifying extraneous demands. By accurately distinguishing between perceptual and working memory load through fixation-based measures, educators and system designers can minimize unnecessary cognitive strain and maximize germane load, resulting in more effective instructional strategies.

For instance, excessively high perceptual load, reflected by shorter fixation durations and higher fixation frequencies, indicates that learners process only small segments of relevant information per fixation due to the visual density of the material. Conversely, excessively high working memory load, marked by longer fixation durations and lower fixation frequencies, suggests difficulties in organizing and integrating the presented information, implying challenges in identifying essential content and efficiently allocating cognitive resources (Liu et al., 2022). In both cases, redesigning instructional materials for improved clarity and organization, together with training learners in effective interaction strategies, can reduce unnecessary mental load and enhance overall learning outcomes.

Principle 2: Individual eye-movement behavior profiles.

It is important to recognize that individuals exhibit idiosyncratic and stable eye-movement patterns, reflecting consistent differences in how they visually explore and process information. Although all individuals with normal vision share broadly similar eye-movement behaviors - characterized by rapid shifts between locations (saccades) and brief moments of relative stability (fixations) during which information is extracted - the specific parameters of these movements, such as their frequency and duration, vary across individuals and contexts (Poynter et al., 2013).

While the basic eye-movement program remains universal across visual scenes and tasks, its fine-grained characteristics depend on both visual and psychological factors, including attentional control, cognitive style, and task demands. Empirical studies have shown that individuals display stable and idiosyncratic eye-movement signatures across multiple visual tasks (Castelhano & Henderson, 2008a; Rayner et al., 2007; Poynter et al., 2013). For example, fixation duration and saccade amplitude tend to remain consistent within individuals despite variations in task type, and similar stability has been observed for fixation rate, fixation size, microsaccade rate, and microsaccade amplitude (Castelhano & Henderson, 2008a; Rayner et al., 2007; Poynter et al., 2013). These findings suggest that each learner possesses a relatively stable eye-movement behaviour profile (EmBP) that reflects their characteristic attentional and perceptual processing patterns.

Because eye movements occur with remarkable frequency, it is likely that the spatio-temporal patterns of visual attention associated with these movements are largely governed by automatic, subconscious mechanisms. As a result, variations in an individual's Eye-Movement Behaviour Profile can serve as a sensitive marker of subconscious neural activity, offering valuable insight into the processes that precede and shape conscious perception and behaviour (Poynter et al., 2013).

Individual configurations of eye-movement metrics may serve as reliable indicators of a person's attentional capacity and control. Poynter et al. (2013) demonstrated that participants with higher attention-deficit scores exhibited a distinctive eye-movement pattern - characterized by more frequent fixations of shorter duration and larger spatial extent, combined with fewer microsaccades of greater amplitude. This pattern parallels the oculomotor behaviour typically observed in individuals with attention-deficit/hyperactivity disorder (ADHD), who often experience challenges in maintaining fixation. These findings provide compelling evidence that even among typically developing individuals, there exist unique and stable EmBPs that reflect enduring differences in attentional regulation, perceptual strategies, and cognitive control mechanisms.

Only a limited number of studies have investigated fixation-related parameters in the context of adaptive displays. One of the earliest examples is E5Learning (Calvi et al., 2008), which utilized a combination of eye-tracking metrics - including number of blinks, number of fixations, and pupil diameter - to identify learner states such as tiredness or a "high workload or non-understanding phase." To detect high workload, the system compared data across two consecutive 120-second intervals and used one or more of the following indicators: a decrease in blink frequency, an increase in fixation count, or an increase in the arithmetic mean of pupil diameter. However, the study's description of how adaptive adjustments were triggered lacked specificity. The condition for opening a new window was defined only as occurring when "fixation time within a region of interest exceeds a threshold," without further clarification of how this threshold was calculated.

In a later study, Lalle et al. (2019) developed a system designed to guide users' attention toward relevant chart data at moments when it was most pertinent - for instance, when their gaze corresponded to a specific piece of text. Eye-tracking was employed to extract fixation-based parameters, but a key challenge lay in determining how many fixations were needed to process a reference. The researchers addressed this by computing the average fixation count from prior datasets (ranging from 8 to 45 fixations; M = 24, SD = 10). During piloting, an initial trigger threshold of 60% was found to be too delayed and was subsequently reduced to 40%. The results indicated that adaptive highlighting interventions improved performance primarily among users with low visualization literacy, while no additional benefit was observed for those with high visualization literacy. These findings reaffirm that fixation duration and rate are highly idiosyncratic, suggesting that group-level thresholds are insufficient and that thresholds should instead be individually calibrated for each learner to ensure effective adaptation.

Principle 3: Proper adaptation of learning content.

Proper adaptation of learning content plays a crucial role in reducing cognitive load and enhancing learning outcomes. As demonstrated by Poynter et al. (2013), participants with higher attention-deficit scores exhibited eye-movement patterns similar to those commonly observed in individuals with attention-deficit/hyperactivity disorder (ADHD) - including difficulties in maintaining fixation, inhibiting intrusive saccades, and controlling eye movements. These findings highlight the potential of adaptive interventions, such as real-time guidance that directs users' attention toward relevant information in charts or text through contextual highlighting, to support learners' attentional control and information processing.

It is also important to note that attentional skills, such as attention switching and selective focus, can be improved through deliberate training. Research has shown that both children and adults who frequently play action video games experience greater interference from distractors under high perceptual load but simultaneously develop more efficient attentional control mechanisms (Dye et al., 2009; Murthy et al., 2016). This suggests that such interactive activities may strengthen the ability to manage perceptual load, offering valuable insights for future educational research. Training students in general attentional strategies, such as flexible shifting of focus and efficient filtering of irrelevant stimuli, may produce transferable benefits across a variety of tasks and learning domains (Martin, 2014). Nevertheless, educators should remain aware of individual differences in attentional capacity and cognitive style, as these factors can moderate the effectiveness of adaptive interventions.

Among the possible ways in which TEL systems can integrate fixation rate and fixation duration to enhance learning, two principal approaches can be identified: highlighting information and updating the display. The first approach involves using eye-tracking–based adaptive displays that direct learners' attention toward the most relevant information on the screen without altering or adding new elements (Chahine et al., 2023). For example, Sharma et al. (2016) employed red rectangles to highlight key areas while participants watched instructional videos, and Lalle et al. (2019) applied gaze-driven adaptive interventions in narrative visualizations, where relevant text passages were dynamically highlighted based on users' gaze behavior. Such attention-guiding mechanisms can be especially beneficial for learners with higher attention-deficit scores, as they help maintain focus on essential content and minimize distraction.

The second approach, updating the display, entails modifying the interface or its content in real time based on the learner's visual behavior. One form of this adaptation involves rendering or emphasizing only the region at the point of gaze, as demonstrated by Bektas Coltekin et al. (2015), who applied a vignette effect that dimmed peripheral areas while maintaining brightness and contrast in the focal region. Another example concerns bringing items closer to the point of gaze, such as in reading applications where translations appear dynamically near the user's fixation point (Ho et al., 2018). A further variation includes adding supplementary information to support task performance, for instance, displaying numerical indicators that show how long users have viewed specific graphs within an information dashboard (Toreini et al., 2022). Finally, adaptive systems may adjust interface settings, such as automatically modifying the difficulty level of an interactive game like Tetris in response to fluctuations in measured mental load (Spiel et al., 2019). Together, these examples illustrate how fixation-based adaptation can make TEL environments more responsive, optimizing cognitive efficiency, reducing extraneous load, and fostering personalized learning experiences.

Discussion

Research on digital learning technologies often attributes individual differences in learning outcomes to variations in mental load; however, the direct measurement of the mental load experienced by learners is rarely conducted due to significant practical and theoretical challenges in obtaining reliable and valid measures (Brünken et al., 2003; Martin, 2014). Understanding how individual differences influence performance on learning tasks is crucial, as these differences can substantially affect how load impacts working memory processes. Working memory capacity is closely linked to an individual's ability to regulate attention and varies considerably across individuals (Martin, 2014). Moreover, variations in the sources of mental load can lead to similar overall levels of perceived load across learners, making it challenging to determine the precise origin of cognitive demands. Therefore, measures of mental load should not be interpreted as representing a single, uniform construct but rather as indicators of distinct load types, each of which contributes differently to learning outcomes (Kalyuga & Sweller, 2005; Martin, 2014). The study by Lalle et al. (2019) highlights the significant influence of long-term user characteristics - including cognitive abilities and personality traits - on how individuals process visual information. Factors such as visualization literacy, verbal working memory, reading proficiency, verbal IQ, and need for cognition collectively shape how efficiently users engage with complex visual and textual materials. These findings reinforce the importance of providing adaptive support tailored to individual differences, as such characteristics directly influence mental load.

In recent decades, the world has witnessed a rapid increase in the volume of digital data available across educational and professional contexts. However, human cognitive capacities are often insufficient to effectively discern which elements of a complex visual display or information stream are most relevant—particularly under conditions of high cognitive workload (Chahine et al., 2023). One promising approach to addressing this challenge is the use of adaptive displays, which dynamically adjust visual or informational content based on user behavior and performance (Hameed & Sarter, 2009).

This study underscores the significant role of eye-tracking technology in advancing adaptive displays for TEL systems and introduces the ET-MLA (Eye-Tracking Mental Load Assessment) framework, designed for application within TEL environments. The framework emphasizes the importance of establishing individual baselines for fixation-related metrics, acknowledging the idiosyncratic nature of these measures (Poynter et al., 2013). The combined analysis of fixation rate and fixation duration provides meaningful insight into differentiating between perceptual and working memory load (Lavie & Dalton, 2014; Liu et al., 2022). In future work, we plan to implement the ET-MLA framework within an e-learning platform and conduct an experiment integrating objective performance metrics, eye-tracking data, and subjective self-reports to further validate its applicability.

Conclusion

This study highlights the importance of assessing and differentiating mental load in technology-enhanced learning (TEL) environments. The proposed ET-MLA (Eye-Tracking Mental Load Assessment) framework offers a novel approach to distinguishing between perceptual and working memory load using fixation-related eye-tracking metrics. By accounting for individual baselines in eye-movement behavior, this model enables more accurate, personalized interpretations of cognitive states. Implementing ET-MLA in adaptive TEL systems can enhance instructional design, reduce extraneous cognitive load, and improve learning efficiency.

References

Ayres, P. & Van Gog, T. (2009). State of the art research into cognitive load theory. *Computers in Human Behavior*, 25, pp. 253–257. https://doi.org/10.1016/j.chb.2008.12.007

Bektaş, K., Çöltekin, A., Krüger, J., Duchowski, A. T., Fabrikant, S. I. (2019). GeoGCD: Improved visual search via gaze-contingent display. In *Proceedings of the 11th ACM Symposium on Eye Tracking Research & Applications* (pp. 1- 10). Conference on Visualization (EuroVis) - Short Papers, pp. 67–71. The Eurographics Association, 2015. https://doi.org/10.1145/3317959.3321488

Bend, J. & Öörni (2025). A. Sex Differences in Numerosity Perception: Eye-Tracking Insights on Perceptual Load and Visuospatial Abilities. *Journal of eye movement research.* 18(2), 9. https://doi.org/10.3390/jemr18020009

Brünken, R., Plass, J. L., Moreno, R. (2010). Current issues and open questions in cognitive load research. In J. L. Plass, R. Moreno, & R. Brünken (Eds.), Cognitive load theory, pp. 253–272. Cambridge, NY: *Cambridge University Press.*

Brünken, R., Plass, J. L., Leutner, D. (2003). Direct measurement of cognitive load in multimedia learning. *Educational Psychologist*, 38, pp. 53–61. https://doi.org/10.1207/S15326985EP3801_7

Calvi, C., Porta, M., Sacchi, D. (2008). e5Learning, an e-learning environment based on eye tracking. *In Advanced Learning Technologies*. ICALT'08. Eighth IEEE International Conference on. IEEE, Los Alamitos, CA, pp. 376– 380. http://doi.org/10.1109/ICALT.2008.35.

Castelhano M.S. and Henderson, J. M. (2008a). Stable Individual Differences Across Images in Human Saccadic Eye Movements. *Canadian Journal of Experimental Psychology*, Vol. 62, No. 1, pp. 1–14. https://doi.org/10.1037/1196-1961.62.1.1

Castelhano, M. S. & Henderson, J. M. (2008b). The influence of color on the perception of scene gist. *Journal of Experimental Psychology: Human Perception and Performance,* 34, pp. 660–675. https://doi.org/10.1037/0096-1523.34.3.660

Castelhano, M. S., Mack, M., Henderson, J. M. (2009). Viewing task influences eye movement control during active scene perception. *Journal of Vision*, Vol.9, 6. https://doi.org/10.1167/9.3.6

Chahine, W., Hachem, N., Moacdieh, N.M. (2023). Eye Tracking-Based Adaptive Displays: A Review of the Recent Literature. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 2023, Vol. 67(1), pp. 927–932.

https://doi.org/10.1177/21695067231192631

Chandler, P. & Sweller, J. (1991). Cognitive load theory and the format of instruction. *Cognition and Instruction*, 8, pp. 293–332. https://doi.org/10.1207/s1532690xci0804_2

Charles, R. L. & Nixon, J. (2019). Measuring mental load using physiological measures: A systematic review, *Applied Ergonomics*, Vol. 74, pp. 221-232, https://doi.org/10.1016/j.apergo.2018.08.028

Choi, Y., Lee, H. (2022). Psychometric Properties for Multidimensional Cognitive Load Scale in an E-Learning Environment. *Int. J. Environ. Res. Public Health*, *19*, 5822. https://doi.org/10.3390/ijerph19105822

Cierniak, G., Scheiter, K., & Gerjets, P. (2009). Explaining the split-attention effect: Is the reduction of extraneous cognitive load accompanied by an increase in germane cognitive load? *Computers in Human Behavior*, 25, pp. 315–324. https://doi.org/10.1016/j.chb.2008.12.020

De Rivecourt, M., Kuperus, M.N., Post, W.J., Mulder, L.J. (2008). Cardiovascular and eye activity measures as indices for momentary changes in mental effort during simulated flight. *Ergonomics* 2008, *51*, pp. 1295–1319, https://doi.org/10.1080/00140130802120267

Di Stasi, L.L.; Antolí, A.; Cañas, J.J. (2013). Evaluating mental load while interacting with computer-generated artificial environments. *Entertain. Comput*, *4*, pp. 63–69, https://doi.org/10.1016/j.entcom.2011.03.005

Dye, M. W. G., Green, C. S., Bavelier, D. (2009). The development of attention skills in action video game players. *Neuropsychologia*, 47, pp. 1780–1789. http://doi.org/10.1016/j.neuropsychologia.2009.02.002

Foy, H.J. & Chapman, P. (2018). Mental load is reflected in driver behaviour, physiology, eye movements and prefrontal cortex activation. *Appl. Ergon*, *73*, pp. 90–99, https://doi.org/10.1016/j.apergo.2018.06.006

Grandchamp, R., Braboszcz, C., Delorme, A. (2014). Oculometric variations during mind wandering. *Frontiers in Psychology*, 5. https://doi.org/10.3389/fpsyg.2014.00031

Guri-Rosenblit, S., and Gros, B. (2011). E-Learning: Confusing Terminology, Research Gaps and Inherent Challenges, *Journal of Distance Education*, 25.

Gütl, C. & García-Barrios, V. M. (2005). Towards an Advanced Modeling System applying a Service-based Approach. *Proceedings of the Fifth IEEE International Conference* *on Advanced Learning Technologies (ICALT'05).* https://doi.org/10.1109/ICALT.2005.289

Hameed, S., & Sarter, N. (2009). Context-Sensitive Information Presentation: Integrating Adaptive and Adaptable Approaches to Display Design. *Human factors and ergonomics*, pp. 1694-1698. https://doi.org/10.1177/154193120905302208

Henderson, J. M., & Ferreira, F. (2004). Scene perception for psycholinguists. In J. M. Henderson & F. Ferreira (Eds.), The interface of language, vision, and action: Eye movements and the visual world (pp. 1–58). New York: *Psychology Press.*

Ho, T., Wang, H., Lai, S. (2018) Non-native Language Reading Support with Display of Machine Translation Based on Eye- Tracking and Sentence-Level Mapping. In *Proceedings of the Sixth International Symposium of Chinese CHI (ChineseCHI '18)*. Association for Computing Machinery, New York, NY, USA, pp. 57–63. https://doi.org/10.1145/3202667.3202675

Ivanović, M., Klašnja-Milićević, A., Ivković, J., Porta, M. (2017). Integration of Eye Tracking Technologies and Methods in an E-learning System. *In Proceedings of BCI* '17. https://doi.org/10.1145/3136273.3136278

Ivanović, M., Klašnja Milićević, A., Aleksić, V., Bratić, B., Mandić, M. (2018). Experiences and perspectives of Technology-enhanced learning and teaching in higher education – Serbian case, *Procedia Computer Science,* Volume 126, pp. 1351-1359. https://doi.org/10.1016/j.procs.2018.08.086.

Kalyuga, S., Ayres, P., Chandler, P., Sweller, J. (2003). The expertise reversal effect. *Educational Psychologist*, 38, pp. 23–31, https://doi.org/10.1207/S15326985EP3801_4

Kalyuga, S. & Sweller, J. (2005). Rapid dynamic assessment of expertise to improve the efficiency of adaptive e-learning. *Educational Technology Research and Development*, 53, pp. 83–93. https://doi.org/10.1007/BF02504800

Kalyuga, S. & Liu, T.-C. (2015). Guest Editorial: Managing Cognitive Load in Technology-Based Learning Environments. *Journal of Educational Technology & Society,* 18(4), pp. 1–8. http://www.jstor.org/stable/jeductechsoci.18.4.1

Keeble, R. J. & Macredie, R. D. (2000). Assistant agents for the world wide web intelligent interface design challenges. *Interacting with Computers*, pp. 357-381. https://doi.org/10.1016/S0953-5438(99)00004-1

Kirkwood, A. & Price, L. (2014). Technology-enhanced learning and teaching in higher education: what is 'enhanced' and how do we know? A critical literature review.

Learning, Media and Technology, 39 (1), pp. 6–36. https://doi.org/10.1080/17439884.2013.770404.

Lallé, S., Toker, D., Conati, C. (2019). Gaze-driven adaptive interventions for magazine-style narrative visualizations. *IEEE Transactions on Visualization and Computer Graphics*, *27*(6), pp. 2941-2952. https://doi.org/10.1109/tvcg.2019.2958540

Lavie, N. & Dalton, P. (2014). Load theory of attention and cognitive control. In *The Oxford Handbook of Attention*; Oxford University Press: Oxford, UK, pp. 56–75.

Lazarides, R., Dietrich, J., Taskinen, P.H. (2019). Stability and change in students' motivational profiles in mathematics classrooms: The role of perceived teaching. *Teaching and Teacher Education*, 79, pp. 164-175. https://doi.org/10.1016/j.tate.2018.12.016

Leppink, J., Paas, F., Van der Vleuten, C.P.M. *et al.* (2013). Development of an instrument for measuring different types of cognitive load. *Behav Res* 45, pp. 1058–1072. https://doi.org/10.3758/s13428-013-0334-1

Liu, J.C., Li, K.A., Yeh, S.L., Chien, S.Y. (2022). Assessing Perceptual Load and Cognitive Load by Fixation-Related Information of Eye Movements. *Sensors*, 22, 1187. https://doi.org/10.3390/s22031187

Martin, S. (2012). Does instructional format really matter? Cognitive load theory, multimedia and teaching English Literature. *Educational Research and Evaluation*, 18, pp. 125–152. https://doi.org/10.1080/13803611.2012.659899

Martin, S. (2014). Measuring cognitive load and cognition: metrics for technology-enhanced learning. *Educational Research and Evaluation*, *20* (7–8), pp. 592–621. https://doi.org/10.1080/13803611.2014.997140

Mayer, R.E. & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist*, 38 (1), pp. 43-52, https://doi.org/10.1207/S15326985EP3801_6

Murthy G., Groeger J.A., Greene C.M. (2016). Twenty years of load theory—Where are we now, and where should we go next? *Psychon Bull Rev.,* 23, pp. 1316–1340, http://doi.org/10.3758/s13423-015-0982-5

Poynter, W., Barber, M., Inman, J., Wiggins, C. (2013). Individuals exhibit idiosyncratic eye-movement behavior profiles across tasks. *Vision Research*, 89, pp. 32–38. http://dx.doi.org/10.1016/j.visres.2013.07.002

Rayner, K., Li, X., Williams, C., Cave, K., Well, A. (2007). Eye movements during information processing tasks: Individual differences and cultural effects. Vision Research, 47, pp. 2714–2726. https://doi.org/10.1016/j.visres.2007.05.007

Recarte, M.A. & Nunes, L.M. (2000). Effects of verbal and spatial-imagery tasks on eye fixations while driving. *J. Exp. Psychol. Appl.*, *6*, pp. 31–43, https://doi.org/10.1037/1076-898X.6.1.31

Sharma, K., Alavi, H. S., Jermann, P., Dillenbourg, P. (2016). A gaze-based learning analytics model: in-video visual feedback to improve learner's attention in MOOCs. In *Proceedings of the sixth international conference on learning analytics & knowledge,* pp. 417-421. https://doi.org/10.1145/2883851.2883902

Skuballa, I.T., Dammert, A., Renkl, A. (2018). Two kinds of meaningful multimedia learning: Is cognitive activity alone as good as combined behavioral and cognitive activity? *Learning and Instruction*, 54, pp. 35-46. https://doi.org/10.1016/j.learninstruc.2018.02.001

Spiel, K., Bertel, S., Kayali, F. (2019). Adapting Gameplay to Eye Movements-An Exploration with TETRIS. In *Extended Abstracts of the Annual Symposium on Computer- Human Interaction in Play Companion Extended Abstracts,* pp. 687-695. https://doi.org/10.1145/3341215.3356267

Tao, D., Tan, H., Wang, H., Zhang, X., Qu, X., Zhang, T. (2019). A Systematic Review of Physiological Measures of Mental load. *Int. J. Environ. Res. Public Health*, 16, 2716, https://doi.org/10.3390/ijerph16152716

Toreini, P., Langner, M., Maedche, A., Morana, S., Vogel, T. (2022). Designing Attentive Information Dashboards. *Journal of the Association for Information Systems*. https://doi.org/10.17705/1jais.00732

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Chapter IV

Research Trends on Youth Political Participation A Bibliometric Analysis

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Abstract

Political participation represents a form of voluntary engagement by citizens in the process of electing leaders and shaping public policy, either directly or indirectly. In recent decades, youth political participation has gained significant attention in political science studies, in line with the growing awareness of their strategic role in strengthening democracy. This study employs a bibliometric analysis of 1,076 articles from the Scopus database published between 2020 and 2025 to examine trends, dominant keywords, geographical contributions, author and institutional impact, and the development of scientific literature related to youth political participation. Data analysis using RStudio, VOSviewer, and Excel identifies five major thematic clusters: (1) Active Citizenship and Political Socialization among Youth; (2) Digital Political Participation and Social Media in Generation Z; (3) Social Identity, Critical Consciousness, and Civic Development in Adolescents; (4) Social Well-being and Health as

Foundations for Youth Political Engagement; and (5) Youth Activism and Leadership in Global Issues. These findings are expected to serve as a valuable reference for scholars and practitioners interested in further developing this field of study and to contribute to the enhancement of civic education and democratic engagement among young people.

Keywords: political participation, youth, bibliometric analysis, trend analysis, democratic engagement

Introduction

Political participation is generally defined as the involvement of individuals or groups in activities aimed at influencing political decision-making, whether through formal channels such as elections or through non-electoral actions such as protests, public discussions, or social campaigns. This activity serves as a key indicator of a country's democratic quality, as it reflects the degree of citizen engagement in public decision-making processes. Beyond voting, political participation encompasses various forms of involvement, including advocacy, the use of social media, and civic education elements that have become increasingly significant in the digital era and in modern democracies.

In recent developments, international studies highlight a shift in patterns of political participation from conventional practices toward more digital and issue-based forms. Globally, participation is measured not only by voter turnout at polling stations but also by engagement in public discourse, involvement in collective action, and participation in policy advocacy (Jeroense & Spierings, 2022).

This transformation is strongly influenced by the advancement of information technology and the shifting characteristics of the younger generation, who have now become key actors in the constellation of democracy. The younger generation plays an increasingly central role in addressing contemporary democratic challenges such as declining public trust, social polarization, and low levels of formal participation. This generation is known for its distinct patterns of engagement compared to previous generations. They are more digitally connected, tend to engage in episodic and issue-based participation, and utilize social media and digital technology as their primary channels for political involvement (Suhariyanto & Rozak, 2025). National and international studies indicate that social media plays a significant role in enhancing the political engagement of young generations, both through online discussions, digital campaigns, and advocacy on specific issues (Sadikin, 2025).

However, their patterns of participation do not always follow formal channels such as political party membership or involvement in elections. Instead, their engagement is often manifested through digital actions, such as disseminating information, conducting social media campaigns, and participating in social movements centered on issues like environmental protection, social justice, or human rights. On the other hand, civic education, government institutional support, and the role of civil society are considered key factors that can encourage young people's political engagement. In other words, the concept of political participation has now expanded in both form and meaning, in line with the socio-political dynamics and technologies utilized by this generation (Haris et al., 2024).

The phenomenon of youth political participation has become an interdisciplinary subject of increasing interest, particularly within political science, sociology, communication studies, and civic education. Nevertheless, studies employing a bibliometric approach to systematically map the direction, trends, and development of literature on youth political participation remain limited. In fact, bibliometric analyses of hundreds or even thousands of articles in databases such as Scopus reveal a significant upward trend in research on this topic, with dominant themes including civic education, digital democracy, engagement through social media, and youth activism.

Furthermore, literature mapping has identified five main thematic clusters frequently appearing in research: (1) political socialization and active citizenship, (2) digital participation and the use of social media, (3) social identity and critical consciousness, (4) social well-being as the foundation of participation, and (5) youth activism on global issues. Unfortunately, much of this research remains context-specific, confined to certain countries or regions, and thus fails to present a comprehensive global landscape (Kitanova, 2020).

The absence of a comprehensive literature mapping hampers the consolidation of knowledge, the identification of research gaps, and the integration of findings across regions and disciplines. Therefore, a bibliometric study capable of developing a global knowledge map on youth political participation research trends is urgently needed. Such a study is crucial for evaluating the development of the field, identifying central themes, and strengthening international collaboration in research and policy-making.

The urgency of this research lies in its contribution to providing a systematic mapping of the global literature from 2020 to 2025 through a bibliometric approach. Using the Scopus database, this study aims to identify key keywords, publication trends, the geographical distribution of authors, and patterns of collaboration between countries and institutions.

Previous studies indicate that research on youth political participation is increasingly focused on issues such as digital engagement, political education, and the role of social media technology, with countries such as the United States, Belgium, and the United Kingdom emerging as leading contributors.

Most existing approaches are quantitative in nature, focusing on variables such as political interest, gender, socioeconomic status, as well as the influence of family, school, and media. Consequently, the mapping generated through this bibliometric analysis is expected to serve as an important reference for identifying trends, dominant themes, and research gaps that can enrich knowledge and support evidence-based participatory policy development.

Thus, this research not only contributes academically to expanding the body of knowledge on youth political participation but also has practical implications for enhancing the quality of a more participatory democracy. Through systematic and data-driven mapping, this study is expected to foster cross-country collaboration among researchers and institutions, while also providing inspiration for educators, activists, and policymakers to design more inclusive and adaptive strategies to promote constructive and transformative political engagement among young people.

Method

Research Design and Data Collection Procedure

This study conducts a descriptive bibliometric analysis to examine the landscape of scientific publications on science literacy from 2020 to 2025. Bibliometric analysis is widely recognized as a powerful approach for reviewing large volumes of scientific literature. This method enables researchers to trace the evolution of a discipline and identify emerging trends (Donthu et al., 2021). It also allows both researchers and readers to gain a comprehensive understanding of the research themes explored within a given time span, supported by statistical assessments of academic contributions (Rejeb et al., 2023). Moreover, bibliometric techniques are effective for mapping the intellectual structure of a research field and identifying new areas of study that are currently developing. Through performance analysis and scientific mapping, bibliometrics facilitates a detailed examination of publication sources, document types, citation patterns, and keyword dynamics (Lethulur, 2024).

This bibliometric analysis follows a rigorous multi-stage screening protocol to ensure the relevance, scientific rigor, and thematic alignment of the literature (Aria & Cuccurullo, 2017; Donthu et al., 2021; Kusharyadi et al., 2023; Singh et al., 2022). This process aligns with established bibliometric methodologies as recommended by (Singh et al., 2022), consisting of database search, scientific screening, language screening, and subject screening. In the first stage (database search), an initial search was conducted in the Scopus database using the keywords *youth* OR *"Youth Activism"* AND *"political engagement"* OR *"Political Participation"* OR *"political involvement"* for the period 2020 to 2025. This search yielded 686 documents. The use of Scopus is justified due to its comprehensive coverage of peer-reviewed publications and its status as a standard reference in bibliometric studies (Paul et al., 2021). In the second stage (scientific screening), to ensure academic validity, only journal articles were retained. This stage excluded 136 documents, such as book chapters, editorials, and non–peer-reviewed publications, leaving a total of 550 documents. This step is consistent with Aria & Cuccurullo's (2017) recommendation to exclude grey literature in order to enhance the scientific credibility of bibliometric datasets. In the third stage (language screening), a language filter was applied to retain only English-language publications. Out of the 550 documents, 499 met this criterion. This practice ensures consistency in analysis and interpretation, given that English remains the dominant language in academic discourse (Singh et al., 2022).

This structured screening approach ensures the validity and reliability of the dataset used for bibliometric mapping, in line with best practices in systematic reviews and scientific mapping studies (Hajjaji et al., 2021). The sequence of the screening process is illustrated in the flowchart below, depicting each stage from initial identification to final inclusion of documents for analysis.

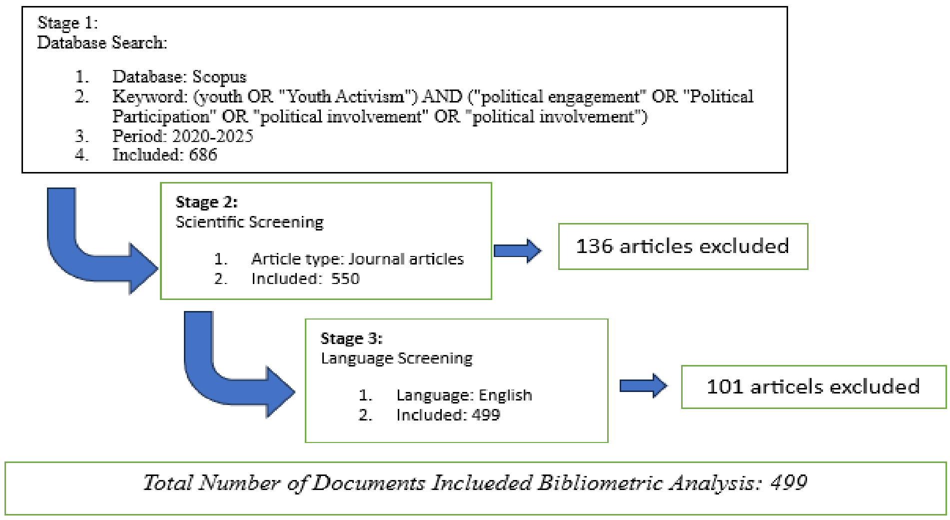

Figure 1. Research Design and Data Collection Procedure

Data Analysis Methods, Validity and Reliability

This study employed VOSviewer version 1.6.20 to generate dynamic and structural visualizations of datasets related to political participation and political science within civic education, following established bibliometric procedures. The data were obtained from the Scopus database, covering the period from 2015 to 2025, and exported in CSV (Comma-Separated Values) format. The CSV file was imported into VOSviewer to construct co-authorship networks, keyword co-occurrence maps, and citation mapping. Simultaneously, the same CSV file was processed using Biblioshiny, the web-based interface of the Bibliometrix R-package, to calculate bibliometric indicators such as the h-index, g-index, total citation count, and to explore thematic evolution and conceptual structures (Aria & Cuccurullo, 2017). In addition, Microsoft Excel was used not only to visualize the global distribution of publication outputs by region on a world map, but also to enhance the clarity and readability of the visualizations for easier interpretation and presentation.

To strengthen the credibility and transparency of the research process, this study provides detailed documentation of each methodological step. This includes the exact date of data retrieval (August 13, 2025), the search syntax applied to the TITLE-ABS-KEY field (*youth* OR *"Youth Activism"* AND *"political engagement"* OR *"Political Participation"* OR *"political involvement"*), the inclusion and exclusion criteria, and the screening flow clearly illustrated in an accompanying process diagram. The analysis was conducted with methodological rigor, documenting the four screening stages database search, scientific screening, language screening, and relevance screening resulting in a final dataset of 499 documents eligible for bibliometric analysis.

It is important to note that this research does not provide interpretive commentary on the findings, in order to ensure objectivity and analytical accuracy. Ethical approval was not required, as the dataset consisted entirely of open-access metadata sourced from the Scopus database. The overall methodological framework aligns with recommended standards for systematic mapping and bibliometric reviews, thereby ensuring the validity and reliability of the results for use in future academic studies.

Table 1. *Summary of the Review* (*Main Information*)

Description	Results
Main Information About Data	
Timespan	2020:2025
Sources (Journals, Books, Etc)	318
Documents	499
Annual Growth Rate %	-0,78
Document Average Age	2,43
Average Citations Per Doc	6,479
References	3895
Document Contents	
Keywords Plus (Id)	735
Author's Keywords (De)	2007
Authors	
Authors	2218
Authors Of Single-Authored Docs	0
Authors Collaboration	
Single-Authored Docs	0
Co-Authors Per Doc	7,19
International Co-Authorships %	18,04
Document Types	
Article	499

Results

The following section will present research trends in science literacy, the countries with the highest contributions to science literacy research, a visualization analysis using VOSviewer, as well as the novelty and focus of research on social literacy and political science.

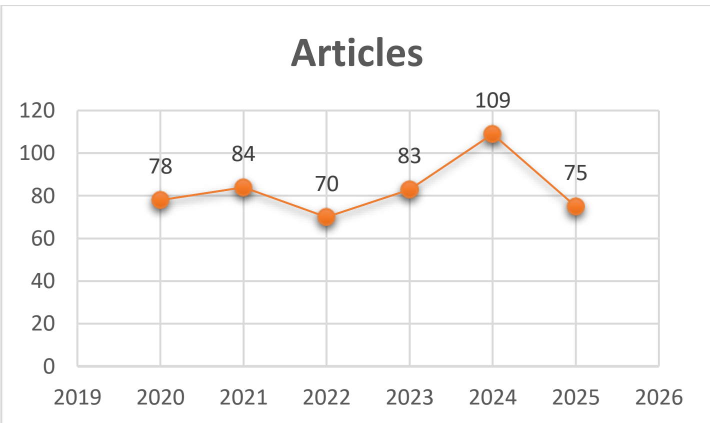

Figure 2. Publication Trends

Figure 2 illustrates the annual distribution of publications on the selected topic from 2020 to 2025. The trend shows moderate fluctuations in the number of articles published during the observation period. In 2020, a total of 78 articles were recorded, followed by a slight increase to 84 articles in 2021. However, this number declined to 70 articles in 2022, marking the lowest point in the dataset. The following year, 2023, saw a recovery with 83 articles, indicating a renewed interest in the research topic. A significant increase occurred in 2024, reaching 109 articles the highest number over the six-year span signaling more intensive academic engagement during this period. Conversely, in 2025, there was a substantial decline to 75 articles, a decrease likely due to the incomplete data collection process for the ongoing year. Overall, the data indicate a momentum of increasing publication volume after 2022, with 2024 standing out as the peak of research activity.

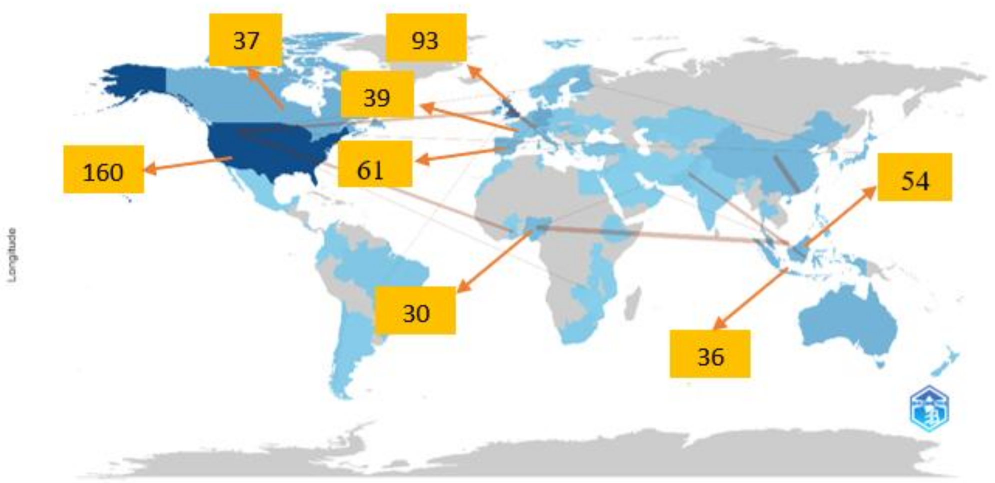

Figure 3. Geographic Distribution

Figure 3 shows that the United States is the leading contributor to research on youth political participation, with a total of 160 recorded publications. This underscores the country's position as a central hub of academic inquiry in this field, likely driven by its strong focus on democracy, civic engagement, and participatory political culture. The United Kingdom ranks second with 93 publications, followed by Portugal in third place with 61 publications. Malaysia ranks fourth with 54 publications, reflecting the significant role of this Southeast Asian nation in the international discourse on youth political participation. Germany and Spain each recorded 39 publications, while Canada produced 37. Indonesia ranks eighth with 36 publications, indicating growing interest and involvement from local scholars in studying political phenomena among young people, although domestic structural challenges and political culture remain obstacles. Nigeria, with 30 publications, represents an important contribution from a developing country in Africa, albeit with a smaller volume compared to leading nations.

The distribution of research contributions reveals a substantial gap between countries with high publication output and others. The dominance of the United States and Western European countries highlights the concentration of research resources and strong academic networks in these regions. Meanwhile, participation from developing countries—though increasingly visible—still requires strengthened international collaboration, increased funding support, and enhanced research capacity. This gap presents a strategic opportunity for developing nations, including Indonesia and Nigeria, to expand their engagement in youth political participation research through global partnerships and multidisciplinary approaches.

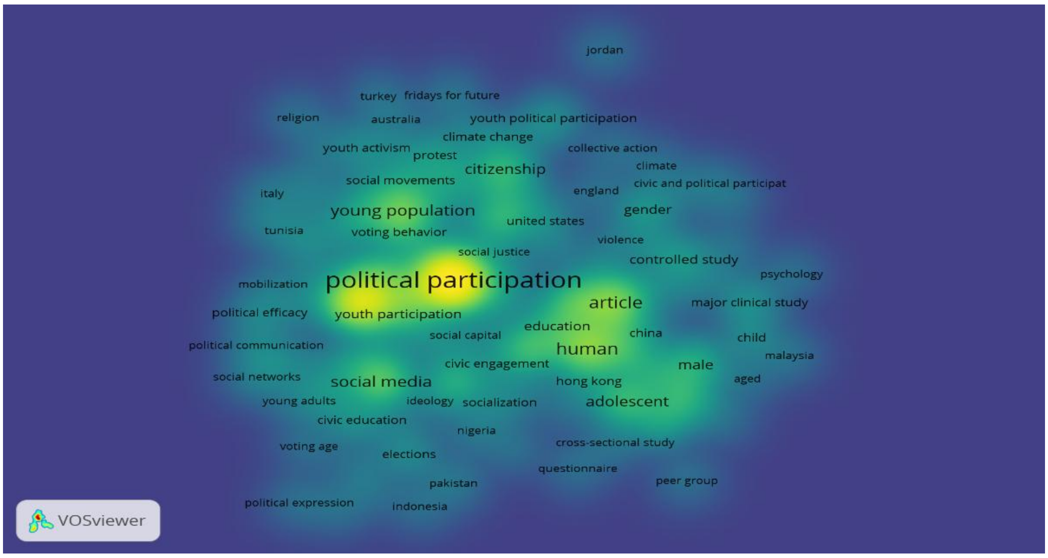

Figure 4. Density Overlay

Figure 4 presents a density visualization map illustrating the relationships and frequency of keyword occurrences in publications on political participation during the study period. The yellow areas indicate keywords with the highest density or most frequent appearances, while green to blue areas represent lower density. This visualization clearly shows that the term *"political participation"* is the central focus of research, marked by a bright yellow color that signifies its dominance in the academic discourse.

Other high-density keywords include *"youth participation"*, *"social media"*, *"citizenship"*, *"human"*, and *"adolescent"*, reflecting the research emphasis on youth engagement in political activities, particularly through social media and civic education. In addition, themes such as *"social justice"*, *"social capital"*, *"civic engagement"*, *"voting behavior"*, and *"civic* *education"* indicate an interest in the social and educational factors influencing political participation. Several geographic keywords, including *"Indonesia"*, *"China"*, *"Malaysia"*, *"United States"*, and *"Nigeria"*, also appear, highlighting the international and comparative dimensions of these studies. Other topics such as *"climate change"*, *"youth activism"*, and *"protest"* suggest that political participation is also linked to contemporary global issues like climate change and social movements. The emergence of terms like *"gender"*, *"education"*, and *"ideology"* further signifies that demographic aspects and political values are important components of this body of research.

In conclusion, the map demonstrates that political participation research in academic literature centers on the interaction between youth, social media, civic education, and global issues. The visualization also reveals the multidimensional interconnections between social, educational, geographical, and ideological factors that shape patterns of political participation across different countries.

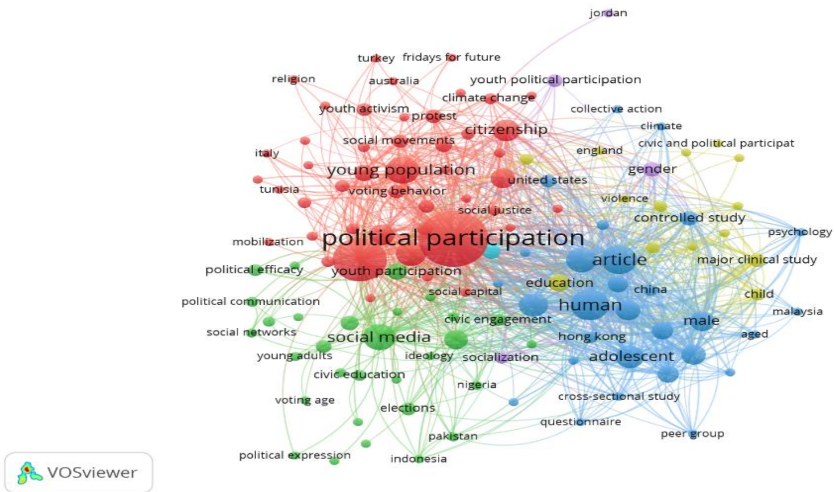

Figure 5. Network Visualization

Figure 5 presents a network visualization map of keywords related to political participation, based on publication data from the past decade. Each node represents a keyword, with its size reflecting the frequency of its occurrence in the literature. Different colors indicate clusters of interrelated research themes, while the connecting lines between nodes represent the relationships or co-occurrences of keywords within publications.

The red cluster is dominated by keywords such as *"political participation"*, *"youth participation"*, *"citizenship"*, *"young population"*, and *"social movements"*. This theme refers to the engagement of citizens particularly the younger generation in political activities and social movements. Terms such as *"climate change"*, *"protest"*, *"youth activism"*, and *"social justice"* indicate the connection between political issues, global agendas, and environmental movements.

The green cluster focuses on keywords like *"social media"*, *"civic education"*, *"civic engagement"*, *"social capital"*, and *"political communication"*. This theme highlights the role of digital technology and social media as new channels for mobilizing political participation, shaping public opinion, and strengthening civic engagement. Keywords such as *"ideology"*, *"elections"*, and *"voting age"* point to a focus on contemporary political dynamics.

The blue cluster contains keywords such as *"human"*, *"adolescent"*, *"male"*, *"education"*, as well as methodological terms like *"cross-sectional study"*, *"controlled study"*, and *"questionnaire"*. This indicates a focus on empirical studies often adopting quantitative approaches that analyze demographic, psychological, and educational factors in political participation.

Although smaller, the yellow cluster includes keywords such as *"gender"*, *"collective action"*, *"climate"*, and *"civic and political participation"*. This theme emphasizes the dimensions of identity and cross-community collaboration in political processes.

Overall, the map demonstrates that research on political participation covers a broad spectrum, ranging from global issue-based activism, the role of social media and civic education, empirical analyses of individual factors, to collective engagement across identities. The interconnections between clusters reveal the multidisciplinary nature of this field, integrating political science, sociology, psychology, education, and media studies. These findings affirm that contemporary political participation is no longer confined to the institutional sphere, but also thrives in digital spaces, social movements, and global public discourse.

Figure 6. Categorization of Keywords

Figure 6 presents a treemap visualization depicting the distribution of keyword occurrence frequencies in research related to political participation, analyzed based on the number of documents containing each keyword. Each box represents a single keyword, with its size indicating the frequency of occurrence, while the percentage reflects its proportion relative to the total dataset.

The keyword *"political participation"* is the most dominant, appearing 234 times (15%), indicating that political participation is the primary focus within the related literature. The keywords *"youth"* (142 occurrences, 9%) and *"human"* (71 occurrences, 5%) follow, highlighting the significant attention given to youth engagement and human aspects in the context of political participation. Additionally, keywords such as *"article"* (67 occurrences, 4%), *"young population"* (57 occurrences, 4%), and *"social media"* (53 occurrences, 4%) demonstrate that academic publications frequently address youth demographics and the role of social media in mobilizing political participation.

Other noteworthy topics include *"political engagement"* (47 occurrences, 3%), *"juvenile"* (45 occurrences, 3%), *"politics"* (41 occurrences, 3%), and *"adolescent"* (39 occurrences, 3%), reinforcing the view that literature pays considerable attention to political involvement across various stages of youth development. Terms such as *"citizenship"*, *"democracy"*, and *"election"* underscore the close connection between civic literacy, democratic processes, and voting behavior. Keywords like *"activism"*, *"civic engagement"*, *"social movement"*, and *"protest"* suggest that political participation extends beyond voting, encompassing collective action and social movements.

Meanwhile, the presence of terms such as *"controlled study"*, *"major clinical study"*, and *"human experiment"* indicates the use of systematic, data-driven empirical research in this field.

Overall, this visualization affirms that the study of political participation is centered on youth engagement, the role of social media, democratic dynamics, and non-electoral forms of participation. These findings are significant as a foundation for understanding global trends in political participation and their relevance to public policy, particularly in promoting youth engagement in the digital era.

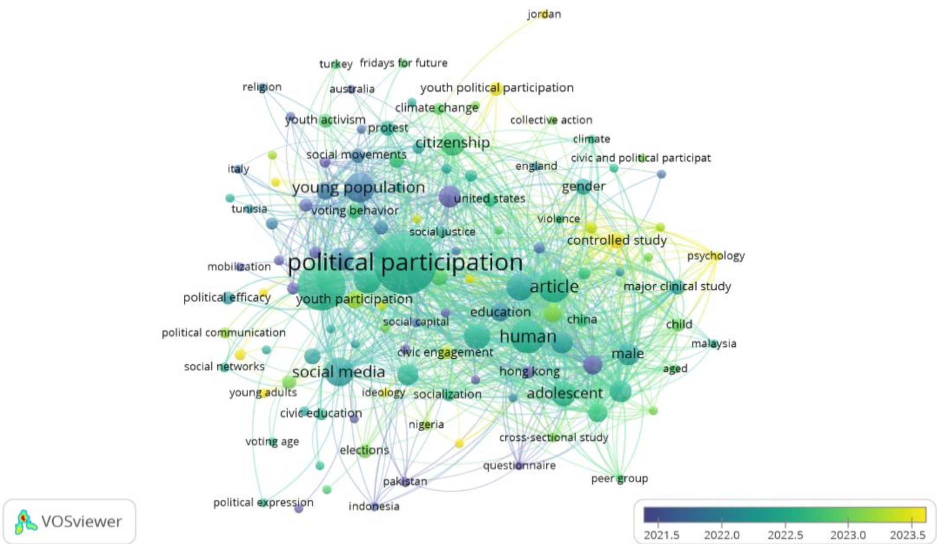

Figure 7. Overlay Visualization

Figure 7 presents an overlay visualization mapping the interrelation of keywords related to political participation over time, using a color scale from blue (early research period around 2021) to yellow (most recent period, 2023). Each node represents a keyword, while connecting lines (edges) indicate co-occurrence relationships in research documents. Node size reflects the frequency of keyword occurrence, whereas color indicates the average year of publication for studies containing the keyword.

The keyword **"**political participation" occupies the central position with the largest node size, indicating it as the primary focus of the research, followed by keywords such as *youth*, *human*, *social media*, *citizenship*, and *adolescent*. Based on color distribution, themes such as *social movements*, *youth activism*, and *climate change* began to appear more frequently during the mid-period (around 2022), while themes such as *controlled study*, *citizenship*, and *youth political participation* emerged as more recent research trends (2023).

This analysis indicates a shift in political participation research from a focus on conceptual and general issues toward more specific and contemporary topics, including youth activism, engagement in environmental issues, and data-driven controlled study approaches. The pattern of keyword connections reveals that political participation research is multidisciplinary, encompassing sociology, education, psychology, and digital media studies.

Therefore, this mapping provides strategic insights that the latest research trends lie at the intersection of youth engagement, global issues such as climate change, and stronger research methodologies. It can thus serve as a reference for developing future research agendas and fostering cross-disciplinary collaborations.

Discussion

The bibliometric analysis indicates that youth political participation has been a steadily growing research topic over the past decade and holds high relevance to global socio-political dynamics. Keyword network visualizations reveal that *political participation* serves as the central theme, with strong connections to topics such as *youth*, *social media*, *citizenship*, *civic engagement*, and *adolescent*. This underscores that youth political engagement is not merely viewed as a matter of democracy, but also as a social phenomenon influenced by developments in technology, education, and civic values.

From a publication trend perspective, the United States occupies a dominant position as the primary contributor to research, followed by countries such as Australia, Germany, Indonesia, and Canada. The significant contribution gap between developed and developing countries suggests untapped research opportunities, particularly for nations where youth political participation remains low. Indonesia, while increasingly visible in the international publication landscape, still has substantial potential to enhance its contribution through international collaborations, capacity building in research, and integrating this topic into education and democracy policies.

The density and network visualizations highlight three main orientations in research on youth political participation. First, a focus on the role of social media and digital technology as tools for mobilizing youth political engagement. Second, attention to demographic, educational, and identity-related factors (such as gender and age) that influence the level of political involvement. Third, connections to global issues such as climate change, social activism, and the *Fridays for Future* movement, indicating that youth political participation is becoming increasingly transnational and issue-driven.

Meanwhile, the overlay visualization suggests a shift in research trends from conceptual studies toward more empirical and data-driven approaches, including controlled and cross-sectional studies. This shift is significant, as it can provide stronger evidence for developing strategies to enhance youth political engagement.

These findings carry practical implications for policymakers, academics, and civil society organizations. First, the need for policies that promote political literacy from secondary school through university, leveraging digital media in a positive way. Second, the importance of building an inclusive democratic ecosystem that opens participatory spaces for youth across diverse social, economic, and cultural backgrounds. Third, the necessity for cross-national collaborative research to identify successful patterns and challenges in youth political participation across various socio-political contexts.

In conclusion, youth political participation is not only an academic subject to be understood but also a strategic issue for ensuring the sustainability of democracy in the global era. Future research should aim not only to map trends but also to develop evidence-based interventions to strengthen the voice and role of young people in political processes.

Conclusion

A bibliometric analysis of research trends in youth political participation shows that this topic has emerged as a significant focus within global academic discourse, with consistent publication growth over the past five years. The geographical distribution of studies reveals the dominance of developed countries particularly the United States, the United Kingdom, and Australia as major hubs of scientific production. However, developing countries have begun to demonstrate increasing contributions, indicating a widening attention to this issue across diverse socio-political contexts.

Keyword categorization reveals five closely interconnected clusters: pedagogical approaches, social contexts, learning strategies, environmental issues, and educational policy. This underscores that youth political literacy does not stand alone but is instead the result of interactions between education, social environments, and public policy.

Overall, these findings provide a comprehensive intellectual map of youth political participation. They serve as a foundation for designing more systematic, relevant, and impactful educational programs and research initiatives, while also fostering international collaboration to broaden cross-cultural understanding and enhance youth political participation on a global scale.

Recommendations

Based on bibliometric findings on research trends in youth political participation, several strategic recommendations can serve as references for researchers, policymakers, and political education practitioners. The analysis of author networks and geographical distribution shows that research remains concentrated in certain regions, while the involvement of developing countries is relatively low. Therefore, more intensive international collaboration should be encouraged, particularly those connecting researchers from developed and developing countries, and integrating multidisciplinary perspectives such as political science, sociology, education, and information technology.

On the other hand, the keyword mapping results indicate that major research themes are still dominated by general issues such as political participation, youth engagement, and civic education, while local aspects and country or community-specific political cultures remain underexplored. This highlights the need for studies that examine cultural, social, and economic factors influencing youth political participation in specific contexts, so that the findings become more contextualized and relevant.

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References

Aria, M., & Cuccurullo, C. (2017). bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics*, *11*(4), 959–975. https://doi.org/10.1016/j.joi.2017.08.007

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research*, *133*, 285–296. https://doi.org/https://doi.org/10.1016/j.jbusres.2021.04.070

Hajjaji, Y., Boulila, W., Farah, I. R., Romdhani, I., & Hussain, A. (2021). Big data and IoT-based applications in smart environments: A systematic review. *Computer Science Review*, *39*, 100318. https://doi.org/https://doi.org/10.1016/j.cosrev.2020.100318

Haris, A., Aksa, Y. A. D., & Prastyo, A. B. (2024). The Influence of Social Media Instagram on Generation Z's Political Participation. *Paradigma*. https://doi.org/10.33558/paradigma.v21i1.8814

Jeroense, T., & Spierings, N. (2022). Political participation profiles. *West European Politics*, *46*, 1–23. https://doi.org/10.1080/01402382.2021.2017612

Kitanova, M. (2020). Youth political participation in the EU: evidence from a cross-national analysis. *Journal of Youth Studies*, *23*, 819–836. https://doi.org/10.1080/13676261.2019.1636951

Kusharyadi, R., Pertiwi, S., Siahaan, E. Y. S., & Dasari, D. (2023). Bibliometric Analysis: Sofware Usage Trends GeoGebra in Mathematics Learning From 2017 - 2022. *Prisma Sains : Jurnal Pengkajian Ilmu Dan Pembelajaran Matematika Dan IPA IKIP Mataram*, *11*(1), 196. https://doi.org/10.33394/j-ps.v11i1.6786

Lethulur, N. D. (2024). *1 st Decade of E-learning in Mathematics Education : A Bibliometric Analysis*. *38*(2020), 68–79.

Paul, J., Lim, W. M., O'Cass, A., Hao, A. W., & Bresciani, S. (2021). Scientific procedures and rationales for systematic literature reviews (SPAR-4-SLR). *International Journal of Consumer Studies*, *April*, 1–16. https://doi.org/10.1111/ijcs.12695

Rejeb, A., Rejeb, K., Appolloni, A., Kayikci, Y., & Iranmanesh, M. (2023). The landscape of public procurement research: a bibliometric analysis and topic modelling based on Scopus. In *Journal of Public Procurement* (Vol. 23, Issue 2). https://doi.org/10.1108/JOPP-06-2022-0031

Sadikin, K. R. (2025). The Influence of Social Media Use on the Political Participation of Generation Z. *De Cive : Jurnal Penelitian Pendidikan Pancasila Dan Kewarganegaraan*. https://doi.org/10.56393/decive.v5i2.2499

Singh, S., Solkhe, A., & Gautam, P. (2022). What do we know about Employee Productivity?: Insights from Bibliometric Analysis. *Journal of Scientometric Research*, *11*(2), 183–198. https://doi.org/10.5530/jscires.11.2.20

Suhariyanto, D., & Rozak, A. (2025). Political Participation, Civic Education, and Social Media on Generation Z's Political Engagement. *The Eastasouth Journal of Social Science and Humanities*. https://doi.org/10.58812/esssh.v2i02.455

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Chapter V

Educating Non-STEM Students in Information Science and Technology Using a Top-Down Approach to Teach the Required STEM Concepts

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Abstract

This paper discusses how information science and technology education is sought-after by students from both science, technology, engineering, and mathematics (STEM) backgrounds, as well as those from non-STEM backgrounds. As all office jobs today rely on information technology tools and systems, all professionals require at least a basic education in information science and technology. This paper explores how the education of information science and technology comes in varying degrees and levels, and how non-technology professionals would only require a basic level of information science and technology education. Even though information science and technology, having a mathematical foundation, falls under the STEM category, a basic education in information science and technology does not require as strong a STEM background. If required STEM concepts are taught using a top-down approach, even non-STEM students can successfully obtain a basic education in technology, without being overwhelmed by mathematical concepts which would otherwise be difficult to grasp. This paper explores how these required STEM concepts could be taught in a manner stemming from day-to-day occurrences, to provide non-STEM students with just the required amount of mathematical knowledge sufficient for successfully obtaining a basic level of information science and technology education.

Keywords: Information science, Technology, Education, Non-STEM, Top-down approach

Introduction

Information Science and Technology education has become one of the most sought-after subject areas by many students regardless of their profession, or field of study. This includes not only students from science, technology, engineering, and mathematics (STEM) backgrounds, but also students from non-STEM backgrounds such as arts and humanities, who require some knowledge of information science and technology for their professions. No job in today's technologically advanced world is totally exempt from the use of information science and technology-based tools and systems for performing at least a few tasks. Office jobs in areas such as health information, banking, inventory management, and library information systems, etc. are heavily reliant on information systems (IS) and information technology (IT) tools and applications. Thus, for information professionals in fields such as these, it is paramount to obtain at least a basic education in information science and technology in order to have some understanding as to how these information systems that they use for their day-to-day tasks work, so that they may be able to utilize these systems and tools in an optimal manner. Some higher level professionals in managerial positions, for instance, need to understand the basic inner workings of these systems so that they might know the capabilities of these systems, and understand what goes on behind the scenes when the IT department is called in to fix any issues these systems would inevitably present from time to time. This knowledge is especially helpful when these IT department employees are also subordinates working under these high-level managers, as one would not want to rely completely on one's subordinates for this crucial knowledge. Further, as Senanyake and Fernando (2018) point out, at least a basic knowledge of information security is integral to ensure that users of any information system access and share the information required for their jobs in a proper and secure manner.

Undoubtedly, information science and technology falls under the STEM category, and therefore, in order to fully understand the more advanced concepts of IT and programming it is essential for students to have a strong STEM background with a good foundation in mathematics. However, not all users of information systems come from a STEM background. In fact, the majority of these information users may be from non-STEM backgrounds such as arts and humanities. Yet, as information science and technology education is crucial to their success in their professional careers, their lack of a STEM background should not prevent them from obtaining that education. It is important to realize, however, that not every student requires the same level or depth of knowledge. In fact, information science and technology education could be obtained in varying degrees and levels depending on a person's chosen career or profession. Students pursuing careers in technology, such as software engineering, networking, etc. would undoubtedly require a deeper understanding of information technology, and would therefore require a strong STEM background in order to obtain that in-depth knowledge, whereas others, whose professions would make them information users, but not technology professionals, would only require a basic knowledge of information science and technology so that they may be able to properly utilize the information systems and tools they use, and may obtain that knowledge without a strong STEM background.

Yet, as information science and technology is a subject area which is founded in mathematics, it is undeniable that it would require certain mandatory mathematical and STEM concepts to be studied in order to understand the subject matter. However, first teaching those mathematical concepts and then the information science and technology concepts in the usual bottom-up fashion, where we first lay the required STEM foundation and then build the information science and technology education on top of it, might be rather overwhelming for students from a non-STEM background. Instead, this work proposes a top-down approach to providing information science and technology education to non-STEM students, which would allow them to learn these required mathematical and STEM concepts in a more natural manner stemming from day-to-day occurrences rather than deriving them from mathematical laws and processes, thereby allowing them to successfully obtain the basic level of information science and technology knowledge that they need.

The Need for a Top-Down Approach to Information Science and Technology Education

The commonly practiced method of teaching information science and technology is the bottom-up approach, where the first step is to teach the mathematical concepts that lay the STEM foundation, so that the education of information science and technology can be built on top of that. While this method is straight forward, and perfectly well-suited for students from a STEM background who have an aptitude for mathematics, and while this is the preferred method for students who plan to become technology professionals as they require an in-depth understanding of the theory of information science, so that they may, themselves, create such systems, fix system issues, or invent new tools and technologies in the future, such a deep level of understanding of information science and technology and the theory behind it might not be required by most general users of information systems and tools. Instead, laying a thick mathematical foundation as in a bottom-up approach might lead to non-STEM students being overwhelmed by theoretical concepts for which a practical application might not seem obvious to them. This could lead to these non-STEM students who wished to obtain a basic education in information science and technology being confused and frustrated, and eventually, unsuccessful in their pursuit of education. This paper discusses how utilizing a top-down approach, instead of the usual bottom-up approach could prevent the above scenario and enable these non-STEM students to successfully obtain their basic information science and technology education. It is important to note that the focus of this paper is not those students intending to be technology professionals, but rather, those intending to be information users in other (non-technology-based) industries, but who still need an understanding of these IT systems and tools, and therefore, seek a basic education of information science and technology.

Even though it might seem like stripping down the education of information science and technology, so as to avoid teaching these non-STEM students the mathematical and STEM concepts behind it, is a lazy approach, this is not actually the case. Angell and Demetis (2010) discuss how linearity (one thing after another) is a delusion in this non-linear world. Thus, it can be construed that, as long as it is only a basic level of education, it is not mandatory for an information science and technology education to be built upon a full, solid foundation of mathematics. One of the most beneficial facets in today's world is that education is better available to people, where a person can obtain their higher education at any stage in life, or resume their education even after a long hiatus where they were focusing on their professional careers instead. This being the case, it is of utmost importance that there are multiple different paths of entry into a formal higher education, and that degree programs focus not only on those who have an aptitude towards STEM subjects, but also provide the means for students from non-STEM backgrounds to obtain a basic education in information science and technology.

Another important factor to consider is the advantage that non-STEM thinking brings into the design of information systems, and how the addition of non-STEM students can enrich courses in information science and technology. In fact, it is easy and natural for students with a solid STEM background to think programmatically and create algorithms that provide clear instructions which are understood by computers, as those are the students who would create computers and other IT systems and tools in the future. However, when thinking like a computer, it is also rather easy to forget the importance of the user aspect, and to forget that the end users of these systems might be laymen who are not experts in technology. Hence the need for the roles of domain experts and business analysts etc. to work as intermediaries between the technology professionals – the software engineers and architects who design and develop these IT systems –, and the end users of the system who might not be technology professionals, so that the ideas and expectations of these information users can be translated to the IT experts and vice versa. Thus, the inclusion of non-STEM students in an information science and technology course enriches it further, by bringing a fresh, new perspective into the analysis of requirements and design of an information system (Fernando, 2024). The human mind is not naturally broken into separate segments. Instead of considering the processing of the mind as an isolated and compartmentalized phenomenon (Anderson et al., 2004; Carroll & Bandura, 1987; Newell, 1994), separate domains of education need to come together in a system to attain different, but common outcomes (Koechlin, Basso, Pietrini, Panzer, & Grafman, 1999; Salvucci & Taatgen, 2008). That being the case, it is paramount that we provide an approach of information science and technology education that is accessible to non-STEM students without overwhelming them by first laying a thick mathematical foundation.

Varying Levels of Information Science and Technology Education

A thorough and in-depth education in information science and technology would cover certain mandatory subject areas such as computer hardware, the central processing unit, arithmetic logic unit, etc. which comprise of electronic components such as digital circuits, transistors, gates, wires, registers, memory, etc., machine language programming which entails commands using a series of 1s and 0s, which instruct this circuitry to either send or not send an electronic pulse at each clock cycle, assemblers which translate human-readable programming code into computer-readable machine language, firmware and mid-level languages, software and high-level programming languages, networking and telecommunication including communication systems, network structures, devices and protocols, etc. It should also cover information security education including access control, network security, cryptography, security architecture and models, etc. (Fernando, 2018; Harris & Maymi, 2016).

However, as not all students of information science and technology require, nor seek, a thorough and comprehensive education in it, their required depth of knowledge in the subject area varies based on the needs of the student and their intended profession. For instance, a hardware engineer would need a solid education in electronics, while a software engineer might only need a basic understanding of it as they might not be dealing with the digital circuits and wiring directly the way a hardware engineer would. Similarly, as computer languages could be categorized as low-level, mid-level, and high-level (Friedman & Wand, 2008), while a machine language programmer would require an in-depth knowledge of the hardware components and clock system and electronic pulses, etc., thanks to the assemblers (which are developed by assembly language programmers) which translate high-level programming code written in languages such as C++, Java, Python, etc. into machine language, high-level programmers – the usual software engineers – can do with a shallower understanding of those hardware concepts which are required for low level programming languages. This is comparable to how even though information security professionals who analyze security risks and implement countermeasures require a thorough understanding across all areas and domains of information security, a basic education in information security would equip most users of information and communication systems with the knowledge to protect themselves in cyberspace (Fernando, 2018). Hence, for those non-technology professionals from non-STEM backgrounds who require a basic level of information science and technology education, so that they may have sufficient knowledge to utilize the IT systems and tools required for their jobs and day-to-day needs, higher education programs should provide an approach to information science and technology education that does not involve first laying down that thick, solid foundation in mathematics that is required by computer scientists and IT professionals. The remaining sections of this paper explore some of the mandatory STEM components for certain aspects of information science and technology education, and how a top-down approach could help in providing that education to non-STEM students.

Identifying the Mandatory STEM Components for Information Science and Technology

In order to provide a top-down approach to information science and technology education, the STEM components and mathematical concepts that are mandatory for properly understanding certain subject areas must first be properly identified. After having identified these required STEM components, we must then explore how a top-down approach could be used when teaching those information science and technology subject areas along with those mandatory STEM components identified for each of those subject areas.

Table 1 lists some information science and technology subject areas and certain mandatory STEM components required for properly understanding those subject areas.

Table 1. Some subject areas and mandatory STEM components

Subject Area	Some Mandatory STEM Components
Programming and algorithm development	Procedural thinking, logical thinking, algebra, data structures, permutations and combinations, binary and hexadecimal numbering, etc
Relational databases	Set theory and Boolean logic, order of precedence, binary trees
Information security	Binary and hexadecimal numbering, arithmetic

As shown above, in subject areas such as programming and algorithm development, we can see that concepts such as procedural thinking and logical thinking would be required for writing conditional statements such as if-then-else, and loops such as for loops, while loops, and do-while loops. Knowledge of algebra would be needed for algebraic equation and formula construction. Knowledge of data structures such as stacks, heaps, queues, linked-lists, trees, etc. would be required when writing algorithms for searching, sorting, recursion, etc. And knowledge of permutations and combinations would be required for figuring out the different possible outcomes for switch-case conditions, and so on.

When teaching databases (database design and development, as well as data access), for instance, students would certainly need the knowledge of set theory and a basic understanding of Boolean logic. They would also need an understanding of the order of precedence to properly write data queries using parentheses as appropriate, and a very basic understanding of binary tree data structures to understand the concept of binary search, which is commonly used in databases and database indexing.

For students of information security, a knowledge of binary numbers would be of high importance, as concepts such as cryptography and networking utilize binary numbers in multiple ways. For instance, binary addition, subtraction, shift, etc. are often used as parts of a cryptographic key when encrypting a message. Packet headers for networking packets are created in binary form, where each bit or each set of bits represents a certain element. Binary and hexadecimal numbering is also used when creating internet protocol (IP) addresses – both version 6 (IPv6) and the previous version 4 (IPv4). And the subnet masks used to identify the subnets that each device in a network belongs to in the IPv4 network addressing scheme is also based on the binary system (Harris & Maymi, 2016). More advanced concepts of cryptography might require knowledge in geometry, while advanced networking concepts might require knowledge in trigonometry and calculus. However, as this paper focuses on basic information science and technology education, and not the more advanced and in-depth education, these advanced concepts will not be covered here.

A Top-Down Approach to Teaching Information Science to Non-STEM Students

As binary and hexadecimal numbering is required by multiple information science and technology subject areas, the next subsection of this paper will examine how to utilize a top-down approach to teaching these STEM concepts to non-STEM students. Another subsection of this paper will examine how to utilize a top-down approach to teaching relational database systems, as most professionals are users of information systems, and therefore, require a basic knowledge in relational database systems. Algebra, and permutations and combinations are also some important mathematical concepts which are required for programming and algorithm development. Therefore, another subsection of this paper will also examine how a top-down approach could be utilized to teach these mathematical concepts to non-STEM students.

A Top-Down Approach to Teaching Binary and Hexadecimal Number Systems to Non-STEM Students

The bottom-up method of teaching binary numbering utilizes long division to convert a decimal (base 10) value to a binary (base 2) value. Although this is a very simple calculation for any STEM student, long division is an area where most non-STEM students struggle with, and if binary numbering is introduced in this manner, there is a good chance that non-STEM students might get overwhelmed and frustrated and avoid binary numbering altogether. Yet, as the base of a computer system is binary, even a basic information science and technology education requires some knowledge of binary numbering.

However, instead of addressing binary systems directly, the top-down approach would first describe how and why binary systems are required. For instance, after teaching non-STEM students a simple code snippet in a high-level, user-friendly programming language, we can then explain that even though we used a user-friendly programming language, in reality, the computer goes through a much bigger process in the back-end in order to be able to execute that code and produce the result. They should then be taught that the instruction that a computer understands is whether an electrical signal should be passed or not at a given clock cycle – i.e., 1s and 0s: 1 for when a signal should be passed, and 0 for when a signal should not be passed. So, for an instruction that looks like: 1001110101101000, the electrical signal wave being passed would look like what is shown in figure 1 below.

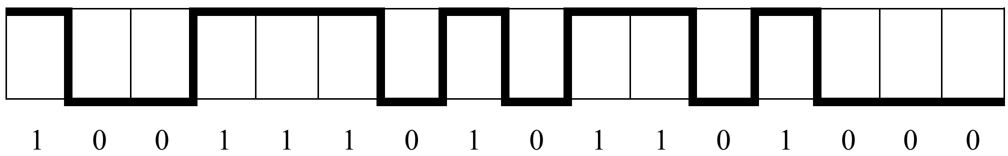

Figure 1. Electrical signal for 1001110101101000

We can also teach these students that each character is depicted in computers using Unicode, which is also a binary number, which is also depicted in hexadecimal (base 16) for ease of use. For example, the Unicode for uppercase 'A' would be 01000001, while the Unicode for lowercase 'a' would be 011000001, and the Unicode for asterisk '*' would be 00101010.

Another practical aspect that would appeal to these students would be how a computer monitor or screen is composed of a grid of pixels, where the more pixels fill up the monitor, the higher its resolution will be. And in order to print a character, the computer will have to color the required pixels in such a way that it creates that character. But as the naked eye cannot see each separate pixel, it will only see the printed character. However, when printing this character, the color for each pixel is also assigned using binary codes which are assigned to each color that the monitor is capable of displaying. For instance, the RGB color system assigns codes to each color red, green, and blue from 0 through 255 in order to figure out the required saturation of each of these colors to create the required color. And even these non-STEM students might be somewhat familiar with the hexadecimal codes such as #FF0000 for red, #00FF00 for green, #0000FF for blue, #FFFF00 for yellow, etc.

Teaching them these important concepts concerning computers and reminding them of some of these binary or hexadecimal codes that they might already be somewhat familiar with, would be a good point of entry to ease into this otherwise feared topic of binary and hexadecimal numbering. Having first spoken of some of their uses, this top-down approach then goes into teaching them how to convert decimal numbers into binary and hexadecimal numbers, so that they can then make sense of these codes that they are familiar with, but did not exactly know what they represented. For instance, even though they utilize these color codes, they might not exactly know what the letter F, or any of the other characters, for that matter, represents in that code. So we can then teach them that learning binary and hexadecimal numbering will help them figure that out.

Having first emphasized the importance of these numbering schemes, and having already piqued their interest in them, the next step would be to teach these non-STEM students how these numbering schemes are created. Of course, a binary numbering scheme means that instead of working with decimal, as in with the numbers 0,1,2,3,4,5,6,7,8,9, and then counting in 10s, we will simply be counting using the numbers 0 and 1. Instead of leaping into long division to convert a decimal number into its binary value, the students should be reminded that different numbering schemes are not something they are unfamiliar with. The best example is that of time, where we count from 0 through 59 seconds, and then once it goes beyond that and hits 60, instead of stating 60 seconds, we simply state 1 minute. And when we go another second, instead of stating 61 seconds, we state 1 minute and 1 second. Similarly, when it comes to minutes, we count up to 59 minutes, and then beyond that, the 60th minute would be 1 hour, and so on until we hit 23 hours and 59 minutes and 59 seconds and then on the next second it becomes 1 day, and so on. Time is not the only instance where we differ from our usual decimal counting scheme. When we look at distance, we count up to 11 inches and after that, the 12th inch makes 1 foot, and 13 inches is 1 foot and 1 inch. Similarly, 3 feet make up a yard, and so on. The same applies when we are measuring weight where we count up to 15 ounces and then the 16th ounce is called a pound, and 17 ounces would be 1 lb. and 1 oz, etc. This shows students that they are already familiar with multiple different numbering systems which they use in practice, even though they do not consciously make the conversions.

In decimal counting we go from 0 to 9 and then 10 is formed by resetting our rightmost digit back to 0 and adding a second digit to the left as 1 to form '10', as depicted in figure 2.

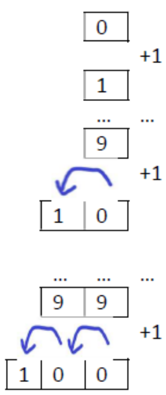

Figure 2. Decimal (base 10) counting system

Note that once that second digit from the right as well as the rightmost digit are filled up to 9 to give us 99, and we no longer have any numbers left to go on those two digits, then we reset those two digits to 0 and add a third digit to the left as 1 to form '100', and so on. This top-down method also shows them how to perform these conversions by visualizing containers for the rightmost digit and each digit to the left thereafter, instead of worrying about long division.

Binary Number System

Then we teach them that in binary, similarly to what was shown above, as we only have the numbers 0 and 1 to work with, we count to 0, then 1, and then when we need to go another number higher, we reset that rightmost digit to 0 and then add another digit to the left and set that to 1 to create 10. However, in this case, as this is binary and not decimal, this binary 10 stands for the value 2 instead of the decimal value 10 that we are familiar with. This is depicted in figure 3 below.

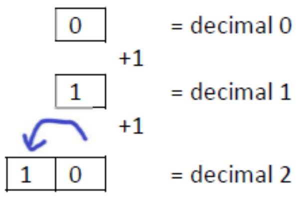

Figure 3. Binary (base 2) counting system

This will be further continued to add 1 more to binary 10 to make it 11, which is equal to decimal 3 (figure 4), and adding 1 more to 11 will make it 100, which is equal to decimal 4, and so on, as depicted in figure 5.

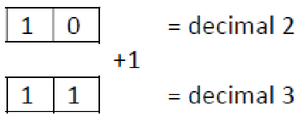

Figure 4. Counting to binary 11 (decimal 3)

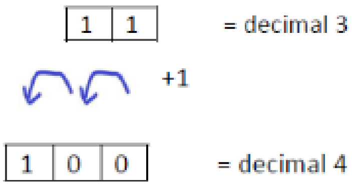

Figure 5. Counting to binary 100 (decimal 4)

We can then teach them to look at the instances when a new digit is created. For instance, in the decimal system, a new digit is created at 1, 10, 100, 1000, and so on, where upon closer inspection, we see that $1 = 10^0$, $10 = 10^1$, $100 = 10^2$, $1000 = 10^3$. So then we show them that whenever we go up a power to the 10 is when we create a new digit to the left in the decimal system. We then show that it must also hold true in the binary system, where each time we go up a power to the 2, as in: $2^0 = 1$, $2^1 = 2$, $2^2 = 4$, $2^3 = 8$, $2^4 = 16$, etc., we would create a new digit to the left, as shown in table 2.

Table 2. Binary numbers which create new digits

Binary	Decimal
1	1
10	2
100	4
1000	8
10000	16

This would also show the students a very important number series, that of the series of numbers of the power of 2, which is 2^0, 2^1, 2^2, 2^3…., on in other words, the series: 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024, 2048, 4096, etc. We can then help the students notice that they are already somewhat familiar with this series, as they have noticed that memory such as computer memory or SD cards have the values 32 GB, 64 GB, 128 GB, 256 GB, and so on. We can then emphasize that this is due to the fact that computers, and of course computer memory, work in binary, and that that is why it is called digital memory, as it contains 2 states, that of either 1 or 0.

Hexadecimal Number System

We can then segue into hexadecimal numbers which are of base 16. As $16 = 2^4$, converting a binary number into hexadecimal means that we would separate the binary number into segments of four digits each starting from the right and moving to the left, and then figure out the hexadecimal value for each segment. For instance, binary 10011110 can be separated into the two segments of 1001 and 1110, and then the hexadecimal values for each segment can be considered.

For hexadecimal, of course we can use the values 0 through 15, but as there is no single digit to represent the double-digit numbers of 10, 11, 12, 13, 14, and 15, we use the uppercase letters A through F to represent 10 through 15 in hexadecimal numbering scheme as shown in table 3.

Table 3. Representing double-digit numbers in hexadecimal

Decimal	**Hexadecimal**
10	A
11	B
12	C
13	D
14	E
15	F

So that the two binary segments of 1001 and 1110 above, will be represented as 9 and E (decimal 14) in hexadecimal, to make binary 10011110 equal to hexadecimal 9E. And similar to any other numbering system, when you reach value 16 in hexadecimal, as the rightmost hexadecimal digit is full at F (decimal 15), we reset that to 0 and add a new digit to the left as 1, to represent decimal 16 as hexadecimal 10. This makes decimal 17 equal to hexadecimal 11, and so on, until we reach hexadecimal FF, which is equal to decimal 255, and once we reach decimal 256, which is equal to 16^2, we denote that as 100 in hexadecimal. At this point, we can remind the students about the RGB color codes which contained values such as #FF0000 for red, #00FF00 for green, #0000FF for blue, which can also be translated into decimal as 255-0-0 for red, 0-255-0 for green, and 0-0-255 for blue. We can thereby show them that the saturation of each color could go from 0 through 255, which when converted to hexadecimal is what gives us these RGB color codes containing the # symbol followed by six hexadecimal digits which could include 1 through 9 and A through F.

At this point, based on the requirement, we can teach the students how to convert a decimal value to binary by performing long division if needed. We can also move on to binary additions and subtractions as needed. The important thing to note is that as this is a top-down method, you only need to go down as deep as needed and if more intense mathematics is not required, then you do not need to go into those details that might overwhelm non-STEM students. Approaching this vast subject area of binary and hexadecimal numbering in this top-down method would allow even non-STEM students who are not used to intense mathematics to understand these required mathematical concepts behind computing.

The next subsection of this paper will discuss how to utilize a top-down approach when teaching relational database systems to non-STEM students.

A Top-Down Approach to Teaching Relational Database Systems to Non-STEM Students

The commonly used bottom-up approach of teaching relational database systems would start by teaching about the tables consisting of fields or columns, and rows or tuples, then move on to teaching about how each of the tables in a database are related to others in either a many-to-many relationship, a one-to-many relationship, or in rare cases in a one-to-one relationship, and then move on to designing a database by creating the entity-relationship diagrams (ER diagrams), followed by the very important, yet very intense and difficult to understand concept of normalization, sometimes with not too much thought given to the exact requirements of the intended database system (Fernando, 2024). After normalizing the database, the students will then be taught how to implement it on a database management system (DBMS) and then plug it into a front-end user interface (UI). And the students are expected to have a prior knowledge of set theory and order of precedence so that they may be able to write SQL statements to query data from multiple tables properly, and a prior knowledge of binary searching so that they may understand the concept of indexing.

Even though the bottom-up approach outlined above works smoothly for students from a STEM background who already have that expected prior knowledge, it is not a successful method when teaching relational database systems to non-STEM students, who most likely would not have studied set theory or binary trees. More importantly, these students would find the concept of normalization of tables, especially difficult to comprehend, due to its very complicated nature.

Instead, this paper proposes a top-down approach to teaching relational database systems – focused mainly on non-STEM students, who, as previously discussed, may bring in a fresh perspective and a lot of domain expertise to the process of designing and developing information systems. Hence, instead of beginning with the tables, this top-down approach begins by examining database systems the students have used or are currently using to identify how the interface may be made more user-friendly, how certain important features or functionality that is omitted in the systems they examine should be included, while how certain other features that are available in these systems are not often used, and determine other strengths and weaknesses of these systems. Based on those findings, the students are then required to propose a purpose for which they would like to design and develop a database system, and to visualize and sketch what they would imagine the front-end UIs of that system might look like. These interfaces might be subject to change as they move along the process of designing and developing the database system, but it starts by looking at the front-end interfaces at the top, and then going down to look at the rest of the database system, all the way down to the back-end database. This allows the students to be in control of the design of their database system, rather than their understanding of theoretical concepts and principles of relational database design limiting their thinking and design (Fernando, 2024).

When designing the database by creating the ER diagrams, most students struggle with properly identifying tables or entities. Hernandez (2013) discusses a method of looking at the requirements to write a clear, concise mission statement for the intended system, and a list of mission objectives expected by the system, and then reading through this mission statement and these objectives to identify the nouns, and then removing duplicates, in order to create a list of entities or tables. The students would then be taught to identify the attributes that describe these entities, and thereby arrive at a set of fields for each of these tables. Hernandez (2013) also states the importance of naming tables using plurals to imply that there would be multiple instances or data records which would result in multiple rows of data in a table, and of naming fields using singular nouns to imply that there would only be a single value in each field. This, in turn, allows the students to identify incorrect fields which should either be broken into multiple separate fields, should be dropped entirely as they can be calculated using other existing fields, or should be dropped from that existing table to create a separate table (Hernandez, 2013). The students are then taught to create a linking table, to resolve the many-to-many relationship between the original table and the newly created table, by breaking it into two separate one-to-many relationships, which can be properly enforced and implemented in a database. In this very practical manner, the complicated theories behind the process of normalization are bypassed, allowing the students to create relational database tables which are normalized to at least the 3rd degree.

When teaching SQL, the dominant language used for querying relational databases, instead of first teaching how to create tables and populate those tables with data, the students should first be taught to query an existing database that is provided to them (Fernando, 2024). They should begin by learning to query from a single table, and then be taught how to join multiple tables together to query from them. They should be taught how to include a ‘WHERE’ clause, which would allow them to filter out individual rows, before being taught how to group rows of data together, and then filter out groups using the ‘HAVING’ clause, etc. The students should be given business questions to be answered and taught how to write queries in SQL to obtain a result set to answer those given business questions. Similarly, they should also be given SQL queries to figure out the business questions that they would answer when the queries are executed.

Teaching Set Theory and Boolean Logic

It is when constructing the filtering conditions for the ‘WHERE’ or ‘HAVING’ clauses, that the concept of set theory comes into play. When two or more conditions need to be evaluated in these filter statements, one would need to use the logical operators ‘AND’ or ‘OR’ based on whether they require both parts of the condition to be fulfilled, or whether they only require at least one of the parts to be fulfilled, respectively. Even though students understand the concept of these logical operators ‘AND’ and ‘OR’, it is when these are taken together with negation (NOT), that most non-STEM students find the use of these confusing. For example, if they are asked to select records from a table of transactions, for ‘all transactions that did not take place on date A or date B’, they might be confused whether to use the logical operator ‘AND’ or ‘OR’ within their WHERE condition. In the above instance, as they need to look at all other dates but the two given dates, they need to use the logical operator ‘AND’ as depicted in the following example:

WHERE (date != ‘A’ AND date != ‘B’)

Instead, if they were to incorrectly write this filter condition using the logical operator ‘OR’, as in the following example:

WHERE (date != ‘A’ OR date != ‘B’)

Then they would be looking at all the dates, including A and B, since when the condition looks at “date != ‘A’ ” it includes B, and when the condition looks at “date != ‘B’ ” it includes A. And as the logical operator ‘OR’ would accept any value which satisfies either one of these conditions, then it will accept all the available dates, and not filter out any dates. So instead of filtering out the transactions that took place on either of these two dates, this incorrect condition will not filter out any rows.

Once students have experienced this confusion with the logical operators ‘AND’ and ‘OR’, it is then time to teach them the basics of set theory and Boolean logic. By sketching the dates ‘A’ an ‘B’ on a Venn diagram as shown in figure 6 below, they can be taught how to look at A separately, B separately, everything but A { NOT(A) }, and everything but B { NOT(B) }.

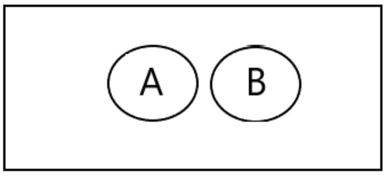

Figure 6. Venn diagram depicting two mutually exclusive entities

Having shown how two mutually exclusive entities would look on a Venn diagram, we can then show them how two entities which are not mutually exclusive would be depicted (see figure 7).

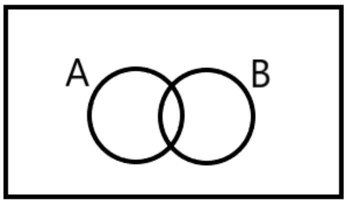

Figure 7. Venn diagram depicting two mutually non-exclusive entities

We can then depict what the negation of each of these entities would look like. Figure 8 depicts NOT(A), while figure 9 depicts NOT(B).

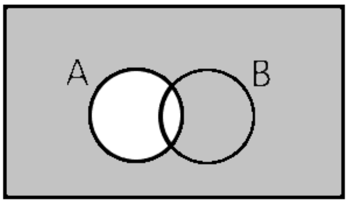

Figure 8. Shaded area depicting negation of A: 'NOT(A)'

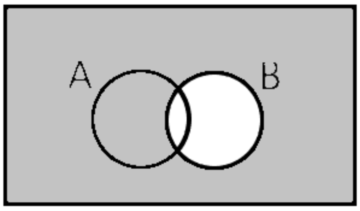

Figure 9. Shaded area depicting negation of B: 'NOT(B)'

The students can now also be taught to look at 'A AND B' (see figure 10), and 'A OR B' (see figure 11).

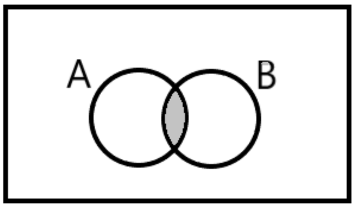

Figure 10. Shaded area depicting intersection: 'A AND B'

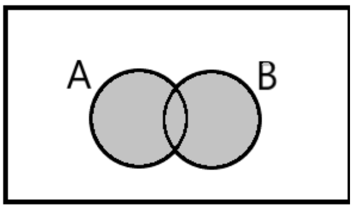

Figure 11. Shaded area depicting union: 'A OR B'

Even though non-STEM students do not require a thorough knowledge of logic gates for a basic information science and technology education, showing them a simple truth table to depict the cases of 'A AND B' and 'A OR B' (see table 4), at this stage, would help them to get a visual understanding of what these intersections and unions would result in:

Table 4. Truth table depicting ‘A AND B’ and ‘A OR B’

A	B	A AND B (Intersection)	A OR B (Union)
0	0	0	0
1	0	0	1
0	1	0	1
1	1	1	1

The next step would be to teach them to look at the negations of the above: ‘NOT(A AND B)’ (see figure 12), and ‘NOT(A OR B)’ (see figure 13).

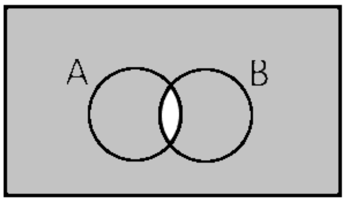

Figure 12. Shaded area depicting negation of intersection: ‘NOT(A AND B)’

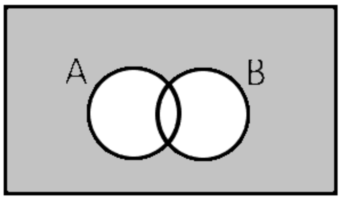

Figure 13. Shaded area depicting negation of union: ‘NOT(A OR B)’

By considering the total shaded parts of figure 8 and figure 9 together and comparing that with figure 12, this will then teach the students how to deduce the Boolean logic of:

NOT(A AND B) = NOT(A) OR NOT(B)

And by considering the common parts of figure 8 and figure 9 together and comparing that with figure 13, it will teach students how to deduce the Boolean logic of:

NOT(A OR B) = NOT(A) AND NOT(B)

Which in turn, will help them to understand when to use the logical operator 'AND' and when to use the logical operator 'OR' when combining two conditions to create a filter condition for a SQL query.

Visually depicting sets in Venn diagrams as above would also make it easier for the students to understand that when executing a query, the database will only retrieve unique rows – as in, duplicate rows will not be recorded in the result set. So for example, in the above diagrams of two mutually non-exclusive entities, if we consider A to be the set of months in the first three quarters of a year (January through September), and B to be the months in the last half of the year (July through December), then if we look at the intersection A AND B, we get the months that belong to both sets, which are July, August, and September. And if we look at the union A OR B, then we will get the result containing all the months from January through December, but the intersection (July, August, September) will not be repeated, but will only appear once. This further teaches them that the union A OR B is equal to the addition of A to B, and then subtracting the intersection A AND B from it:

(A OR B) = A + B – (A AND B)

When looking at multiple-table queries, we can further utilize the concepts of union and intersection in set theory so that the students may, for instance, be able to query a subset of rows which belong to multiple tables. For example, let's consider a scenario where the students are required to look at a database consisting of tables for the branches of a bank, and the employees of a bank. If the bank consists of the branches 'X', 'Y', and 'Z', and if the employees fall into the designations of 'manager' and 'teller', and if the students are required to find the 'tellers' in branch 'X', then they will need to look at an intersection of 'tellers' and 'X' (similar to what is depicted in figure 10) to create the filter condition:

WHERE(branch='X' AND designation='teller')

And if they were to look at 'all employees' in either branch 'Y' or 'Z', then they will need to look at the union of 'Y' and 'Z' (similar to what is depicted in figure 11) to create the filter condition:

WHERE(branch='Y' OR branch='Z')

This practical and top-down approach to teaching the basics of set theory and basic Boolean logic, takes away the fear of STEM subject matter that most of these non-STEM students are faced with and provides them with sufficient STEM knowledge required for their education of relational database systems.

Teaching Order of Precedence

Another point that does not come naturally to non-STEM students is the order of precedence. A strong STEM-educated mind thinks mathematically – somewhat similar to a computer. Therefore, assigning parenthesis to specify the order of precedence is a process STEM students do automatically (Fernando, 2024). This is not, however, the case with non-STEM students. As they think more in terms of natural spoken language rather than in the way computer programming languages work, non-STEM students need to be taught how to properly assign parenthesis to dictate the order of precedence – i.e. the order in which they want the computer or database compiler to execute the given conditions. For instance, in the above example with tellers and bank managers working in multiple branches of a bank, if they were to select either tellers or managers, all of whom should be working at branch 'X', then the filter condition for the WHERE clause should look like:

WHERE((designation='teller' OR designation='manager') AND branch='X')

The use of parenthesis in this example, clearly specifies that the selected tellers or managers should be working at branch X. But if the inner pair of parentheses were omitted to write the following instead:

WHERE(designation='teller' OR designation='manager' AND branch='X')

Without the use of the proper parenthesis, in this case, it would be difficult to determine whether the selected tellers or managers are all working at branch X, or whether the selected managers are working at branch X, while the selected tellers could be working at any branch. Hence, the need for parenthesis to properly specify the order of precedence.

Should the requirement be to find any teller (working at any branch), or the managers who are only working at branch X, then the condition should be properly written with the inner pair of parentheses combining the managers with branch X as shown below:

WHERE((designation='teller') OR (designation='manager' AND branch='X'))

Examples such as these would help non-STEM students to understand the importance of using parenthesis to specify the exact order of precedence, and thereby, incorporate this habit of parenthesizing into their information science and technology practices.

Teaching Binary Search

Next, the students should be taught how to sort the results in ascending or descending order and to create indices. At this point in time, the concept of binary search should be explained (Fernando, 2024). As the students are, by this time, familiar with sorting the data in a certain order, the idea of splitting the sorted data in the middle, continuously, until the value being searched for is found (as depicted in figure 14), becomes a lot clearer when taught in this top-down fashion, than if one was to first teach the advanced STEM concepts of tree data structures, followed by binary trees and tree traversal, etc. which are not needed by these non-STEM students at this level.

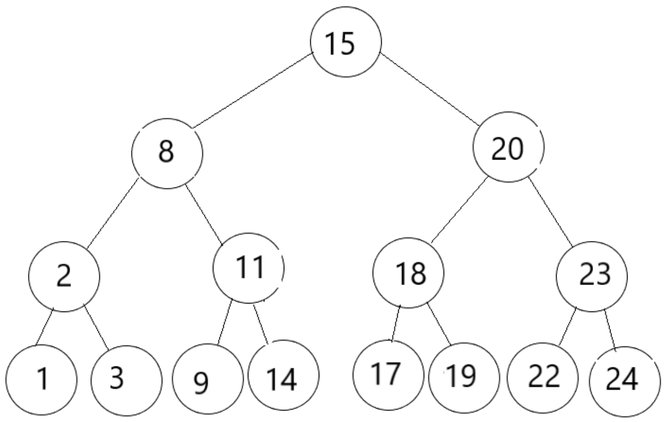

Figure 14. Example binary tree to depict binary search

Figure 14 above shows how an example set of values 1, 2, 3, 8, 9, 11, 14, 15, 17, 18, 19, 20, 22, 23, and 24, are sorted in ascending order as depicted on the binary tree from left to right. If we needed to search for a specific number such as 22, for example, then by using this visual representation, we can easily depict to the students how this list is split down the middle at 15, then as 22 is greater than 15, we consider only the right side, which contains the values greater than 15, which is the set of values: 17, 18, 19, 20, 22, 23, and 24. We then split that set of numbers down the middle at 20, and once again as 22 is greater than 20, we consider only the higher set of values on the right which contain 22, 23 and 24. When splitting this set of values down the middle at 23, we see that 22 is less than 23, and so we consider the set on the left side, which now consists only of the value 22, which is the value we seek. Thus, this example visually depicts how binary search works to search for a specific item within a sorted list of items.

Only after being able to properly query from a database, should the students be taught how to create tables and insert data to populate these tables, and then to update them and to delete from them. And finally, the students should be taught how to connect their back-end database to a front-end UI in such a way that provides the data access functionality to the system's users as they previously identified in their requirements analysis. As explained above, depicting these important STEM concepts of set theory, order of precedence, or binary search in a practical manner, once the students have already been exposed to a similar practical scenario through their education of relational database systems (a top-down approach), rather than first teaching them all these STEM concepts and then beginning their education in relational database systems (a bottom-up approach), allows non-STEM students to understand the required STEM concepts without being overwhelmed, and helps them obtain their education successfully. This top-down approach to teaching relational database systems to non-STEM students depicted here, can further be applied to other areas of information science and technology education as well.

A Top-Down Approach to Teaching Algorithm Creation to Non-STEM Students

Even basic programming and algorithm development requires some knowledge of algebra. Further, knowledge of permutations and combinations is also required to figure out all the possible options or outcomes, so that all bases will be covered when writing an algorithm with conditional statements. Therefore, this subsection will explore how a top-down approach could be utilized in teaching these mathematical concepts to non-STEM students.

Teaching Algebra

If students are taught to create a small program which outputs a visual result such as when printing a symmetric triangle such as what is depicted within a grid in figure 15, it will require some mathematical reasoning.

		*		
	*	*	*	
*	*	*	*	*

Figure 15. A symmetric triangle of 3 rows

If the total number of rows is known, then the students can specify printing a certain calculated number of blank spaces before printing a certain number of asterisks to create the triangle. However, if they needed to write a program to print a symmetric triangle for any number of rows, where the user can select the number of rows they wish to have, then they would need to figure out how many columns the grid would contain based on the user-selected number of rows, and then figure out how many blank spaces to print before printing the asterisks in each row. To develop an algorithm such as this, the students would need to create an algebraic equation. For instance, if the user-selected number of rows is 1, then the number of columns would be 1 and the number of blank spaces before the asterisks would be 0, while if the number of rows was 2, then there would be 3 columns with 1 blank space before the asterisk in the 1^{st} row, and if the number of rows was 3, then there would be 5 columns with 2 blank spaces before the asterisk in the 1^{st} row as depicted in figure 15 above. This shows us that for 1 row we should have 1 column, for 2 rows we should have 2 + the number of columns for 1 row (i.e.: 2+1 = 3 columns), for 3 rows we should have 2 + the number of columns for 2 rows (i.e.: 2+3 = 5 columns). And so we can teach the students to deduce that if there were 4 rows, it should have 2 + the number of columns for 3 rows, which would be 2+5 = 7 columns. We also see that as the final row would not contain any blanks, the number of asterisks on that final row would be equal to the number of columns, so the 4^{th} row would have 7 asterisks printed on it. We can further see that 5 rows would require 2+7 = 9 columns, and 6 rows would require 2+9 = 11 columns, and so on. Then we need to figure out the common factor in all of these rows in order to determine the kind of series that is being created by these values: 1,3,5,7,9,11, etc., and we see that they are all adjacent odd numbers. However, without knowing the number of columns for the previous triangle, we will not be able to add 2 to figure out the required number of columns, or the number of asterisks in the final row. But if we think further, we can deduce another pattern as shown in table 5.

Table 5. Deducing patterns for a symmetric triangle

Number of Rows (*n*)	(*n* * 2) -1		Number of Columns
1	(1 * 2) -1	= 2-1	= 1
2	(2 * 2) -1	= 4-1	= 3
3	(3 * 2) -1	= 6-1	= 5
4	(4 * 2) -1	= 8-1	= 7
5	(5 * 2) -1	= 10-1	= 9
6	(6 * 2) -1	= 12-1	= 11

In other words, we can deduce that the number of columns for a given number of rows is 1 less than double the number of rows. So we can derive the algebraic equation for the number of columns for a given number of rows to be (*n* * 2) – 1.

As we know that the final row consists only of asterisks and no blank spaces, we know that the number of columns on our grid will be the same as the number of asterisks for the final row, so for user-selected *n* number of rows, there will be (*n* * 2) – 1 columns. So we can then create a grid with (*n* * 2) – 1 columns and *n* rows.

We then need to figure out how many blank spaces followed by how many asterisks each row should contain. We know that each row should have *r* = (*r* * 2) – 1 asterisks, and that these need to be center aligned. Therefore, an equal number of blank spaces should be on either side of the string of asterisks. As we do not need to print the blank spaces following the asterisks, we need to figure out how many blank spaces precede the asterisks. We can figure out the total number of blank spaces in each row *r* by deducting the number of asterisks in that row from the total number of columns: [(*n* * 2) – 1] – [(*r* * 2) – 1] and then halving that to figure out the number of blank spaces to be printed before printing the string of asterisks: {[(*n* * 2) – 1] – [(*r* * 2) – 1]}/2. And once these equations are derived, the students can then go on to print a symmetric triangle of *n* rows, by running a counter for the row *r* from 1 through *n*, and then printing {[(*n* * 2) – 1] – [(*r* * 2) – 1]}/2 number of spaces followed by *r* = (*r* * 2) – 1 asterisks for each row. This top-down method of first getting students to write a simple program with visual results for a known number, then adding to it by making the number an unknown variable, and then teaching them to analyze the results for a few rows to figure out the patterns that create the series will help them derive the algebraic equations required for creating the algorithm for writing the code with that unknown variable. Of course, this might still be intense for some non-STEM students, but if they require the knowledge for developing algorithms and creating programs, then they would need to delve into the derivation of algebraic equations such as this. But once again, if such algorithm development and programming is not required for their level of information science and technology education, then those students do not need to first be taught algebra in order for them to gain their basic technology education.

Teaching Permutations and Combinations

If the required information science and technology education for a certain non-STEM student goes to the depth of finding out all possible options or outcomes so that they may write conditional statements which state what to do for each option, then they need a proper method of figuring out the number of viable options for a certain situation. An example scenario would be where they are creating an algorithm to play a game where they roll maybe five dice and consider the face values of those dice rolls. In cases such as these, they would need to study the mathematical concepts of permutations and combinations.

Similar to how other STEM components were approached in this paper, this too can be taught in a top-down manner, by first introducing them to the practical exercise of dice rolls, and then considering the mathematics behind it. The more practical examples that are attached to these mathematical concepts, the easier they become for these non-STEM students to grasp.

We should teach them that when the order does not matter, like in the above dice throwing example, or when considering the ingredients in a salad, for instance. then we look at combinations, while when the order matters like in a locker combination or a kabob where the ingredients are placed in a specific order, then we look at permutations. In other words, a permutation is an ordered combination.

Providing examples such as the salad and kabob help non-STEM students to visualize these mathematical concepts easier. For instance, if they had to compute how many different types of salads could be created by using 3 out of 4 total ingredients such as tomato (t), cheese (c), olives (o), and lettuce (l), then they can first write out the different salad combinations they can create such as t-c-o, t-c-l, c-o-l, t-o-l, then they would find that there are 4 possible combinations. If we also added grapes (g) to the list of ingredients and increased the number of total available ingredients to 5 and had to create a salad out of 3 ingredients, then they would come up with 10 possible different combinations. As the number of combinations and permutations could get very big very fast, we then teach them to derive this number in an easier manner. To teach permutations and combinations you need to first teach them the concept of factorials which are calculated using the equation: factorial $n! = n\ (n - 1)!$. So the students can try computing the factorials for a few numbers such as:

5! = 5 * 4! = 5 * 4 * 3! = 5 * 4 * 3 * 2! = 5 * 4 * 3 * 2 * 1 = 120.

We can then show them how to utilize the equations for combinations: ${}^{n}c_{r}$ = n!/r!(n-r)! where n is the total number of ingredients, while r is the number of ingredients that you can use in a salad. So, for our first example for number of combinations of 3-ingredient salads out of 4 ingredients (i.e.: $r = 3$, $n = 4$), then we teach them to compute:

${}^{4}c_{3}$ = 4!/3!(4-3)! = 4!/(3! * 1!) = 4*3!/3! = 4 as we found out above.

When the number of total ingredients (n) is increased to 5, then the number of combinations of 3-ingredient salads out of 5 ingredients would be computed as:

${}^{5}c_{3}$ = 5!/3!(5-3)! = 5!/(3! * 2!) = 5*4*3!/3!*2*1 = 5*4/2 = 20/2 = 10.

When looking at kabobs, where the order matters, then if we were to see how many different kabobs we can make using 3 out of 4 ingredients and using each ingredient only once (not repeating ingredients), then we can ask the students to write these options out as in t-c-o, t-o-c, c-t-o, c-o-t, t-c-l, etc. As you can see, there will be many different options (permutations) when the order is important. After letting the students complete this exercise, it is then time to introduce the equation for permutation ${}^{n}p_{r}$ = n!/(n-r)! to them, which they would then realize is a much more efficient and simpler method of computing this. In our example of 3-ingredient kabobs out of 4 ingredients without repetitions, where $r = 3$, and $n = 4$, the number of different possible kabobs would be computed as:

${}^{4}p_{3}$ = 4!/(4-3)! = 4!/1! = 4! = 4 * 3 * 2 * 1 = 12.

And if we were given 5 ingredients (n = 5), then we can compute the number of possible different 3-ingredient kabobs without repetition of ingredients as:

${}^{5}p_{3}$ = 5!/(5-3)! = 5!/2! = 5 * 4 * 3 * 2!/2! = 5 * 4 * 3 = 60.

As with algebraic equations, permutations and combinations are somewhat more advanced mathematical topics that might not be easy for some non-STEM students to grasp, but as with other STEM concepts, they should only be taught if required by the level or depth of information science and technology education they seek, and even then, they should be taught in a top-down fashion as shown above, using practical examples, so that the students comprehend these concepts better. Attempting to teach complicated STEM concepts such as these in a bottom-up manner instead could result in non-STEM students being overwhelmed, frustrated, and not understanding why they need to study these seemingly highly theoretical mathematical concepts for which they might not initially see a use. Therefore, a top-down approach, where the practical application or need for these concepts for their required level of information science and technology education is made clear, and where these concepts are approached in as practical and natural a manner as possible, is best.

Conclusion

In conclusion it can be stated that information science and technology education is required by many, if not all, students, but in varying levels or degrees. A complete and thorough education in information science and technology, which also requires a thorough and solid foundation in STEM concepts will only be required for students intending to become technology professionals such as computer scientists or engineers, and IT professionals, etc., who design and develop computer hardware, software programs, and IT systems and tools. Yet, any non-technology professional who uses such information systems and tools should have a basic information science and technology education in order to utilize those systems and tools in an optimal fashion. As most of these non-technology professionals may come from a non-STEM background, gaining a deep understanding and complete knowledge of the STEM concepts on which information science and technology is rooted, may be overwhelming, and the usual bottom-up approach to teaching information science and technology by first laying a mathematical foundation may be unsuccessful. However, by providing information science and technology education in a top-down approach, and teaching the basic STEM components required for the information science and technology subject areas taught in a practical and natural manner as needed, non-STEM students would be able to successfully obtain the basic information science and technology education sufficient for their non-technology professions. Thus, it can be concluded that information science and technology education for non-STEM students should be provided using a top-down approach.

References

Anderson, J. R., Bothell, D., Byrne, M. D., Douglass, S., Lebiere, C., and Qin, Y. (2004). An integrated theory of the mind. *Psychological review, 111(4)*, 1036-1060. doi:10.1037/0033-295X.111.4.1036

Angell, I.O. and Demetis, D.S. (2010). *Science's first mistake*. Bloomsbury Academic

Carroll, W. R., and Bandura, A. (1987). Translating cognition into action. *Journal of motor behavior, 19(3)*, 385-398. doi:10.1080/00222895.1987.10735419

Fernando, S. (2024). Information science and technology education for non-STEM students: A top-down approach. In Proc., *International Science and Technology Conference 2024* (pp. 416-423).

Fernando, S. (2018). The different aspects of information security education. In Z. Fields (Ed.), *Handbook of research on information and cyber security in the fourth industrial revolution* (pp. 182-204). Hershey, PA: IGI Global.

Friedman, D.P. and Wand, M. (2008). *Essentials of programming languages (3rd Ed.)*, MIT Press.

Harris, S. and Maymi, F. (2016). *CISSP all-in-one exam guide (7th Ed.)*, New York, NY: McGraw-Hill Education

Hernandez, M.J. (2013). *Database designs for mere mortals: A hands-on guide to relational database design (3rd Ed.)*, Upper Saddle River, NJ: Addison-Wesley

Koechlin, E., Basso, G., Pietrini, P., Panzer, S., and Grafman, J. (1999). The role of the anterior prefrontal cortex in human cognition. *Nature, 399(6732)*, 148-151. doi:http://dx.doi.org/10.1038/20178

Newell, A. (1994). *Unified theories of cognition*: Harvard University Press.

Salvucci, D. D., and Taatgen, N. A. (2008). Threaded cognition: An integrated theory of concurrent multitasking. *Psychological Review, 115(1)*, 101-130. doi:10.1037/0033-295X.115.1.101

Senanayake, T. and Fernando, S. (2018). Information security education: Watching your steps in cyberspace, *The online journal of science and technology*, *8(2),* 96-101.

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Chapter VI

Children's Literature, Popular Science, and Technology: The Magnificent Trio

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TÜBİTAK, Turkey

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Introduction

Today, the rapid advancement of technology and the consequent evolution of educational processes toward technology have fundamentally transformed access to information (Arslan & Şendurur, 2017). Traditional classroom environments have been replaced by virtual classrooms and digital platforms, providing students with more engaging and interactive learning experiences. Video lessons enriched with animations, online quizzes, and interactive games offer alternative pathways for students to better grasp lesson topics. The contribution of popular science to this process should not be overlooked. Popular science books and resources, which render medium or advanced scientific topics comprehensible through language tailored to the target audience, help students develop scientific thinking skills (Taşdelen & Güven, 2024) while also reinforcing their sense of curiosity. It can be argued that children's literature plays a crucial role in technology-oriented educational approaches. Works written for children stimulate their imagination, enhance language skills, and contribute to their social and emotional development. Interactive storytelling, digital books, and other animation-based applications not only promote reading habits among children (Yılmazsoy, 2020) but also increase their interaction with technology. The role of literature in education paves the way for children to develop critical thinking skills, empathy, and the ability to understand different perspectives. Thus, children's literature not only offers an enjoyable reading experience but also plays an important role in the integration of education with technology, making the learning process more enjoyable.

Children's literature plays a significant role in every aspect of education. In science-oriented educational models, for instance, natural phenomena and scientific concepts are presented in a fun and engaging way through stories written for children, thereby stimulating their curiosity. In one story, a group of children might be solving problems encountered during space exploration, while in another, a group of volunteers may be working in a nanotechnology research lab. Such narratives serve as valuable starting points for fostering scientific thinking skills. In language learning classes, children's literature is supported by works that expand vocabulary in addition to developing linguistic skills. Fairy tales and poems help children enrich their language development by aiding them in learning more words and understanding language structures. Furthermore, in social studies classes, stories provide information about historical events, cultures, and individuals, while also strengthening children's ability to empathize. By witnessing different characters' perspectives, children can gain a broader understanding of the world. In subjects such as mathematics, biology, and chemistry, children's literature facilitates the entertaining presentation of mathematical concepts, the better discussion of formulas, life cycles, and issues such as climate change, thus contributing to deeper understanding. Counting, addition, and subtraction operations embedded in stories involving objects and characters enhance children's mathematical thinking skills. For example, in one story, children might calculate the necessary supplies to feed animals in a zoo. In another, they might investigate the causes of drought, or conduct chemical experiments on various topics to make life easier.

Children's Literature

Children's literature is a field that appeals to the emotions and thoughts of children, aiming to develop these through language (Yükçü, İzoğlu, & Kangal, 2019). The works written for this purpose are considered children's literary products. In general, this genre includes stories, fairy tales, poems, plays, and novels that are tailored to children's age, level of understanding, and areas of interest.

Beyond entertaining, children's literature also contributes to the development of children's artistic and aesthetic sensibilities. Imagination, language skills, and socio-emotional development in children are supported through children's literary works (Çer, 2019). Children's literature contributes to the linguistic, expressive, artistic, and aesthetic development of its target audience from early childhood through adolescence. Stories and fairy tales read during the preschool period shape children's perception of the world and support their language development. With the support of parents, children who are introduced to books begin to understand life through the fictional narratives they encounter. During the school years, children's literature assists in comprehension and the learning of new information. Novels and storybooks help children develop critical thinking skills and enhance their decision-making abilities. Literary works enable children to think from different perspectives and strengthen their capacity for empathy. This, in turn, supports healthier social relationships and contributes to their development as well-rounded individuals. Additionally, children's literature plays a significant role in helping children develop positive habits from an early age, which in turn contributes to their happiness and well-being. The values, virtues, and moral attitudes they encounter in books play a determining role in their character development (Enginün, 2006). Fairy tale characters who distinguish right from wrong and understand the balance between good and evil help shape children into more conscious and responsible individuals in the future.

The Development of Children's Literature

Books specifically written for children in the modern sense first emerged in Europe in the 17th century. In antiquity, there were no distinct works written solely for children. However, works such as Aesop's Fables—although not written exclusively for children—appealed to both adults and children with their moral lessons delivered through animal characters. During the Middle Ages, education was centered around religion and the number of literary works was quite limited. With the Renaissance, the individual and education gained prominence, and the first books intended for children began to appear. The 17th century is considered the foundational period of modern children's literature as a distinct genre. With the Industrial Revolution, the employment of child labor in factories became widespread. One reason behind the emergence of works directed at children during this era was the belief that children needed to be educated to contribute more effectively to production. Manuals were developed to help child workers become more efficient, and these were written in a language and style comprehensible to children, thereby also aiming to contribute to their education. Such materials are regarded as the early foundations of children's literature. One of the prominent figures of this period, John Locke, emphasized the importance of books in children's education. During this time, books that conveyed general moral lessons to children were particularly prominent.

In the 18th century, childhood began to be recognized as a unique developmental phase. Rousseau's *Emile* played a pioneering role in children's literature. The 19th century is considered the "golden age" of children's literature. Fairy tales, stories, and fantasy novels became increasingly popular. Examples of influential works from this period include *Andersen's Fairy Tales*, the collected tales of the *Brothers Grimm*, and Lewis Carroll's *Alice's Adventures in Wonderland*. In the 20th century, children's literature diversified significantly, with psychological, social, and cultural dimensions coming to the forefront. Authors such as Roald Dahl, Dr. Seuss, and J.K. Rowling have shaped the modern face of children's literature. From its origins to the present day, some of the foundational authors and works of children's literature (Koyuncuoğlu, 2021) can be listed as follows:

- **Germany**: *The Brothers Grimm* (Jacob and Wilhelm Grimm): Compiled and transcribed folk tales. Classics such as *Little Red Riding Hood*, *Hansel and Gretel*, and *Snow White* have had a profound impact on Western children's literature.
- **Denmark**: *Hans Christian Andersen*: Brought emotional depth to children's literature with works such as *The Little Match Girl*, *The Little Mermaid*, and *The Ugly Duckling*.
- **United Kingdom**: *Lewis Carroll*: Laid the foundation of fantasy literature with *Alice's Adventures in Wonderland* (1865). *Beatrix Potter*: Known for the *Peter Rabbit* series, featuring charming animal characters. *A.A. Milne*: Highlighted themes of friendship and simplicity through *Winnie the Pooh*. *Roald Dahl*: Combined entertainment and critique in works such as *Charlie and the Chocolate Factory*, *Matilda*, and *James and the Giant Peach*. *J.K. Rowling*: Had a global impact on contemporary children's and young adult literature with the *Harry Potter* series.
- **France**:*Charles Perrault*: Created children's literature classics such as *Cinderella*, *Sleeping Beauty*, and *Little Red Riding Hood*.
- *Antoine de Saint-Exupéry*: *The Little Prince* (1943) stands out with its philosophical depth.
- **Italy**: *Carlo Collodi*: *Pinocchio* (1881) is a universally known work emphasizing the consequences of lying.
- **In the United States**: L. Frank Baum's *The Wonderful Wizard of Oz* (1900) presents a fantastical journey story. Dr. Seuss is known for his poetic style and rhythmic language in books such as *The Cat in the Hat* and *Green Eggs and Ham*. E.B. White's *Charlotte's Web* emphasizes the importance of friendship and loyalty.

In Turkey, children's literature has evolved from the Ottoman era to the present, progressing through the periods of Divan Literature, Tanzimat, Servet-i Fünun, and the National Literature movement. Although there was no distinct literary genre specifically created for children during the Divan Literature period, many works from that era can be seen as indirectly addressing children. Fairy tales, poems, and elegies written in this period served as important sources for both the education and entertainment of children. For instance, the allegorical narrative in Şeyh Galip's *Hüsn ü Aşk* employs a fantastical language that enriches children's imagination and can therefore be regarded as an early example of children's literature.

The Tanzimat era represents a turning point in the development of children's literature. During this time, in response to societal and educational needs, works specifically aimed at children began to be written. Namık Kemal's play *Akif Bey*, considered the "first Turkish drama," is one of the earliest examples of children-oriented literature. Additionally, *Tercüman-ı Ahval*, a newspaper launched in 1869, featured sections dedicated to children, containing educational stories, fairy tales, and content that contributed to children's development. Many Tanzimat-era authors wrote literary works for children as part of this cultural shift.

Children's literature continued to evolve during the Servet-i Fünun period. Writers such as Tevfik Fikret and Halit Ziya Uşaklıgil created works that supported children's intellectual and emotional development. Novels for children and literary works such as stories and poems appeared in magazines of the time. The popular magazine *Mektep* played a significant role in publishing and disseminating children's literature during this period.

The National Literature era approached children's literature from a broader perspective. Influenced by the rise of Turkish nationalism, greater emphasis was placed on producing works specifically for children. Ömer Seyfettin emerged as a prominent figure during this period. His stories such as *Kaşağı* and *Bomba* left lasting impressions on young minds through their entertaining yet instructive content. Moreover, children's magazines such as *Çocuk Dünyası* and *Güneş* served as significant platforms for presenting children's literary works. These magazines contributed substantially to the development of children's literature by including stories and activities aimed at strengthening children's national identity (Sınar, 2006).

With the establishment of the Republic, the development of children's literature accelerated. Significant milestones include the publication of *Children's Books* by the Turkish Language Association in 1928 and *The First Children's Book* in 1933. In the following decades, various public institutions contributed to the field through children's books and magazines. After the 1950s, first radio and then television, followed by the internet in the 2000s, increasingly influenced the development of children's literature. Today, children's literature plays a crucial role both in the transmission of cultural heritage and in raising a new generation of readers.

Was Children's Literature Created Merely to Increase Consumption?

Following the Industrial Revolution, it is known that production increased significantly, and in order to meet growing production demands, child labor became prevalent. In Europe, where adult literacy rates were already low, the education of child workers emerged as a serious issue. Some of the texts developed to address this problem and written specifically for educating child laborers are considered by certain scholars to form the foundation of children's literature (Şimşek & Kartal, 2022).

From this point of view, there are authors who argue that the emergence and development of children's literature were driven purely by consumer-oriented motives. Advocates of this perspective claim that children's literature initially developed solely for economic purposes, and that the emotional and intellectual needs of children were largely neglected. They argue that many early works aimed at children were didactic in nature, lacking elements of entertainment and failing to nurture children's imagination, emotions, and sense of identity. Such critiques highlight that although children's literature has gained more diverse and enriching content over time, its initial use as a utilitarian tool brought certain limitations.

In contrast, other scholars argue that children's literature emerged from necessity and fulfilled multiple functions from the very beginning (Orhan, 2021). Proponents of this view contend that, alongside its practical purposes, literature of the time also aimed to foster children's imagination and intellectual development. They emphasize that children's literature is not only educational but also entertaining, contributing to children's social and cultural growth. Thus, children's literature evolved from being merely a means to prepare child laborers for industrial work into a tool that supports children's integration into society as individuals in their own right.

What Are the Forms of Children's Literature?

Children's literature encompasses a wide range of works designed to help young individuals acquire knowledge in an enjoyable and educational manner. Among the most common forms are books and magazines. Storybooks, fairy tales, and poetry anthologies, for example, play a crucial role in fostering children's imagination. Additionally, comic books and picture books prepared for children also hold a significant place within this genre. Magazines offer children access to information on current topics, while digital content—such as educational apps and interactive stories—has become an integral part of contemporary children's literature. In this context, the term “children’s literature” should not be understood solely as limited to printed materials; rather, it includes all forms of literary works produced in digital environments as well (Sayer, 2007). This broad and evolving definition reflects the multifaceted nature of children’s literature in the modern era, where traditional and digital mediums coexist to support children’s cognitive, emotional, and cultural development.

The Current State of Children’s Literature Products

Today, children’s literature products have diversified significantly in both quantity and quality. This variety is evident in both printed and digital formats of children's literature. While children's books remained largely black-and-white until the mid-20th century, the second half of the century marked the beginning of more colorful and visually engaging works. With the advent of the 21st century, new design approaches have also emerged in printed literary works. In addition to traditional paper books, digital formats such as e-books and audiobooks have become increasingly popular, especially among children growing up in the digital age. Children’s literature today also attracts considerable attention from educators and parents, leading to a growing body of research and scholarly analysis in the field. In Turkey, many new authors have entered the field of children’s literature, and alongside locally produced works, translations from world literature have also gained popularity. International events and competitions provide opportunities for authors to develop their craft and reach broader audiences. These developments have significantly increased children’s access to a wider range of high-quality and diverse literary content.

Popular Science

Popular science refers to the communication of scientific findings—derived from academic research—to the general public in an accessible and comprehensible manner (Güner & Çitçi, 2010). The language of academia is universal and often complex, making it difficult for non-specialists to understand. Popular science plays a critical role in publicizing scientific research, fostering public interest in science and scientists, and enhancing scientific literacy. Works produced in this style are referred to as popular science publications and can include books, magazines, and a wide range of digital media.

The Emergence and Development of Popular Science

Communication is believed to have begun with the earliest humans, as evidenced by cave paintings, standing stones, and tree markings used to convey messages. With time, writing was invented and evolved from pictographic forms into more complex systems. Throughout history, writing has served numerous purposes—including the expression of emotions, dissemination of news, and transmission of truths. Archaeological findings show that writing was also used to communicate scientific knowledge and preserve it for future generations. The Industrial Revolution marked a turning point, accelerating scientific research, particularly in chemistry and mechanics, and increasing mechanization and production. The need to convey scientific developments and consumer products to broader audiences led to a demand for clear, accessible language. This necessity gave rise to popular science writings in the 18th century. During and after this period, industrialists, engineers, and scientists began contributing articles to newspapers and magazines to explain their work to the public. Over time, publications focusing solely on scientific and technical subjects emerged, and popular science began to develop rapidly. As a result, science started to become part of daily life (Dursun, 2010), and scientific topics became more accessible. Popular science books simplify complex scientific concepts and present them in an understandable manner, aiming to make scientific knowledge widely available. These publications contribute significantly to education by helping students understand scientific concepts, improve critical thinking skills, and increase scientific literacy. Studies have shown that reading popular science books in classroom settings enhances students' interest in science and supports their cognitive development (Eren, 2022).

The growth of popular science publishing has not only supported the dissemination of industrial and scientific discoveries but has also been influenced by increasing literacy rates, the spread of printing technology, and the evolution of journalism. Consequently, science communication became a recognized field (Dursun, 2010). Scientific journals, encyclopedias, and books became more common, and scientists started explaining their discoveries in more accessible language to engage the public.

In Turkish literature, there are early examples of texts that may be classified as popular science. During the Divan Literature period, poems addressing natural sciences were written, often in Arabic and Persian—the scholarly languages of the time. Although these texts were stylistically ornate and not easily understood by the public, topics such as astronomy, medicine, mathematics, and natural phenomena were occasionally addressed (Güler, 2018). Ali Kuşçu, a renowned scientist, produced literary works in astronomy that represent the intersection of science and literature (Pattabanoğlu & Uymaz, 2021). Other Divan authors who touched on scientific subjects include Nabi, Kâtip Çelebi, and Seydi Ali Reis. In Turkish folk and Sufi literature, scientific themes were often presented in a language accessible to the general public. For example, Aşık Veysel's poem *"Bir Dert Ehli Bulsam Derdim Söylesem"* deals with the pain of an incurable illness, while his poem *"Erzincan (Sam Değmiş)"* describes the destructive impact of the 1939 Erzincan earthquake. Traces of popular science can even be found in proverbs such as: "Cloudy mountains always bring rain," "Rain follows the wind, quarrels follow jokes," and "South wind brings summer, north wind brings winter."

In modern Turkey, popular science gained significant momentum starting in the mid-20th century. Public institutions, scientists, and authors began publishing and organizing seminars to bring science closer to the people. One major milestone was the establishment of the Scientific and Technological Research Council of Turkey (TÜBİTAK) in 1963. Since then, TÜBİTAK has played a crucial role in supporting scientific research and popularizing science across Turkish society through its publications and educational programs. Among TÜBİTAK's most influential contributions are its popular science magazines. *Bilim ve Teknik* (Science and Technology), launched in 1967, is Turkey's longest-running popular science magazine and has been a key medium connecting science with society. To reach school-aged children, *Bilim Çocuk* (Science for Children) began as a supplement in 1996 and became an independent magazine in 1998. Later, to introduce preschoolers to science, *Meraklı Minik* (Curious Little One) was launched in 2007. In 2015, TÜBİTAK expanded its efforts to digital platforms through *Bilim Genç*, a web-based science communication outlet. In addition to its periodicals, TÜBİTAK publishes popular science books for all age groups and supports various outreach programs including "TÜBİTAK 4004: Nature Education and Science Schools," "TÜBİTAK 4005: Innovative Educational Practices," "TÜBİTAK 4006: Science Fair Support Program," and "TÜBİTAK 4007: Science Festivals Support Program." Besides public institutions, private organizations and NGOs in Turkey also contribute to the dissemination of popular science through books, magazines, documentaries, competitions, conferences, congresses, scientific excursions, and observational studies. The rapid pace of technological advancement continues to play a significant role in the expansion and accessibility of these efforts.

The Current State of Popular Science

Globally, interest in popular science continues to grow rapidly, especially in developed countries, where research and dissemination activities are intensifying. This growing interest has accelerated the production and accessibility of popular science materials. One notable example is the *International Science Olympiads*, which began in 1978 and continue to expand with increasing participation. In addition, international exchange and educational programs such as *ERASMUS, Farabi, Mevlâna, ISEP, IAESTE, Global UGRAD, YES,* and *YFU* have further contributed to the spread and development of popular science across different age and education groups. Contemporary popular science publications address a wide range of subjects, including health, education, architecture, food, and technology. Health has become a particularly prominent topic in popular science, especially in the wake of the COVID-19 pandemic. Topics such as public health, virology, vaccine development, and healthy lifestyle practices are widely discussed, helping readers understand ways to protect their health while learning about groundbreaking scientific research. In the field of education, popular science enriches knowledge with books that explain fundamental learning processes and effective pedagogical strategies. Research on the role of technology in education, innovative teaching methods, and child development attracts the attention of educators and parents. These data-supported strategies contribute to the creation of more effective learning environments. In architecture, popular science literature covers themes such as sustainable building design, smart city applications, and green architecture. These topics not only promote environmental awareness but also foster public understanding of future trends in architecture. In the realm of food, popular science explores nutrition science and food safety. Subjects such as organic farming, innovative food production methods, and diet trends are frequently discussed, providing readers with important insights into healthy living. Technology remains one of the most significant focal points of popular science. Topics such as artificial intelligence, biotechnology, space exploration, and nanotechnology captivate the curiosity of scientists and the general public alike. These subjects help explain transformative innovations that affect daily life.

In this way, popular science serves to communicate complex scientific developments in a simplified and engaging manner, making science more accessible to broader audiences.

Technology

The term *technology* is derived from the Greek words *techne* (art, skill) and *logos* (knowledge, discourse). It can be broadly defined as the ability to create and utilize tools based on scientific knowledge to meet the needs of humans or other living beings (Günay, 2017). From an academic perspective, technology refers to the integration of knowledge, skills, methods, and processes to produce goods, services, or systems. In its most general sense, technology represents the practical application of theoretical knowledge. For instance, understanding that lenses can magnify is knowledge; however, using lenses to manufacture glasses or similar tools for everyday use is considered technology.

Are Technological Advancements Beneficial to Humanity?

Technological advancements arise from human needs. If humans had the physical strength to lift tons of weight, there would be no need for heavy vehicles or lifting devices, and consequently, no technological developments in this field. In this context, it is fair to assert that technology, in general, serves the benefit of humanity. Indeed, throughout history, technological innovations have introduced groundbreaking changes in various domains, significantly easing human life and enhancing the quality of living. The 20th century, in particular, stands out as a period where scientific knowledge and technological production became deeply intertwined, resulting in transformative progress in crucial fields such as health, communication, transportation, and food. In the medical field, the discovery of antibiotics, the development of vaccines, and the invention of imaging technologies like MRI and tomography have enabled the diagnosis and treatment of countless fatal diseases. Conditions once deemed incurable can now be effectively treated. Moreover, new, durable, and biocompatible materials have been invented for use in diagnostics and treatment, leading to a tangible improvement in overall quality of life. In the field of communication, the advent of technologies following the telephone, radio, and television—namely the internet, social media, and mobile technologies—has greatly facilitated interpersonal and societal interaction. These innovations have opened new horizons in education, employment, and personal development. Today, remote education, teleworking, and telemedicine services are made possible through these technological developments. Individuals can now consult with doctors, receive diagnoses, and even get test results without visiting a hospital. In transportation, advancements in automobiles, trains, airplanes, and maritime systems have not only supported economic development but also increased individuals' social mobility, effectively rendering the world "smaller." Thousands of people and tons of goods can now be transported swiftly, and intercontinental travel is possible within hours. In the domain of food technologies, innovations such as agricultural machinery, fertilization, and irrigation systems have significantly improved productivity and allowed food to reach a wider population (Pakdemirli, Birişik, Aslan, Sönmez, & Gezici, 2021). In large-scale agribusinesses, food products capable of meeting the needs of millions are produced without human contact.

Are Technological Advancements Detrimental to Humanity?

While many argue that technological advancements serve the benefit of humanity, there is also a considerable body of thought emphasizing their adverse effects. The negative consequences brought about by technology are far from negligible. Particularly during the 20th century, the two World Wars exemplify how technologies originally developed with good intentions were transformed into weapons of mass destruction, leading to catastrophic outcomes. The most devastating instance was the dropping of atomic bombs by the United States on the Japanese cities of Hiroshima and Nagasaki in 1945—a threat that still lingers today. Another critical issue arising from technological progress is environmental pollution and the growing problem of electronic waste (e-waste). Rapid technological development has significantly altered consumption habits. Millions of new electronic devices are introduced to the market annually, while outdated ones are discarded. This cycle has exacerbated the problem of e-waste. Devices such as phones, computers, and televisions often contain hazardous materials like lead, mercury, and cadmium, which pose serious risks to both the environment and human health. For instance, heavy metals from e-waste can seep into soil and water sources, disrupting ecosystems. Moreover, improper disposal methods release toxic gases, contributing to air pollution (Gürcan & Açıksöz, 2023). The widespread use of fossil fuels, which began with the Industrial Revolution and accelerated during the 20th century, has brought along numerous environmental challenges. Technological advancements have also led to social inequalities. Access to fundamental rights such as justice, education, healthcare, and employment is increasingly dependent on digital tools. As a result, individuals without access to technology are being further marginalized (Atasoy, 2007). Emerging threats such as cyberbullying, privacy violations, and ethical concerns related to artificial intelligence reflect the darker side of digital technologies. The psychological impacts of technology are also noteworthy. Social media, for example, has contributed to increased loneliness, comparative dissatisfaction, and attention disorders. Screen addiction among children and adults, as well as rising rates of depression among youth, demonstrate the detrimental effects of unchecked technology use (Arslan E., 2022). In this regard, technological progress poses risks to mental health as well. Additionally, rapid technological development has raised concerns about data security and digital threats. While access to information has become easier due to advances in communication technologies, the protection of personal data has become increasingly challenging. Sensitive information—such as personal details, banking credentials, and location data—can be exploited by malicious actors. Cyberattacks now target not only individuals but also state institutions. Critical infrastructures like power plants, hospitals, and financial institutions have become vulnerable. For example, the 2017 WannaCry cyberattack affected over 150 countries, paralyzing hospital systems and public institutions (Çifci, 2024). While technological advancements have enhanced production efficiency, they have also reduced the demand for human labor in many industries. Robots, software, and artificial intelligence systems are increasingly replacing human workers in sectors such as manufacturing, banking, transportation, and services, thereby creating a threat of unemployment for thousands. This also highlights a major drawback of technological progress. In light of these examples and concerns, it becomes crucial to educate future generations—our children—about both the positive and negative aspects of technology through popular science and educational tools.

Reflections of the Digital Revolution on Children's Literature

The rapid digital transformation driven by technological advancements has profoundly reshaped children's literature. Today, children's interaction with literature has changed significantly due to the prevalence of digital platforms. Traditional print books are increasingly being replaced by digital materials. Although digital children's literature offers numerous advantages, it also presents certain drawbacks (Bardakçı, 2018). Accessibility is one of the key advantages of digital children's literature. With an internet connection—or even in offline environments—children can easily access a wide range of digital materials. This increased accessibility is believed to positively influence reading habits. Many parents, although ambivalent, view digital reading tools as beneficial for providing rich content to their children. Furthermore, interactive books engage children actively in stories, making the learning experience more enjoyable. Despite the physical limitations of digital devices, digitization has vastly expanded the functional capacity of children's literature. For instance, comparing a standard 32-page printed book with the volume of content stored on a 50 GB memory card clearly illustrates the storage and access potential of digital formats. In this sense, digitalization offers a remarkable advantage for children's literature. However, digital transformation in children's literature is not without its drawbacks. Prolonged screen exposure poses significant risks to children's eye health. Unlike reading printed materials, digital reading or viewing has notable negative implications for vision. Although recent advancements in digital screen technology have attempted to mitigate these risks, they remain insufficient. Another downside of digitalization is the decrease in physical activity among children. While printed books offer limited visual stimulation, digital formats can include unlimited animation, colors, and designs that attract children's attention. Interactive and animated digital books often result in children remaining sedentary and screen-dependent for extended periods. Additionally, there is concern over visual laziness or amblyopia. Some educators and parents argue that children who listen to or watch narrated digital stories tend to develop weaker reading habits compared to their peers (Kurşun, 2022).

Envisioning the Future of Children’s Literature from the Perspective of Technology and Artificial Intelligence

Children are naturally curious, open to learning, and possess limited knowledge due to their developmental stage. These characteristics make children critically important for the future of both nations and the world. By designing appropriate educational programs, it is possible to cultivate the kind of citizens one envisions for the future (Ayvacı & Yurt, 2016). At this point, children’s literature plays a pivotal role. Any type of information or message—whether direct or indirect—can be conveyed to children effectively through children’s literature. Modern governments and educators are well aware of this fact and have consequently concentrated their efforts in this direction. To support the desired type of education for children, artificial intelligence tools are being developed at a breathtaking pace and are rapidly being integrated into educational systems. Societies and nations that fail to keep pace with technological developments are already at risk of falling behind in this race. When scientific and technological progress merges with children’s literature and artificial intelligence, it may sometimes yield unsettling outcomes for humanity. Therefore, experts from various fields—especially educators, but also professionals in security, health, food, and communication—emphasize the importance of guiding this integration toward beneficial uses.

Children’s Literature as a Shield Against Harmful Habits Induced by AI and Technological Advancements

With the development of artificial intelligence technologies, we are entering an era where systems that influence individual behavior are becoming increasingly prevalent. Children are particularly vulnerable, as they are exposed to a flood of written and visual information in AI-enhanced digital environments. While some of this content positively contributes to their physical and mental development, a portion of it poses risks. Currently, certain applications can analyze users’ health data to monitor calorie intake, sugar consumption, and levels of physical activity. While these systems function like digital assistants promoting healthy lifestyles, there is a growing concern that in the future, such systems might become increasingly authoritarian. Hence, it is of great importance that these themes are addressed in children’s literature—both in print and digital formats. Studies indicate that children in countries or regions where such education is provided, even if insufficiently, are more sensitive to these issues. Considering that these children will likely carry this awareness into adulthood, the long-term negative effects of AI and technological advancements on human physical and mental health can be significantly mitigated. Through these educational efforts, children will develop greater caution when consuming food and beverages deemed harmful to their health. As a result, numerous illnesses can be prevented, harmful habits curbed, and healthier generations fostered. While legal regulations may limit access to unhealthy foods and substances via technological means, such as software restrictions, this approach is clearly not a comprehensive solution. For example, when a user attempts to order a pizza, the system might issue a warning such as: "Your blood sugar level is not suitable for this food." In more advanced scenarios, the system may outright reject the order. A similar mechanism could be implemented for attempts to acquire illicit substances. However, a child lacking such awareness might still manage to access these harmful items. Therefore, fostering consciousness and critical thinking in children through literature remains a vital and irreplaceable strategy.

Children's Literature as a Remedy for Cultural Erosion Caused by the Union of Artificial Intelligence and Technology

AI-based content filtering systems are already widely implemented on digital platforms such as YouTube, TikTok, and Google. These platforms offer recommendations based on users' age, gender, language preferences, and search history. While these systems enhance user experience, they also introduce "filter bubbles," which limit access to diverse information. In the future, as these filtering mechanisms become even more precise, it may be possible for users to be denied access to certain sources of information based on their religious beliefs, age group, or education level. For example, a school assignment that a student would normally research and prepare independently could instead be generated instantly by AI and presented to the student, perhaps even tailored to the student's national or religious sensitivities. While such a development may seem convenient in the short term and unlikely to cause concern among users, it brings with it serious long-term risks. Personalizing access to information based on user profiles may deepen social polarization, as individuals become confined to their own "digital echo chambers." This limits exposure to diverse perspectives and information sources. Moreover, individuals who, weary of isolation, attempt to reintegrate into society may be vulnerable to harmful ideologies if they lack a robust cultural foundation. Alienation from one's own culture due to cultural erosion may ensue. To prevent such scenarios, children's literature can address topics related to cultural erosion in an age-appropriate manner. It can also guide children on how and how often they should use technology and artificial intelligence, depending on their developmental stage.

Children’s Literature as a Safeguard Against Discrimination in the Era of AI and Technology

AI-supported digital platforms now provide highly personalized services based on various parameters such as users’ religious beliefs, location, nationality, social media behavior, financial history, and spending habits. While such personalization may appear to enhance user convenience, a deeper analysis reveals the potential for serious discrimination. As these systems evolve, the risk increases that individuals may be excluded from essential digital services—such as purchasing transportation tickets, booking hotels, applying for loans, or accessing healthcare and public libraries—based on factors like insufficient bank account balances, low credit scores, or politically unfavorable views. China’s “social credit system,” which tracks and evaluates citizens’ behaviors to grant or restrict privileges, illustrates how widespread digital surveillance may become in the future. Such systems pose significant challenges to the principle of digital equality. Technology should ensure fair, transparent, and equal access for all members of society. Turning identity attributes such as political affiliation, religion, or socioeconomic status into barriers to digital services undermines social justice. This is where regulation and ethical principles become essential. National and international legal frameworks must ensure that AI systems function transparently, accountably, and equitably. To uphold human dignity in technological applications, society must also increase awareness of these risks. At this juncture, the role of children’s literature creators becomes crucial. By presenting these topics in age-appropriate ways, authors can raise awareness in children and contribute to preventing the misuse of AI and technology in the future. In doing so, they can support governmental efforts to build a more just digital society.

Children’s Literature Can Dispel the Myth That AI and Technology Promote Laziness in Students

The integration of AI with technological innovations in education has sparked debate about whether such tools diminish students’ cognitive engagement and contribute to “robotic” thinking. This issue is of growing concern among educators, parents, and policymakers. Increasingly, students rely on AI-driven tools and feel less compelled to conduct their own research. While the use of AI tools such as ChatGPT in completing assignments can save time, overreliance may negatively affect students' learning and research abilities in the long run. Research skills involve not only gathering information, but also analyzing it, comparing sources, and forming personal interpretations—cognitive processes vital to both academic development and real-world problem-solving. When AI provides ready-made answers, students may bypass these essential mental steps and focus only on outcomes, which can lead to a dependency on prepackaged knowledge. However, AI can be utilized as a guide. Instead of completing assignments entirely, it can assist students in sourcing materials, structuring content, and generating ideas. For example, in subjects requiring numerical analysis, AI tools can complete part of the task while encouraging students to complete the rest themselves. The key lies in teaching students how to use AI effectively and responsibly. These skills and principles can be introduced from an early age through children's literature. In this way, children can learn appropriate and purposeful use of AI in education, homework preparation, and daily problem-solving—fostering a balanced relationship with technology.

Children's Literature as a Solution to Issues Stemming from Early Access to Information, Inequitable Information Access for Disadvantaged Children, and Quality of Life Challenges for Vulnerable Individuals in the Context of AI and Technology

Through artificial intelligence and digital technologies, today's children gain access to information at much earlier ages than previous generations. While this presents clear academic advantages, it also introduces psychological risks. Early access to information can support cognitive development; however, when children are exposed to content beyond their developmental stage, they may experience cognitive overload. This can lead to early-onset adolescence, anxiety disorders, or a growing disinterest in knowledge itself. Especially through social media and algorithm-driven content, children's attention spans are shortened, and they increasingly rely on superficial knowledge rather than deep learning. Moreover, children who are compelled to form digital identities at a young age may develop psychological dependencies on online approval and social validation. Hence, alongside the right to access information, age-appropriate content filtering and digital guidance services have become essential. The use of AI in education must be guided by pedagogical principles and tailored to developmental stages. Regardless of legal regulations, behavioral habits must be established for meaningful outcomes—this is where the role of children's literature becomes indispensable. While AI and technology hold potential to promote educational equity, the digital divide continues to pose significant challenges for disadvantaged children. Children from low-income families, rural areas, or those with disabilities often face limited access to technology. On the positive side, technology can provide personalized learning opportunities and adaptive educational content tailored to individual needs. However, this advantage is contingent upon the availability of internet access, devices, and technical support. Without these, disparities in access to information may widen even further. Addressing this issue requires policies and practices that ensure equal technological access for disadvantaged communities—an approach that must be nurtured from an early age through value-based education. To promote educational equity for children in underserved regions, both public policy and inclusive technological design are crucial. Otherwise, unequal access to information will deepen the existing social injustice in education. As such, children’s literature can present these topics in developmentally appropriate ways to contribute to awareness and long-term solutions. The convergence of AI and technology also holds transformative potential for marginalized groups such as individuals with disabilities, the elderly, patients, and those with low incomes. These technologies not only facilitate access to information but also improve daily living by enhancing independence and comfort. For example, AI-assisted audiobooks, screen readers, and facial recognition technologies have removed barriers to information access for visually impaired individuals. Similarly, automatic subtitle systems and real-time sign language translation make education more accessible for those with hearing impairments. Social interaction applications designed for children with autism spectrum disorder help improve communication and language skills. AI-powered robotic arms and smart wheelchairs provide autonomy to individuals with physical disabilities. Personalized learning applications guided by AI adapt to individual learning styles, increasing motivation and engagement—especially for learners with attention deficit disorder or dyslexia. Nevertheless, to ensure inclusive access to these advancements, investments in infrastructure, teacher training, and ethical oversight are essential. Crucially, the responsible use of AI and technological developments depends on the human factor—people capable of managing this power for the collective benefit of society. Educating such individuals must begin at a young age through various forms of children’s literature—stories, novels, poems, memoirs, and diaries—that instill ethical and social responsibility. Otherwise, those who attain power may exploit it for personal comfort and gain rather than for the well-being and happiness of others.

Conclusion

It is well known that technology is advancing at a breathtaking pace. One leg of this triadic development is children's literature, and the other is popular science. While popular science addresses research conducted in fields that constitute the foundation of technological developments, children's literature conveys this knowledge to the target audience from the preschool period onward through a variety of genres such as fairy tales, novels, stories, plays, memoirs, travelogues, essays, and articles. The energy generated by this threefold structure directly influences the social, emotional, and cognitive development of children—who are the adults of tomorrow—and prepares them to become future-ready individuals.

According to this study, it can be concluded that children's literature has adapted to the digitalization process in education. In an era when digitalization continues at an overwhelming speed due to technological advancements, children's literature has kept pace with this transformation. Printed books in the traditional sense are rapidly being replaced by digital materials. Among the new generation of children's literature products, interactive books, audio and animated stories make reading more enjoyable and educational compared to traditionally printed materials. It is well established that individuals who are exposed to popular science books from an early age tend to show greater interest in technical topics and technological developments. For this reason, today’s authors of popular science and children’s literature bear greater responsibility.

While studies in the context of education and technology emphasize the importance of education, the integration of technology into education must also be highlighted. However, the use of technology in education is an issue that stakeholders must approach with great care. It is undeniable that access to information has become much easier with the use of basic technological tools such as mobile phones, tablets, and various applications in educational settings. Yet this positive development also entails certain risks. Extended screen time, attention deficits, physical inactivity leading to obesity, and vision and spinal disorders are among the most critical concerns.

The second conclusion highlights the role of popular science in developing children’s scientific thinking skills. Popular science books and publications simplify complex scientific concepts, making them comprehensible for children and sustaining their sense of curiosity. This early introduction to science fosters scientific inquiry skills and allows children to use their out-of-class time productively through simplified educational content.

As a third conclusion, the role of technology in education can be emphasized. The appropriate use of technology in education is of great importance. In many countries today, there are restrictions on the use of certain technological tools—especially mobile phones—by children below a specific age. The ban on mobile phones in classrooms is a notable example. According to the shared opinion of educators, psychologists, and security experts, the premature use of such devices tends to do more harm than good.

It is also essential to acknowledge the following reality: technology has democratized access to information, individualized learning processes, and contributed to the principle of equal opportunity in education. With the advancement of artificial intelligence technologies, personalized learning experiences can now be provided, and educational materials tailored to individuals' interests and needs can be developed. This presents significant opportunities for disadvantaged groups. Visually or hearing-impaired children, for example, can access information without falling behind in their education thanks to AI-supported tools. Likewise, children living in rural areas can now access quality content through digital educational materials.

However, these opportunities presented by technology also carry inherent risks. Issues such as digital discrimination, inequality in access to information, cultural erosion, and weakened research skills among children reflect the negative side of digitalized education. AI-based systems that evaluate individuals based on parameters such as financial history, political orientation, or religious beliefs may, in the future, deepen issues of digital discrimination and social exclusion. Similarly, personalized information feeds may confine users to their own echo chambers, thereby limiting exposure to diverse perspectives and cultures and fueling societal polarization.

At this point, the critical role of children's literature becomes evident once again. Children's literature fulfills an important function in this context. While conveying popular science topics to the target audience, it also contributes to the process through texts that emphasize the proper and responsible use of technology. Stories that stimulate children's imagination and spark curiosity about exploration help cultivate a positive attitude toward technology. Texts that explain the harmful effects of technological misuse—such as atomic bombs and chemical weapons—are tailored to be age-appropriate. At the same time, articles highlighting the superiority of the human brain over technological tools, and emphasizing the central role of curiosity in all discoveries, are written by popular science authors and delivered to children through literature.

As is well known, children's literature does not merely impart information—it is also a powerful tool for values education, developing empathy, promoting respect for diversity, and instilling ethical awareness. Through children's literature, children learn how to use digital tools appropriately, how to access information, and how to evaluate technology critically. Moreover, children's literature serves as a bridge that enables children to maintain their cultural identities while embracing universal values.

Recommendations

This section presents several recommendations related to the topic addressed in the scope of the study.

- Publishers and authors should produce interactive, audio, and animated books that capture children’s interest in an increasingly digital world. However, these products must be developed in accordance with pedagogical principles and should be filterable based on children's age groups and developmental stages.
- Popular science resources, especially in the fields of science, technology, engineering, and mathematics (STEM), should be presented to children through simple, engaging, and educational content. Teachers should integrate these resources into their lesson plans and implement projects aimed at enhancing students’ scientific thinking skills.
- From the primary education level onward, children should be taught the correct use of digital tools, how to critically evaluate information sources, and issues related to digital ethics and privacy. These topics can be made more enjoyable through the support of children’s literature works.
- Artificial intelligence applications should not only provide information to students but also encourage them to think critically, question, and create. These systems must be continuously monitored and updated to ensure compliance with ethical standards and to prevent any harm to children.
- Children’s books that reflect national cultural values should be made more visible on digital platforms and integrated with technology to ensure effective delivery to children. This would help prevent children from becoming alienated from their cultural roots.
- Seminars, workshops, and online events for parents, teachers, and children should be organized to raise awareness about issues such as screen time, digital addiction, and information security.
- Infrastructure investments should be made to ensure equal access to digital resources for children living in rural and low-income areas. Free digital children’s literature and popular science books should be made available to these groups.
- Prospective teachers should receive specialized training on how to produce digital materials, use popular science resources, and benefit from AI-assisted applications in educational contexts.

- Authors can present contemporary issues such as artificial intelligence, technology ethics, and digital discrimination through storytelling for children. This approach can help cultivate greater technological awareness among young readers.
- Organizing science festivals, children's book fairs, story competitions, and digital storytelling workshops can encourage children to participate in both literary and scientific production.

References

Arslan, E. (2022, September). Dijital Hastalık Bağlamında İz Sürme (Stalk) ve Olan Biteni Kaçırma Korkusu (Fomo) İlişkisi. *Journal of Communication Science Researches - IBAD, 2*(3), 154-166. https://doi.org/10.7456/100203100/001

Arslan, S., & Şendurur, P. (2017). Eğitimde Teknoloji Entegrasyonunu Etkileyen Faktörlerdeki Değişim/İnvestigation of Changes in Factors Affecting The Technology Integration in Education. *Mehmet Akif Ersoy Üniversitesi Eğitim Fakültesi Dergisi*(43), 25-50. https://doi.org/10.21764/efd.21927

Atasoy, F. (2007, Haziran). Kültürler Üzerinde Bilişim Devriminin Etkileri. *Modern Türklük Araştırmaları Dergisi, 4*(2), 163-178.

Ayvacı, H., & Yurt, Ö. (2016). Çocuk ve Bilim Eğitimi. *Çocuk ve Medeniyet*(1), 15-28.

Bardakçı, S. (2018). Dijital Yaşamda Çocuk Kitabı Üzerine Bir İnceleme. H. Odabaşı içinde, *Eğitim Teknolojisi Kuram ve Uygulama* (Cilt 8, s. 232-242). Ankara: PEGEM.

Çer, E. (2019). Çocuk Edebiyatı Yapıtlarının Çocuğa Göre Olmasını Sağlayan Başat Bir Değişken: Eğitsel Özellikler. *Uluslararası Çocuk Edebiyatı ve Eğitim Araştırmaları Dergisi, 3*(1), 1-11.

Çifci, H. (2024). *Her yönüyle siber savaş.* Ankara: TÜBİTAK.

Dursun, Ç. (2010). Dünyada Bilim İletişiminin Gelişimi ve Farklı Yaklaşımlar: Toplum İçin Bilimden Toplumda Bilime. *Kurgu Online International Journal of Communication Studies*(12), 1-31.

Enginün, İ. (2006). Çocuk Edebiyatı ve Çocuk Kitapları. *Uludağ Üniversitesi Eğitim Fakültesi Dergisi, 19*(1), 213-222.

Eren, A. (2022). Popüler Bilim Dergileri Destekli Yaşam Temelli Öğretim Uygulamalarının Akademik Başarıya Etkisi: Güneş Sistemi ve Tutulmalar Örneği. *Yayımlanmamış Yüksek Lisans Tezi*. Bursa: Uludağ Üniversitesi, Eğitim Bilimleri Enstitüsü.

Güler, G. (2018). Fuzuli'nin Türkçe Divanı'nda Gökcisimleri ve Feleklerin Dönemin Astronomi Bilgisiyle Uyumu. *3rd European Convention on Turkic, Ottoman Turkish Studies* (s. 1-14). Bamberg / Almanya: Boğaziçi Üniversitesi.

Günay, D. (2017, Nisan). Teknoloji Nedir? Felsefi Bir Yaklaşım. What is Technology? A Philosophical Approach. *Yükseköğretim ve Bilim Dergisi, 7*(1), 163-166. https://doi.org/10.5961/jhes.2017.194

Güner, B., & Çitçi, M. (2010). Popüler Bilim Anlayışı ve Coğrafyanın Popülerliği. Popular Science Conception and The Popularity of Geography, The Sample of Bilim ve Teknik Journal. *Doğu Coğrafya Dergisi*(24), 131-156.

Gürcan, C., & Açıksöz, S. (2023). Akıllı Atık Yönetimi ve Örnek Uygulamalar. Smart Waste Management And Sample Applications. *Kent Akademisi. Urban Academy, 16*(1), 577-594. https://doi.org/10.35674/kent.881639

Koyuncuoğlu, A. (2021). Çocuk Edebiyatının Dünyadaki ve Türkiye'deki Tarihsel Gelişimi. *Spor, Eğitim ve Çocuk, 1*(1), 1-16. https://doi.org/10.5505/sec.2021.25743

Kurşun, Ü. (2022, Aralık). Dijital Çocuk (Kitap Kritiği). *Academic Platform Journal of Education and Change, 5*(2), 265-270. https://doi.org/10.55150/apjec.1119106

Orhan, M. (2021). TÜBİTAK Çocuk kitaplarının çocuk edebiyatı yönüyle incelenmesi. [Yayımlanmamış doktora tezi]. Kırıkkale Üniversitesi.

Özbay, M. (2005). Bilim ve Kültür Aktarıcısı Olarak Yazı. *Türkiyat Araştırmaları*(2), 71-72.

Özder, D. (2022). Taşlıcalı yahya bey divanı'nda tababet unsurları. M. Ağarı (Başkan) *1. Uluslararası Türkoloji Kongresi: "Arayışlar ve Yönelimler:"* (s. 376-387). Karabük: Karabük Üniversitesi.

Pakdemirli, B., Birişik, N., Aslan, İ., Sönmez, B., & Gezici, M. (2021). Türk Tarımında Dijital Teknolojilerin Kullanımı ve Tarım-Gıda Zincirinde Tarım 4.0.Use of Digital Technologies in Turkish Agriculture and Agriculture-Food Chain Agriculture 4.0. *Toprak Su Dergisi. Soil Water Journal, 10*(1), 78-87. https://doi.org/10.21657/topraksu.898774

Pattabanoğlu, F., & Uymaz, T. (2021). 15. ve 16. Yüzyıl Osmanlı Astronomisi Bağlamında Ali Kuşçu'nun "Fethiyye" ve Seydî Ali Reis'in "Hülâsatü'l-Hey'e" Adlı Eserleri. *Dört Öge*(20), 115-139.

Sınar, A. (2006). Türkiye'de Çocuk Edebiyatı Çalışmaları. *Türkiye Araştırmaları Literatür Dergisi, 4*(7), 175-225.

Sayer, R. (2007). Çocuk kütüphanelerinde elektronik yayınların kullanımı ve yaygınlaştırılması. [Yayımlanmamış yüksek lisans tezi]. Ankara Üniversitesi.

Şimşek , K., & Kartal, A. (2022). Çocuk Edebiyatının Başlangıcına Dair Bir Değerlendirme. *RumeliDE Dil ve Edebiyat Araştırmaları Dergisi*(29), 344-356. https://doi.org/10.29000/rumelide.1164173

Taşdelen, Ö., & Güven, T. (2024). Sınıf Ortamında Popüler Bilim Kitabı Okuma Uygulamasına Yönelik Biyoloji Öğretmen Adaylarının Algıları/Perceptions of Preservice Biology Teachers towards the Practice of Reading Popular Science Books in a Classroom Setting. *Buca Eğitim Fakültesi Dergisi, 62*, 3170-3193. https://doi.org/10.53444/deubefd.1496259

Yükçü, Ş., İzoğlu, A., & Kangal, S. (2019). Çocuk edebiyatının geldiği son nokta: Okul Öncesi Dönem Resimli e-kitaplara Gelişimsel Bir Bakış/The current situation of children's literature: A Developmental overview of the preschool picture e-books. *Erken Çocukluk Çalışmaları Dergisi, 3*(1), 139-164. https://doi.org/10.24130/eccd-jecs.1967201931122

Yılmazsoy, B. (2020). Yapay zekâ Teknolojilerinin Eğitimde Kullanılmasının Önemi (Editöre Mektup). *Açıköğretim Uygulamaları ve Araştırmaları Dergisi, 6*(2), 3-6.

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Chapter VII

Frontiers of Fintech: the synergy of Artificial Intelligence and Blockchain

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Abstract

The integration of blockchain technology and artificial intelligence (AI) is transforming the financial sector by enhancing security, increasing operational efficiency, and fostering innovative financial products. This article conducts a comprehensive review of the current landscape where these technologies intersect, drawing from a broad range of scholarly literature and practical case studies. We explore the effectiveness of blockchain and AI in improving transaction security and compliance, the challenges of scalability and integration with existing financial systems, and the innovative potential these technologies hold for creating new financial instruments and services. Key findings suggest that blockchain's immutable ledger and AI's predictive analytics significantly enhance fraud detection and risk management. However, these technologies also introduce complexities, particularly in scalability and data privacy, which are compounded by stringent regulatory frameworks that struggle to keep pace with rapid technological advancements. Despite these challenges, blockchain and AI are paving the way for groundbreaking changes in the financial sector, such as AI-driven personalized banking services and blockchain-based transparent governance systems. This review not only synthesizes existing research and developments but also identifies gaps in knowledge and suggests future directions for study and implementation. By providing a nuanced understanding of both the opportunities and obstacles presented by blockchain and AI, this article aims to inform researchers, practitioners, and policymakers involved in the ongoing evolution of financial technologies.

Keywords: Blockchain Technology, Artificial Intelligence (AI), Financial Sector, Fraud Detection, Risk Management, Regulatory Compliance, Predictive Analytics, Financial Innovation, Technology Integration, Data Privacy.

Introduction

The convergence of blockchain technology and artificial intelligence (AI) is heralding a new era in the financial sector, characterized by enhanced operational efficiencies, robust security mechanisms, and innovative financial services. These technologies are not just augmenting existing financial systems but are also redefining the paradigms of financial transactions, risk management, and customer engagement. Blockchain ensures the integrity and transparency of financial transactions through its immutable ledger, while AI contributes its prowess in big data analytics to provide deeper insights and predictive capabilities.

This article provides a comprehensive review of the integration of blockchain and AI within the financial sector. It explores how the synergy between blockchain's security features and AI's analytical strengths can address some of the most pressing challenges faced by financial institutions today, including fraud prevention, risk assessment, and compliance with evolving regulatory landscapes. Moreover, the discussion extends to the scalability challenges and ethical considerations that arise with the adoption of these technologies, emphasizing the need for a balanced approach in leveraging their benefits.

Additionally, the transformative potential of blockchain and AI is examined through various case studies and scholarly works, illustrating their role in driving innovation in financial products and services. From blockchain-enabled smart contracts that automate and secure financial agreements to AI-driven algorithms that customize financial advice and investment strategies, these technologies are creating new opportunities and setting new standards in the financial industry.

Through a detailed synthesis of current literature and practical implementations, this introduction sets the stage for a deeper exploration of the dynamic and multifaceted relationship between blockchain and AI in finance. It aims to provide a holistic understanding of both the opportunities these technologies offer and the complex challenges they bring to the forefront of financial innovation and regulation.

Literature Review

The integration of blockchain and artificial intelligence (AI) in the financial sector has garnered extensive scholarly attention due to its transformative potential. This review draws on a wide array of sources to explore how these technologies are reshaping financial services, focusing on enhanced security, operational efficiency, regulatory challenges, and the creation of innovative financial products.

Blockchain's Impact on Finance

Blockchain technology has fundamentally altered the landscape of financial transactions by introducing an immutable ledger for secure, transparent, and efficient transaction processing. Frizzo-Barker et al. (2020) discuss blockchain as a disruptive technology in financial institutions where transparency and security are paramount. Additionally, studies by S.Soni and B.Bhushan (2019) delve into the operational security and potential applications of blockchain, providing a foundational understanding of its impact. Furthermore, the study by Patel et al. (2022) corroborates the importance of blockchain in enhancing transparency and reducing fraudulent activities within banking systems. Marchesi et al. (2022) extend this perspective by discussing blockchain's architectural benefits that support industrial applications, indicating its robustness and adaptability in handling complex financial operations.

AI's Role in Financial Services

AI's capacity to analyze large datasets with speed and accuracy is revolutionizing financial decision-making processes. Patel et al. (2022) highlight how AI enhances service efficiency and improves risk management through sophisticated modeling techniques. A.Hussain Adedoyin and F.Al-Turjman (2021) provide a comprehensive review of AI's role in conjunction with blockchain, enhancing both security and operational intelligence in financial applications. According to Yang et al. (2021), AI facilitates enhanced decision-making by analyzing data patterns more accurately and at a scale previously unmanageable by human capabilities. This point is further supported by Shrier, Wu, and Pentland (2016), who discuss

AI’s role in creating secure and efficient infrastructures that safeguard identities and ensure data security.

Synergy of Blockchain and AI

The combination of blockchain and AI leads to enhanced fraud detection and risk management within the financial sector. Yang et al. (2021) emphasize how AI's predictive capabilities, combined with blockchain's secure environment, create robust tools for fraud prevention. Similarly, the work by G. Zhang et al. (2018) on blockchain-based data sharing for AI-powered network operations illustrates the practical implementations of this synergy, showcasing its effectiveness in real-world applications. The synergy between blockchain and AI can significantly improve fraud detection and overall financial security. Lin et al. (2023) highlight how blockchain-aided frameworks support AI-generated content, ensuring secure and reliable semantic communication. In the context of financial services, this integration ensures that transactions are not only recorded but also analyzed for anomalies in real-time, as explored by Raja et al. (2020) in their work on decentralized secure multiparty computation protocols.

Challenges and Scalability

While the benefits are significant, the integration of blockchain and AI also presents notable challenges. Shrier, Wu, and Pentland (2016) discuss scalability issues, particularly in financial institutions where large volumes of transactions are processed. The work by T.Sharma, S.Satija, and B.Bhushan (2019) further explores the security requirements and challenges in unifying blockchain with IoT, providing insights into the technical hurdles of integrating these technologies. While the integration promises many benefits, it also presents considerable challenges, particularly in regulatory compliance and data privacy. Ren et al. (2023) provide a systematic review of sustainable finance, emphasizing the need for a regulatory framework that accommodates the rapid evolution of blockchain and AI technologies. Additionally, Harris and Waggoner (2019) discuss the decentralized nature of these technologies, which, while beneficial, introduces complexities in maintaining standard regulatory and ethical norms.

Regulatory and Compliance Challenges

While the integration promises many benefits, it also presents considerable challenges, particularly in regulatory compliance and data privacy. Regulatory compliance remains a significant challenge as these technologies evolve. Ren et al. (2023) and Bellagarda, Abu-Mahfouz (2022) discuss the need for dynamic regulatory frameworks that can adapt to rapid technological advancements, ensuring that new innovations adhere to global standards and ethical practices. Additionally, Harris and Waggoner (2019) discuss the decentralized nature of these technologies, which, while beneficial, introduces complexities in maintaining standard regulatory and ethical norms.

Innovations in Financial Products and Services:

Raja et al. (2020) and Shafay et al. (2023) describe the development of new financial instruments and services that leverage blockchain and AI. These innovations offer personalized banking services, automated compliance, and enhanced risk management, illustrating the transformative potential of these technologies in creating more responsive and user-centric financial solutions.This literature review underscores the complex interplay between blockchain and AI within the financial sector, highlighting both the transformative impacts and the challenges that need careful management. The integration of these technologies is redefining the standards of financial operations, enhancing security, efficiency, and the development of innovative financial products.

The future of blockchain and AI in finance looks promising but requires continuous innovation and adaptation to overcome existing challenges. Koller (2019) suggests that as these technologies evolve, they will eliminate intermediaries, thus creating a more secure and streamlined financial environment. This evolution requires not only technological advancements but also a shift in how financial entities perceive and integrate these technologies, as noted by Shafay et al. (2023), who explore deep learning within blockchain frameworks.

Methodology

This study adopts a qualitative research approach, focusing on an extensive literature review and detailed analysis of case studies to explore the integration of blockchain and artificial intelligence (AI) in the financial sector. The primary method of data collection involves a thorough examination of academic journals, industry reports, white papers, and existing case studies that document the implementation and effects of blockchain and AI technologies. The literature includes foundational contributions from scholars such as Frizzo-Barker et al. (2020), Yang et al. (2021), and Patel et al. (2022), along with newer insights from authors like S.Soni and B.Bhushan (2019) and G. Zhang et al. (2018). These sources provide a broad perspective on both the potential and challenges of blockchain and AI within financial services. The data from these sources are analyzed using thematic analysis to identify key themes such as operational effectiveness, security enhancements, scalability issues, regulatory challenges, and innovation in financial products. The review synthesizes findings across different studies to present a comprehensive overview of the current state of blockchain and AI in the financial sector, highlighting significant trends, gaps, and areas for further research. This method allows for a deep understanding of the complex dynamics and transformative potential of these technologies in reshaping financial services.

Results

The integration of blockchain technology and artificial intelligence (AI) within the financial sector has yielded significant findings that span across multiple aspects of financial operations, technology integration, and market innovation. This section details the outcomes observed through our comprehensive review of the literature and case studies.

Table 1. Blockchain AI: Effectiveness, Challenges & Innovation in Fintech

Themes/Authors	Effectiveness	Challenges & Regulatory Compliance	Innovations
Frizzo-Barker et al. (2020)	Enhanced security in transactions	-	-
Yang et al. (2021)	Fraud detection using AI and blockchain	-	-
Lin et al. (2023)	Improved reliability of AI-generated advisories	-	-
Patel et al. (2022)	Operational efficiency	-	-
PeerJ Computer Science (2023)	Streamlined processes and automation	-	-
Shrier, Wu, Pentland (2016)	-	Scalability issues in financial institutions	-
Koller (2019)	-	Integration with existing infrastructures	-
Harris and Waggoner (2019)	-	Data privacy and ethical AI decision-making	-
Ren et al. (2023)	-	Dynamic regulatory frameworks needed	-
Bellagarda, Abu-Mahfouz (2022)	-	Navigating global privacy standards	-
Raja et al. (2020)	-	-	New financial instruments
Shafay et al. (2023)	-	-	Enhanced risk management and customization
S.Soni; B.Bhushan (2019)	-	Security analysis and privacy threats	Potential applications
G. Zhang et al. (2018)	-	-	Blockchain-based data sharing for AI operations
A.Hussain Adedoyin; F.Al-Turjman (2021)	-	-	Overview of AI and blockchain integration
T.Sharma; S.Satija; B.Bhushan (2019)	-	Security requirements and challenges in IoT	Unifying Blockchain and IoT
S.Gupta; S.Sinha; B.Bhushan (2020)	-	-	Blockchain technology fundamentals and implementations
C.LaPointe; L.Fishbane (2019)	-	Blockchain ethical design considerations	-
D.Tapscott (2016)	Impact on financial sectors	-	Blockchain revolution insights
A.Antonopoulos (2018)	Smart contracts effectiveness	-	Building Dapps and Ethereum mastery
G. Ishmaev (2020)	-	Privacy and ethics in identity management	-

Enhanced Security and Efficiency

Blockchain's implementation has notably increased the security and transparency of financial transactions. Frizzo-Barker et al. (2020) and S.Soni and B.Bhushan (2019) highlight how blockchain's immutable ledger and decentralized nature significantly reduce the risk of fraud and unauthorized alterations. Furthermore, AI's role, as discussed by Patel et al. (2022), enhances these capabilities by introducing advanced predictive analytics that aid in early fraud detection and risk management, thereby streamlining financial operations and increasing overall efficiency.

Innovations in Financial Products and Services

The synergy of blockchain and AI has led to the creation of innovative financial products that redefine consumer interaction and service delivery within the sector. Raja et al. (2020) and Shafay et al. (2023) describe new forms of financial instruments that leverage AI for personalized banking experiences and blockchain for enhanced security. These innovations illustrate a shift towards more tailored financial services that meet specific customer needs more efficiently.

Scalability and Technical Challenges

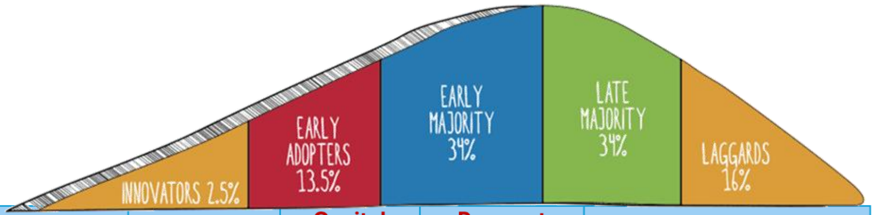
Shrier, Wu, and Pentland (2016) along with T.Sharma, S.Satija, and B.Bhushan (2019) discuss the scalability challenges encountered when integrating blockchain and AI into existing financial infrastructures. These include issues related to the processing power required for AI algorithms and the transaction speed limitations of blockchain networks, which can hinder their practical application on a larger scale.

Economic Impact and Market Adoption

The review also notes a significant economic impact as blockchain and AI increase market efficiencies and reduce operational costs. The case studies explored indicate a positive reception in the market with increasing adoption rates, suggesting a growing trust and reliance on these technologies to solve traditional problems in finance such as transaction delays, access to credit, and cross-border payments. In summary, the results from the literature review and case studies provide a multifaceted view of the impact of blockchain and AI integration in the financial sector. While they bring substantial improvements in security, efficiency, and innovation, they also present complex challenges that require ongoing attention, particularly in areas of scalability, regulatory compliance, and technical integration. These findings set the stage for further discussions on how these technologies can be optimized and better integrated into the financial landscape.

Discussion

In this study, we have designed a comprehensive **three-dimensional matrix** that encompasses themes, technological impacts, and financial sectors affected by the integration of blockchain and artificial intelligence (AI). We structured it around specific themes that reflect the depth and variety of impacts observed. This matrix is structured to provide insights into how different technological aspects affect various sectors within finance.



Themes/Impacts	Banking	Insurance	Capital Markets	Payment Systems	Wealth Management
Fraud Detection and Security	Enhanced real-time fraud detection using AI algorithms that analyze transaction patterns on blockchain	Improved claim verification processes and fraud prevention in claims management	Increased transparency and reduced insider trading through immutable transaction records	Secure and transparent cross-border transactions enabled by blockchain	Enhanced security measures for client portfolios through AI-driven analysis of investment patterns
Operational Efficiency	Automation of routine compliance checks and customer due diligence using AI	Streamlined processing of claims and policy issuance through smart contracts	Faster settlement processes enabled by blockchain-based trading platforms	Reduction in transaction costs and elimination of intermediaries with blockchain	AI-optimized portfolio management and automated advisory services
Innovative Financial Products	Introduction of blockchain-based banking products like syndicated loans and trade finance solutions	Usage of AI to tailor insurance products based on individual risk profiles	Development of new trading instruments and platforms that use AI for predictive analytics	Implementation of blockchain for remittances and real-time payments	Creation of personalized investment solutions using AI-based insights into market trends and customer preferences
Regulatory Compliance and Reporting	Blockchain for ensuring adherence to regulatory standards and transparent reporting	AI tools to help insurance companies comply with evolving regulations and risk assessment requirements	Enhanced reporting capabilities and improved surveillance of market activities using blockchain	Compliance with international payment standards and anti-money laundering directives using blockchain	Use of AI to ensure compliance with global financial advisory standards and ethical guidelines
Scalability and Integration Challenges	Challenges in integrating blockchain with existing banking systems and scaling it for large transaction volumes	Issues with adopting AI in legacy insurance systems and data privacy concerns	Difficulty in integrating blockchain seamlessly with traditional trading platforms	Technical challenges in scaling blockchain for high-frequency, high-volume payment transactions	Challenges in integrating AI with existing wealth management platforms and ensuring data security

Knowledge >> Persuasion >> Decision >> Implementation >> Confirmation

Fig 2. Frontiers of Fintech - Three-Dimensional Matrix: Themes, Technological Impacts, and Financial Sectors – Matrix developed by the authors in this research

Fraud Detection and Security

This category highlights how blockchain's immutability combined with AI's analytical prowess significantly enhances security and fraud detection across all sectors of finance. It emphasizes the practical applications and specific advantages like real-time fraud detection in banking and secure transaction environments in payment systems.

Operational Efficiency

This theme focuses on how both technologies streamline operations, reduce costs, and improve service delivery. For instance, blockchain automates compliance in banking, while AI optimizes processes like claim handling in insurance and portfolio management in wealth management.

Innovative Financial Products

Reflects on the introduction of new products and services that are made possible by AI and blockchain. This includes everything from blockchain-based trade finance solutions in banking to AI-driven personalized investment options in wealth management.

Regulatory Compliance and Reporting

Discusses how these technologies aid in meeting stringent regulatory requirements and simplifying reporting processes. Blockchain provides transparent and verifiable record-keeping that aids compliance, while AI facilitates risk assessments and regulatory reporting.

Scalability and Integration Challenges

This Acknowledges the technical and operational challenges faced when integrating these advanced technologies into existing financial systems. This section is crucial for understanding the hurdles in widespread adoption and operational scalability.

Matrix provides a structured and detailed overview of the intersection between blockchain, AI, and the financial sector, highlighting specific impacts and the broad spectrum of applications across different financial domains. It serves as a tool for identifying areas of opportunity and challenge, guiding future strategies for technology integration in finance.

This matrix aligns with a well-established theoretical framework, the Diffusion of Innovations Theory by Everett Rogers which is an excellent match. This theory explains how, why, and at what rate new ideas and technology spread through cultures. It's particularly relevant for our study as it can provide a structured approach to understanding how blockchain and AI technologies are adopted within financial institutions.

1. Knowledge (Awareness and Understanding):

Assessment of technological readiness: Financial institutions need to first become aware of blockchain and AI technologies and understand how they can benefit their operations. This phase aligns with gaining knowledge about the innovations before making any decisions.

2. Persuasion (Interest and Evaluation):

Integration pathway planning: Once the institution is aware of the technologies, they need to be persuaded of their value. This involves evaluating the technologies' potential impact on existing systems and processes, and planning integration pathways that align with strategic goals.

3. Decision (Adoption or Rejection):

Implementation and scaling: Decisions are made on whether or not to adopt the new technologies based on pilot tests and evaluations. Successful pilot results will lead to further adoption and scaling across the organization.

4. Implementation (Application and Adjustment):

Continuous monitoring and adaptation: After deciding to adopt, the technologies are implemented. During this phase, continuous monitoring is essential to ensure that they function as intended and adjustments are made as necessary.

5. Confirmation (Reinforcement or Rejection):

Innovation and future proofing: Finally, institutions seek confirmation that the technology has integrated well with their systems and is providing the expected benefits. This phase involves reinforcing the decision through feedback loops and adapting to future technological and market changes.

By incorporating the **Diffusion of Innovations Theory,** the model not only describes how blockchain and AI technologies can be integrated into financial institutions but also aligns each phase of integration with a theoretical understanding of how innovations are adopted and diffused within organizations. This approach adds depth to the model, providing a comprehensive framework that accounts for both the practical aspects of technology integration and the behavioral aspects of technology adoption and diffusion.

Conclusion

The exploration of blockchain and artificial intelligence (AI) integration within the financial sector, as framed by the Three-Dimensional Matrix and enhanced by the Diffusion of Innovations Theory, provides a comprehensive perspective on the transformative impact of these technologies. This article has systematically reviewed the multifaceted effects of blockchain and AI across various dimensions of the financial industry, highlighting both the opportunities and challenges that arise from their implementation:

- Enhanced capabilities: The integration of blockchain and AI significantly enhances the security, efficiency, and innovation capacity of financial services. Blockchain's immutable ledger combined with AI's analytical prowess offers a powerful toolset for improving fraud detection, risk management, and customer service.
- Strategic implementation: The Three-Dimensional Matrix offers a structured approach to the strategic implementation of these technologies. It emphasizes the importance of alignment with institutional goals, careful planning, and staged deployment, ensuring that the integration process is both effective and manageable.
- Regulatory adaptation: Navigating the complex regulatory landscape remains a crucial aspect of implementing new technologies in finance. The matrix underlines the need for ongoing dialogue with regulatory bodies and adaptive compliance strategies to ensure that technological advancements do not outpace regulatory frameworks.
- Scalability and integration challenges: Addressing scalability and integration challenges is vital for the widespread adoption of blockchain and AI. The framework advocates for pilot testing and phased scaling, which allows institutions to manage growth effectively and mitigate potential disruptions.

Future Preparedness: The diffusion theory encourages financial institutions to adopt a forward-thinking approach, continuously seeking innovative solutions and preparing for future technological shifts. This proactive stance is essential for maintaining competitiveness in an increasingly digital financial landscape.

Implications for future research and practice:

This article not only contributes to academic literature by providing a detailed analysis of blockchain and AI integration but also serves as a practical guide for financial institutions considering these technologies. Future research should focus on empirical studies that validate the Three-Dimensional Matrix and Diffusion of Innovations Theory, exploring their applicability and effectiveness in diverse financial contexts. Additionally, exploring the impact of emerging technologies like quantum computing and machine learning on blockchain and AI could provide further insights into the future of financial technology integration.

In conclusion, the integration of blockchain and AI holds great promise for the financial sector, offering opportunities to enhance security, increase efficiency, and foster innovation. By adopting a structured and strategic approach as outlined in the Three-Dimensional Matrix, financial institutions can not only overcome the challenges associated with these technologies but also position themselves at the forefront of the next wave of financial innovation.

References

Adedoyin, A.H., & Al-Turjman, F. (2021). Artificial intelligence and blockchain: A review.

Antonopoulos, A. (2018). Mastering Ethereum: Building Smart Contracts and Dapps.

Bellagarda, J. S., & Abu-Mahfouz, A. M. (2022). An updated survey on the convergence of distributed ledger technology and artificial intelligence: Current state, major challenges and future direction. IEEE Access.

LaPointe, C., & Fishbane, L. (2019). The Blockchain Ethical Design Framework.

Tapscott, D. (2016). Blockchain Revolution: How the Technology Behind Bitcoin and Other Cryptocurrencies Is Changing the World.

Frizzo-Barker, J., Chow-White, P. A., Adams, P. R., Mentanko, J., Ha, D., & Green, S. (2020). Blockchain as a disruptive technology for business: A systematic review. International Journal of Information Management, 51, 102029.

Ishmaev, G. (2020). Sovereignty, privacy, and ethics in blockchain-based identity management systems.

Zhang, G., Li, T., Li, Y., Hui, P., & Jin, D. (2018). Blockchain-Based Data Sharing System for AI-Powered Network Operations.

Koller, R. (2019, February 20). Ueli Maurer: «La blockchain éliminera des intermédiaires et créera plus de sécurité». ICT Journal.

Patel, R., Migliavacca, M., Oriani, M. E., & University, N. (2022). Blockchain in banking and finance: A bibliometric review.

PeerJ Computer Science. (2023). Blockchain technology and applications: an overview. 9(1), e1705. DOI:10.7717/peerj-cs.1705.

Raja, G., Manaswini, Y., Vivekanandan, G. D., Sampath, H., Dev, K., & Bashir, A. K. (2020). AI-powered blockchain-a decentralized secure multiparty computation protocol for IoV. IEEE INFOCOM 2020-IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS).

Ren, Y.-S., Ma, C.-Q., Chen, X.-Q., Lei, Y.-T., & Wang, Y.-R. (2023). Sustainable finance and blockchain: A systematic review and research agenda. Research in International Business and Finance, 64, 101871.

Rogers, E. M. (1962). Diffusion of Innovations. Free Press of Glencoe.

Gupta, S., Sinha, S., & Bhushan, B. (2020). Emergence of Blockchain Technology: Fundamentals, Working and its Various Implementations.

Shafay, M., Ahmad, R. W., Salah, K., Yaqoob, I., & Al-Fuqaha, A. (2023). Blockchain for deep learning: review and open challenges. Cluster Computing.

Shrier, D., Wu, W., & Pentland, A. (2016). Blockchain & infrastructure (identity, data security). Massachusetts Institute of Technology-Connection Science.

Soni, S., & Bhushan, B. (2019). A Comprehensive survey on Blockchain: Working, security analysis, privacy threats and potential applications.

Sharma, T., Satija, S., & Bhushan, B. (2019). Unifying Blockchain and IoT: Security Requirements, Challenges, Applications and Future Trends.

Yang, W., Sun, B., Zhu, Y., & Wu, D. (2021). A secure heuristic semantic searching scheme with blockchain-based verification. Information Processing & Management, 58(1), 102438

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Chapter VIII

Deconstructing stereotypes: Towards gender parity in STEM

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Chapter Highlights

Epistemological framework

This article falls within the framework of critical pedagogy and gender studies, assuming that education is never neutral but always permeated by cultural, linguistic and symbolic codes. Following authors such as Bourdieu (1977), Freire (1970) and Butler (1990), the investigation starts from the idea that language, metaphors and teaching practices unconsciously reproduce power relations and stereotypical views. Far from being a neutral place, the school thus becomes a space for the possible reproduction or deconstruction of gender inequalities.

Exploratory qualitative methodological approach

The study adopts a qualitative-hermeneutic approach, with exploratory and transformative aims, structured in three sequential phases:

- Individual introspection (autobiographical narratives of teachers),
- Intersubjective comparison (focus groups and reflective diaries),
- Thematic analysis (Braun & Clarke, 2006).

This framework is consistent with the pedagogical orientation that values subjectivity as a source of knowledge and professional transformation (Delory-Momberger, 2014).

Sample and research context

The research involved 32 teachers from a secondary school in the province of Jonica (18 men, 14 women), with interdisciplinary representation (high schools, technical schools, vocational schools). This plurality allows us to grasp the complexity with which the hidden gender curriculum crosses different disciplinary and organisational structures, in a territory characterised by a plurality of approaches and significant socio-cultural tensions.

Methodological triangulation

To strengthen the robustness of the data, various tools were used:

- Exploratory questionnaires,
- Written narratives,
- Focus groups,
- Reflective diaries.

This triangulation ensured a multifaceted view of the phenomenon and allowed for the integration of individual and collective dimensions of the reflective process.

Use of Thematic Analysis

The analysis was conducted using thematic analysis (Braun & Clarke, 2006), identifying recurring patterns and interpretative categories. This made it possible to organise the complexity of the narratives and provide a coherent picture of the manifestations of the hidden curriculum and gender stereotypes in educational practices.

Main results: four thematic areas

Persistence of implicit stereotypes: educational language and disciplinary representations often convey binary and traditional models, even in the absence of explicit awareness (Sadker & Zittleman, 2009). Discrepancy between intentions and practices: there is a gap between the stated desire to promote equality and everyday actions, confirming a gap between theory and practice (Carlana, 2019). Hidden curriculum and unawareness: only a minority of teachers recognise their role in reproducing stereotypes (Margolis, 2001; Preite, 2024). Potential of narrative co-reflection: autobiographical narration and collective discussion have fostered a progressive critical awareness and revision of practices (Delory-Momberger, 2014; Ireland & Freeman, 2018).

Integrative quantitative evidence

Although qualitative in nature, the study yielded significant data:

- Thematic nuclei recur in over 85% of narratives;
- The ability to recognise stereotypes increased from 30% to 70% in post-workshop self-assessments;
- Reflective journals recorded an average increase of 40% in teachers' critical awareness.

Discussion

The research confirms international literature (Sadker & Zittleman, 2009; Thébaud & Charles, 2018) showing that stereotypes are not just explicit statements, but deeply rooted symbolic devices. At the same time, it highlights the transformative potential of narrative workshops, which are capable of triggering critical co-reflection and unmasking the hidden curriculum. The pedagogical and didactic implications lie in the need to train teachers to recognise their own implicit biases, transforming educational practice into a lever for cultural emancipation.

Conclusions and implications

The research shows how teacher training, if oriented towards narration and co-reflection, can become a vehicle for cultural change and a tool for promoting equity in access to STEM disciplines. The main implications are:

- Integrating autobiographical storytelling into initial and continuing training,
- Designing systemic and institutionalised co-reflection pathways,
- Addressing the hidden curriculum as a priority subject of pedagogical study.

Only a critical transformation of educational practices can promote real equality of opportunity, going beyond mere declarations of intent to have a concrete impact on the construction of students' professional identities.

Abstract

Gender-based segregation in education and stereotypical views of professions originate from beliefs, metaphors and language rooted in patriarchal culture, unconsciously conveyed by teachers who believe, on the contrary, that they use language, materials and relational styles that are universal and neutral with respect to gender (Preite, 2024). These gender discriminations, permeating the school and work environment, cause systematic exclusion and educational inequality (Thébaud & Charles, 2018). But how can we bridge the gap between the orientation and educational opportunities offered to female and male students in STEM subjects? Firstly, it is necessary to bring out the hidden curriculum and the gender implications that are hidden in classroom practices and in teachers' beliefs, exploring their mentality, language and proxemics. A privileged tool for observation and change is the workshop for the development of 'professional prefigurations' in which 32 teachers from various Italian secondary schools in the Ionian province took part. Thanks to this training workshop, teachers will be able to support students in the discovery and elaboration of their professional identity starting from the deconstruction of implicit stereotypes and prejudices surrounding STEM professions, but only after analysing the teaching experiences recounted and experienced through autobiographical narratives that allow us to look at ourselves through multiple perspectives and understand the gap between what teachers remember from their classes and practices and what they notice when listening to the practices of others (Bejerano, Bartosh, 2015). This comparison enhances co-reflection among teachers, promoting a critical review of teaching practices that orients them towards educational-professional paths that value all students, without distinction of gender. This holistic approach promises improvement not only in teaching skills, but also in the rectification of culturally consolidated perspectives of meaning (Ireland & Freeman, 2018).

Keywords: STEM, gender stereotypes, autobiographical narratives.

Introduction

The issue of gender discrimination in education, and more generally in training processes, is currently a crucial focus of pedagogical research and public policies aimed at inclusion and equity. Academic research in recent years, corroborated by a wealth of empirical studies on an international scale, has demonstrated the pervasiveness of stereotypes, social representations and implicit narratives related to gender that have a decisive influence on the academic and professional expectations of students, contributing to the reproduction of structural asymmetries in educational pathways and subsequent career opportunities, particularly in STEM (Science, Technology, Engineering, Mathematics) sectors (Thébaud & Charles, 2018; UNESCO, 2021). In particular, the latest summary of research promoted by the Global Partnership for Education (GPE KIX) highlights how the inclusion of gender-sensitive pedagogy and the deconstruction of stereotypes through transformative approaches are the most effective levers for reducing gaps and promoting substantive gender equality in educational communities.

Gender and the implicit curriculum

Contemporary literature emphasises the deep roots of this phenomenon, tracing them back to the actions of an implicit curriculum, i.e. the set of rules, values and representations conveyed not through stated content, but through teaching practices, language, the organisation of spaces and relational dynamics that structure everyday school life (Jackson, 1968; Margolis, 2001; Preite, 2024; Carlana, 2019). Recent evidence confirms that the implicit curriculum acts as a device for stabilising and reinforcing traditional representations of gender roles, cementing stereotypes in both disciplines and materials, as demonstrated by studies on gender representation in school textbooks (Jehle et al., 2024; Abbott et al., 2005). From this critical perspective, there is a clear need to denaturalise pedagogical and didactic assumptions, refocusing the discourse not only on results but also on the deep structures that underpin the cultural production of gender difference.

From the theoretical perspective of gender performativity, the research of Butler (1990) and Connell (2002) has recently been expanded in the multidimensional paradigms of gender pedagogy, which emphasise how the apparently neutral character of teaching practices and materials is in fact the result of repeated iterations that normalise gender dichotomies, rendering micro-exclusions and symbolic barriers invisible. STEM disciplines remain a privileged observatory of such asymmetries: international research shows that, despite academic results that are similar to or superior to those of their male peers, female students tend to exclude themselves from highly technical courses, victims both of social expectations and of the self-fulfilling prophecy effect resulting from teaching stereotypes (Eccles & Wang, 2016; Blickenstaff, 2005; Carlana, 2019; De Gioannis et al., 2022). This self-exclusion is the result of complex processes that combine socio-cultural, linguistic and relational factors, rooted in both family and school practices (Nosek et al., 2009). Far from being a neutral space, school becomes a place where stereotypes and expectations are internalised and reproduced.

The role of biographical self-narrative as a pedagogical device appears today more than ever to be central to the initial and in-service training of teachers, as evidenced by the growing international literature on the transformation of the professional self through critical reflection and self-narrative (Delory-Momberger, 2014; Demetrio, 1996; Gunn, 2016; Catherwood, 2017). Through autobiography, teachers can question internalised representations, renegotiate their own positions and co-construct educational practices capable of deconstructing implicit stereotypes, triggering processes of change that radiate from the individual sphere into the institutional dimension.

The workshop activity on 'professional prefigurations' proposed here is therefore situated at the intersection between the most recent strands of research on critical gender pedagogy and educational innovation aimed at promoting authentically equitable and inclusive educational environments, using a narrative and reflective methodology that has proven particularly effective in promoting awareness and revision of practices by education professionals (Ireland & Freeman, 2018; Jabbar, 2024).

Research methodology and results

The methodology adopted is characterised by a robust exploratory qualitative approach that favours narration and critical reflection. The division into three sequential phases allows for a meticulous process of introspection, comparison and thematic analysis, consistent with the most advanced qualitative research practices in education (Braun & Clarke, 2006). The choice of autobiographical narratives as a data collection tool is in line with the contemporary hermeneutic approach, which favours subjectivity as a source of knowledge and a transformative tool (Delory-Momberger, 2014). The workshop space for 'professional prefigurations' integrates group methods for active co-reflection, which is essential for unmasking and deconstructing often unconscious implicit stereotypes, helping to generate critical awareness of educational practices.

The sample of 32 teachers from a secondary school in the province of Jonica, with a fairly balanced gender distribution (18M and 14F) and broad interdisciplinary representation, allows us to grasp the complexity of the phenomenon in secondary schools, which is particularly relevant in areas such as the province of Jonica where multiple educational streams coexist. This composition allows the narratives to be interpreted from a multifocal perspective, which is essential for understanding the varied permeation of the implicit curriculum and its manifestations in teaching structures (Eccles & Wang, 2016).

Tools such as exploratory questionnaires, written narratives, focus groups and reflective diaries ensure a methodological triangulation that increases the robustness of the data and allows the phenomenon to be observed from different analytical angles. The use of thematic analysis (Braun & Clarke, 2006) for the coding and interpretation of qualitative data allows for the identification of recurring patterns and thematic categories that provide a coherent and in-depth picture of how gender stereotypes and representations manifest themselves in educational practices.

The results highlight four crucial themes. First, the persistence of implicit stereotypes emerges clearly; the analysis revealed that over 78% of the narratives contained binary linguistic expressions, role attributions or traditional representations of gender, confirming the difficulty of eradicating deep-rooted prejudices, which are often acted upon unconsciously (Sadker & Zittleman, 2009). Secondly, the discrepancy between stated intentions and actual practices highlights a well-known gap between theoretical awareness and everyday behaviour, a factor widely documented in the literature on critical gender pedagogy (Carlana, 2019); Although more than 80% of respondents stated that they supported gender equality, many teachers unconsciously reproduce behaviours and language that reinforce inequalities, highlighting the well-known gap between theoretical awareness and teaching practice. The lack of awareness of the hidden curriculum constitutes the third core issue, highlighting how most teachers do not recognise their active role in reproducing stereotypes, confirming research that highlights the need for specific training interventions (Margolis, 2001; Preite, 2024). Only 25% of participants explicitly recognised their role in transmitting stereotypes. The majority of teachers appear unaware of the weight of the hidden curriculum in reinforcing unequal dynamics, in line with studies that highlight the need for targeted training on these aspects. Finally, the potential of narrative co-reflection as a transformative lever emerges; narrative comparison not only makes implicit stereotypes visible but also stimulates a review of language and representations, paving the way for concrete changes in educational practices (Delory-Momberger, 2014; Ireland & Freeman, 2018). The narrative workshops showed a significant increase in the ability to identify implicit stereotypes: in the final sessions, over 70% of teachers explicitly stated strategies for revising language and practices, compared to less than 30% in the initial stages. This data highlights the transformative impact of narrative co-reflection.

From a quantitative point of view, although the qualitative nature of the research does not allow for statistical generalisations, the uniform recurrence of these thematic nuclei in over 85% of the narratives analysed confirms their generalised relevance. Furthermore, the systematic use of reflective diaries has allowed for longitudinal monitoring of awareness processes: comparative analysis of the first and last writings shows an average increase of 40% in self-assessments of the ability to recognise and problematise stereotypes.

These data suggest that the approach adopted not only produces critical awareness but also promotes effective transformative potential in educational practices, paving the way for future experimentation with systemic and scalable training models.

Pedagogical and didactic implications

When placed within the broad landscape of pedagogical and sociological studies on gender issues, the research results reiterate an often overlooked truth: discrimination and stereotypes are not only imposed through overt or openly discriminatory forms, but are inscribed in an underground web of languages, symbols and everyday practices that constitute the invisible fabric of the school experience (Sadker & Zittleman, 2009; Thébaud & Charles, 2018). In this sense, the notion of the implicit curriculum is still extremely relevant today, as it sheds light on the latent and undeclared dimension of education, in which cultural and social transmission processes operate silently, shaping expectations, roles and future possibilities for students.

However, our investigation, through a workshop focused on autobiographical narratives and professional aspirations, highlights a transformative potential inherent in educational processes: that of deconstructing implicit paradigms and restoring critical power to school actors with regard to their own practices. Where teacher training is not limited to providing technical or methodological tools, but becomes a space for reflection and narrative, profound processes of awareness are activated, capable of revealing the implicit and reorienting educational practices towards truly emancipatory perspectives (Bejerano & Bartosh, 2015; Delory-Momberger, 2014).

From a pedagogical-didactic point of view, this implies recognising the function of self-narration not as a mere exercise in individual introspection, but as a social and dialogical practice capable of generating new forms of teaching professionalism. When shared and placed in dialogue with the narratives of others, narration produces an intersubjective space for co-reflection, in which implicit prejudices and stereotypical representations that often escape the control of pedagogical consciousness emerge. This dynamic confirms Dewey's (1938) argument about the experiential dimension of learning: reflection on experience is the privileged place where authentic educational change occurs.

A further relevant element concerns the dialectic between intentionality and practice. The teachers involved in the workshop often declared themselves to be staunch supporters of equity and inclusion, but the narratives showed how these convictions do not always correspond to actual practices, revealing a misalignment between declared ethos and pedagogical habitus (Bourdieu, 1977). It is in this gap that the workshop exercised its critical function, showing teachers the urgency of ongoing self-training, capable of bridging the inconsistencies between principles and educational actions.

From the point of view of educational implications, the workshop suggests the need to introduce systematic gender awareness education courses into teacher training curricula, not relegated to episodic moments but structured in a continuous manner. Inclusive teaching, in fact, cannot be conceived as an impromptu or accessory addition to traditional practices, but rather as an epistemological perspective that permeates every educational choice, from language to teaching materials, from assessment methods to classroom management (Banks, 2016).

Finally, the research highlights a crucial aspect: the transformation of students' professional imaginaries cannot be separated from a parallel transformation of teachers' professional imaginaries. It is only when educators become aware of their own stereotypes and representations of gender that they can, in turn, guide students towards professional horizons free from preconceptions. From this perspective, teachers are not simply transmitters of knowledge, but symbolic mediators capable of opening up new possibilities for identity and the future.

Conclusion

In light of these findings, the training experience covered by this research serves as a paradigm of how schools can take a proactive role in cultural and social transformation. When aimed at revealing and deconstructing implicit stereotypes, teacher training becomes not only a tool for professional development, but also a genuine means of emancipation, capable of profoundly influencing the identity trajectories of new generations.

The analysis of teachers' autobiographical narratives and discursive practices has revealed how deeply rooted gender stereotypes are in everyday language and gestures, highlighting the need for critical awareness education that addresses both the cognitive and the symbolic and emotional dimensions. It is in this sense that pedagogy is not only a science of knowledge transmission, but also a practice that transforms culture and society.

The pedagogical and didactic implications of the research are manifold. First, there is an urgent need for initial teacher training that includes specific modules on the deconstruction of stereotypes and the hidden curriculum, combining the transmission of subject content with critical reflection on language and relational dynamics. Secondly, in-service training should include permanent storytelling and co-reflection workshops, where teachers can collectively rework their practices and experiment with alternative teaching methods geared towards inclusion. Thirdly, the research calls for a rethinking of school and career guidance processes, not as neutral devices, but as strategic moments in which the possibility of emancipation or, conversely, the reproduction of stereotypes is at stake.

From a broader perspective, the contribution suggests the need for a critical gender pedagogy, capable of bringing together the achievements of feminist theory (Butler, 1990; hooks, 1994) with concrete educational practices, in order to generate school contexts that do not merely 'include' differences, but recognise them as epistemological and existential resources. Such pedagogy, far from being an optional embellishment, is a necessary condition for building a fair, democratic and culturally generative school.

In conclusion, research has shown that change is possible: when teachers are given the opportunity to reflect critically and share their experiences, they can become actors in a process of transformation that goes beyond the classroom to affect the overall social fabric. If school is the place where possible futures are imagined and envisaged, then it has a responsibility to offer every student the opportunity to recognise themselves in those futures, without gender barriers or implicit prejudices. Only in this way can teaching become truly emancipatory, promoting the construction of knowledge that is not only equitable, but also pluralistic, inclusive and generative.

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The present work is the joint work of the authors; however, for the purposes of attribution of the individual parts, it is subdivided as follows: Abstract, introduction and conclusions are attributed to all authors: Mariella Tripaldi §§ 1; Alessandro Barca §§ 2-3.

References

Banks, J. A. (2016). Cultural diversity and education: Foundations, curriculum, and teaching (6th ed.). Routledge.

Bejerano, A. R., & Bartosh, T. (2015). Learning from stories of teaching: A narrative analysis of beginning teachers' experiences. Teaching Education, 26(2), 176–193. https://doi.org/10.1080/10476210.2014.996740

Blickenstaff, J. C. (2005). Women and science careers: Leaky pipeline or gender filter? Gender and Education, 17(4), 369–386. https://doi.org/10.1080/09540250500145072

Bourdieu, P. (1977). Outline of a theory of practice. Cambridge University Press.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Butler, J. (1990). Gender trouble: Feminism and the subversion of identity. Routledge.

Carlana, M. (2019). Implicit stereotypes: Evidence from teachers' gender bias. The Quarterly Journal of Economics, 134(3), 1163-1224.

Catherwood, R. (2017). Crafting critical feminist narrative pedagogies through women's and queer life writing (Doctoral dissertation, Northern Illinois University).

Connell, R. (2002). Gender. Cambridge: Polity Press.

De Gioannis, E., et al. (2022). Implicit gender-science stereotypes and college-major intentions of women and men. European Journal of Education, 57(4).

Delory-Momberger, C. (2014). Biography and education. Milan: FrancoAngeli.

Demetrio, D. (1996). Telling your story: Autobiography as self-care. Milan: Raffaello Cortina.

Dewey, J. (1938). Experience and education. Macmillan.

Eccles, J. S., & Wang, M. T. (2016). What motivates females and males to pursue careers in mathematics and science? International Journal of Behavioural Development, 40(2), 100–106. https://doi.org/10.1177/0165025415616201

Gunn, A. M. A. (2016). Autobiographies in preservice teacher education. Journal of Diversity in Higher Education, 9(2), 123-142.

hooks, b. (1994). Teaching to transgress: Education as the practice of freedom. Routledge.

Ireland, M., & Freeman, M. (2018). The power of collective reflection: Re-examining teacher beliefs about gender and pedagogy. Gender and Education, 30(5), 657–674. https://doi.org/10.1080/09540253.2016.1261218

Jabbar, D. S. A. (2024). Gender-sensitive pedagogy: Tools for promoting inclusion. Diversitas Journal, 12(1), 234-251.

Jackson, P. W. (1968). Life in classrooms. Holt, Rinehart & Winston.

Jehle, A. M. C., et al. (2024). The hidden lessons in textbooks: Gender representation and stereotypes in European classrooms. European Journal of Education, 59(1).

Margolis, E. (2001). The hidden curriculum in higher education. New York: Routledge.

Nosek, B. A., Smyth, F. L., Sriram, N., Lindner, N. M., Devos, T., Ayala, A., ... & Greenwald, A. G. (2009). National differences in gender–science stereotypes predict national sex differences in science and math achievement. Proceedings of the National Academy of Sciences, 106(26), 10593–10597. https://doi.org/10.1073/pnas.0809921106

Preite, M. (2024). Pedagogy and gender discrimination. Carocci.

Preite, V. (2024). Implicit curriculum and gender-sensitive practices. Critical Pedagogy Studies, 13(2), 89-102.

Sadker, D., & Zittleman, K. (2009). Still Failing at Fairness: How Gender Bias Cheats Girls and Boys in School. New York: Scribner.

Thébaud, S., & Charles, M. (2018). Segregation, stereotypes, and STEM. Social Sciences, 7(7), 111. https://doi.org/10.3390/socsci7070111

UNESCO. (2021). Cracking the code: Girls' and women's education in STEM. UNESCO Publishing.

Vu, M. T. (2022). Gender, critical pedagogy, and textbooks. Language Teaching Research, 26(6), 899-917.

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